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PHYSICAL PROPERTIES OF INJECTION MOLDED LIQUID CRYSTAL POLYMERS AND HIGH TEMPERATURE ENGINEERING POLYMERS

Dr Robert R. Schott
Dr Robert E. Nienn
Mifta Rahman
Sudesh Appaji

University of Massachusetts, Lowell
Department of Plastics Engineering
450 Aiken Street
Lowell, Massachusetts 01854

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Final Report

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PHILLIPS LABORATORY
Propulsion Directorate
AIR FORCE MATERIEL COMMAND
EDWARDS AIR FORCE BASE CA 93524-7001

Institute for Plastics Innovation

University of Massachusetts Lowell
333 Aiken Street
Lowell, MA 01854
Telephone (508) 934-3445
Fax: (508) 937-9877

February 25, 94

To:
Mr. Delores Campbell
Defense Technology Information Ctr.
Cameron Station Bldg. 5
Alexandria, VA 22304-614
Tel: (703) 274-6837
Fax: (703) 274-9307

Dear Mr. Campbell:

I am enclosing ASTM D 695-89 specification on "Compressive Properties of Rigid Plastics" which you can use to replace the one with missing pages (p-243-284) in our Air Force Report #PL-TR-92-3056 on "Physical Properties of Injection Molded Liquid Crystal Polymers and High Temperature Engineering Polymers". Please also correct our names on the cover page of the report by the following:

ADA 264918

Dr. Nick R. Schott
Dr. Robert E. Nunn
Dr. Miftahur Rahman
Mr. Sudesh Appaji

Thank you.

Sincerely,

Dr. N. R. Schott
Director, IPI

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FOREWORD

This final report was submitted by University of Massachusette, Lowell, under contract F04611-91-M 0119 for the OLAC, Phillips Laboratory, (AFMC), Edwards AFB, CA. 93524-7001. OLAC PL Project Manager was Dr John J. Rusek

This report has been reviewed and is approved for release and distribution in accordance with the distribution statement on the cover and on the SF Form 298.

JOHN J. RUSEK
Project Manager

STEPHEN L. RODGERS
Chief, Emerging Technologies Branch

LEONARD C. BROLINE, Lt Col, USAF
Director
Fundamental Technologies Division

RANNEY G. ADAMS
Public Affairs Director

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Dr Robert R. Schott, Dr Robert E. Nienn,
Mifta Rahman, Sudesh Appaji

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

University Of Massachusetts, Lowell
Department of Plastics Engineering
450 Aiken Street
Lowell, Massachusetts 01854

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13. ABSTRACT *(Maximum 200 words)*

This experimental study investigated the System Molding of Four Liquid Crystal Polymers, Vectra A 950, Vectra B 950, HX 4000, and Xydar SRT 500 and two High Temperature Engineering polymers, Polyetherimide (Ultem) and Polyphenylene Sufide (Fortran) and evaluation of mechanical properties, tensile, flexural, and compression of molded samples.

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Vectra is a tradename of Hoechst Celanese.
Xydar is a tradename of Amoco Performance Products.
HX is a tradename of DuPont.

LIST OF FIGURES

I. ABSTRACT

This experimental study investigated the Injection Molding of four liquid crystal polymers, Vectra A950, Vectra B950, HX 4000 and Xydar SRT500, and two high temperature engineering polymers Polyetherimide (Ultem) and Polyphenylene Sulfide (Fortron), and evaluation of mechanical properties, Tensile, Flexural and Compression, of molded samples.

It was found that four of the materials (Polyetherimide, Polyphenylene Sulfide, Vectra A950 and Vectra B950) could be molded satisfactorily on a standard injection molding machine to give good quality parts. In order to mold the Xydar SRT500, the machine had to be modified to allow the use of barrel temperatures much higher (725 - 800 deg.F) than the microprocessor controller's capacity. For both the Xydar SRT500 and the HX 4000 materials, problems were found in molded part quality, including surface defects, burn marks and warpage. Despite varying the molding conditions for these materials, it was not possible to achieve defect-free moldings.

The properties showed that the tensile modulus for Vectra B950 was higher, though tensile strength was less than Vectra A950, compared to the other materials. Flexural modulus as well as maximum fiber stress for B950 was higher than for the other materials. Though tensile properties for HX 4000 were lower than other materials, its flexural properties were second to Vectra B950. Xydar SRT500 showed the highest compressive modulus, though Polyetherimide showed higher compressive strength. Compression tests on HX 4000 were not possible due to the warpage in the parts.

II. INTRODUCTION

A. PURPOSE AND SCOPE:

This report summarizes the objective of the project. As per the proposal, four liquid crystal polymers: Vectra A950, Vectra B950, HX 4000, Xydar SRT500, and two high temperature engineering polymers, Polyphenylene Sulfide(Fortron 0205P4) and Polyetherimide (Ultem 1000) were injection molded and tested for mechanical properties. The property tests included tensile, flexural and compressive properties of the molded specimens and were carried out according to the ASTM procedures.

Satisfactory injection molding of Xydar SRT500 and HX 4000 was not possible due to melt inhomogenity. However, injection molding of these materials were attempted. Though samples were molded the quality of the samples was not good.

The tensile, flexural and compressive properties for Polyphenylene Sulfide, Polyetherimide, Vectra A950, Vectra B950 and Xydar SRT500 are given in this report. Tensile and Flexural properties for HX 4000 are given, but the compression test on HX 4000 was not possible due to warpage in the sample The results are tabulated (note) and are shown graphically on pages 18 to 42.

note: The significant figures for the ASTM tests should be considered as three significant figures. The computer print out format shows more but this should not be confused as actual significant figures.

B. BACKGROUND

Liquid Crystal Polymers are advanced high temperature polymers with unique physical properties. The polymers are characterized by low melt viscosities which aid in processing such as in injection molding. Thermotropic liquid crystal polymers can be processed with conventional thermoplastic processing techniques. These materials when injection molded, form parts with very high mechanical properties without fibrous reinforcements. The molded articles also show high anisotropy of physical properties between the flow direction and the cross flow directions. The anisotropy decreases as the thickness of the parts increases. These thermotropic liquid crystal polymers are also called "self reinforcing" polymers, because their properties are very similar to those of fiber filled polymers.

The physical properties of liquid crystal polymers are greatly dependent on the thickness of the molded part. The physical properties are inversely related to the thickness of the specimen. This dependency of properties is greater in unfilled resins than in filled compounds. Injection molded parts exhibit several distinct layers with different morphologies. The two outer skin layers consist of polymer chains aligned in the flow direction. The core is highly crystalline and has the appearance of an annealed polymer, and orientation in the core is generally perpendicular to the flow direction. In the two outer skin layers, the melt freezes spontaneously, because the mold temperatures are usually less than the crystallization temperature or the glass transition temperature

of the polymer used. However in the core, due to low heat conduction, instantaneous solidification does not occur, and the melt is deformed during flow towards the flow front. Thus the ability to relax is reduced considerably and orientation takes place in the opposite direction. The most important parameter during injection molding is the flow process when filling the cavity. By increasing the part's skin thickness, relative to the core, the tensile strength will increase. To obtain maximum physical properties the part must have a larger skin to core thickness ratio.

The mechanical properties of injection molded liquid crystal polymers are greatly influenced by the gate design. Ideally the gate should be designed in such a way that upon entering the mold the melt should touch at least some part of the mold walls to avoid jetting. Conventional gating for thermoplastics, may not give specimens with the highest mechanical properties in the majority of cases.

The processing conditions also influence greatly the mechanical properties of injection molded liquid crystal polymers. Lower injection velocity gives higher properties. Lower injection velocity decreases the amount of viscous heat generated between the already solidified skin layer at the walls of the mold and the molten polymer flowing to fill the remainder of the cavity, thereby increasing the thickness of the skin. The properties can be increased with low injection speed, low injection pressure and low mold temperature. It should also be considered that very low

injection rates can lead to problems of material solidifying prematurely in runners and gates.

The liquid crystal polymers have unprecedented thermal and chemical resistance and at the same time exhibit excellent mechanical properties. The injection molding grades can easily fill thin and long sections and can therefore be used to fabricate both small and large intricate parts.

These liquid crystal polymers are being targeted to a number of market sectors including the aircraft/aerospace sector; some other applications being in fiber optics, electronics, fibers, houseware appliances where thermomechanical stability and wear resistance are important. Due to their chemical inertness and toughness, they are also being used as chemical mass transfer tower packing materials and they also make an excellent replacement for brittle ceramic materials.

III. INJECTION MOLDING

A. MATERIALS:

1. Liquid Crystal Polymer
   Trade name: Vectra A950
   Manufacturer: Hoechst Celanese, New Jersey, U.S.A.

2. Liquid Crystal Polymer
   Trade name: Vectra B950
   Manufacturer: Hoechst Celanese, New Jersey, U.S.A.

3. Liquid Crystal Polymer
   Trade name: HX 4000
   Manufacturer: DuPont Polymers, U.S.A.

4. Liquid Crystal Polymer
   Trade name: Xydar SRT500
   Manufacturer: Amoco Performance Products, U.S.A.

5. Polyetherimide
   Trade name: Ultem 1000
   Manufacturer: GE Plastics, U.S.A.

6. Polyphenylene Sulfide
   Trade name: Fortron 0205P4
   Manufacturer: Hoechst Celanese, New Jersey, U.S.A.

B. EQUIPMENT:

1. Injection Molding Machine
   Manufacturer: Battenfeld, Austria
   Model: BA750/300
   Serial Number: 41.928
   Control: CNC 80/85
   Screw Diameter: 1.765 in.
   L/D ratio: 16:1
   Maximum Shot Capacity: 6.37 oz(GPPS)
   Maximum clamping force: 84.3 tons.
   Clamping: Hydraulic

2. Dehumidifying Drier
   Manufacturer: Conair Inc., U.S.A
   Model: 18002503
   Serial Number: 8D0062

3. Mold Temperature Controller
   Manufacturer: Application Engineering Corpn., U.S.A
   Model: TDO-ID-o
   Serial Number: 87b242
   Heat Transfer Fluid: UCON 500

4. Hand held Thermocouple
   Manufacturer: Omega Engineering Inc., U.S.A
   Model: HH23

5. Mold
   Type: Six cavity ASTM family
   Cavities open: Tensile: Dogbone, 6.0 in long
   Flexural: Rectangular, 5 in x 0.5 in x 0.125 in
   Disc: 4.0 in diameter.

C. PROCEDURE:

Molding conditions for each of the materials were established according to the "short shot" method (a copy of the "Short Shot" method is given in Appendix A). The specific procedure for each material is described briefly in the following paragraphs.

Polyetherimide

Injection molding of all three test specimens (tensile, flexural and disc) in one shot was not possible due to severely unbalanced flow between the three cavities used in the mold, which resulted in one cavity or another flashing or producing a short shot (This problem did not occur during the molding of the other five materials). Consequently, molding was done in two steps: 1. with the disc cavity closed, tensile and flexural specimen were molded and 2. with the tensile cavity closed, disc and flexural specimens were molded. The processing conditions are given in Tables 1 and 2 respectively.

Polyphenylene Sulfide, Vectra A950, Vectra B950

All three test specimens could be injection molded in one shot without any problems of mold balancing. The processing conditions for Polyphenylene sulfide, Vectra A950 and Vectra B950 are given in Tables 3, 4, 5 respectively.

HX 4000

Injection molding of this material was difficult compared to the previous materials. Melt uniformity was not maintainable. Melt non-uniformity was visible in the parts molded. It was also found that this material was very heat sensitive at the processing temperatures. The parts had burn marks at the gate, due to shearing of the melt while flowing through gates. It was not possible to rectify this problem. Reducing the barrel temperatures lead to the material not melting, and reducing the injection speed lead to the cavities being incompletely filled. Another major problem was found with the disc cavity, where the part warped excessively after it was ejected from the mold. By increasing the cooling time from 15 to 60 secs, the warpage was reduced only slightly. Consequently good flat discs were not able to be made. Sometimes, pellets were visible in the disc, showing that the melt uniformity was poor. The reason for this problem might be the size and shape of the pellets which were very different (larger) from the other materials. Increasing the screw L/D ratio might help in rectifying the melt non-uniformity problem. The final processing conditions are given in Table 6.

Xydar SRT500

Initial attempts to mold this material on the standard Battenfeld machine were limited by the maximum barel temperature setpoint in the controller of 690 deg.F. Higher temperatures were necessary to melt the material. In order to provide higher barrel setpoints, an external circuit was built to reduce the thermocouple signal so as to allow the temperature controller to operate at an artificially low setpoint(below the 690 deg.F range limit), even though the actual temperatures was higher. (The circuit modification is shown in Appendix B).

Processing was attempted under these conditions, but the quality of the specimens was poor, again as a result of poor melt quality for reasons thought to be similar to the case of HX 4000. The processing conditions are given in Table 7.

IV. MECHANICAL PROPERTIES

The molded specimens were tested for tensile, flexural and compression properties. ASTM procedures for the tests are included in Appendix - C.

A. TENSILE PROPERTIES

EQUIPMENT

1. Tensile testing machine
   Manufacturer: Instron Inc.
   Model: 6025
   Serial Number: H-1081
2. Vernier caliper

TESTING:

Procedure: ASTM
Number: D638
Atmospheric conditions of the test room:
Temperature: 73 deg.F
Relative Humidity: 50%
Number of specimens tested: Five
Speed of testing: 2.0 in/min.

RESULTS:

The tensile properties for Polyetherimide, Polyphenylene Sulfide, Vectra A950, Vectra B950, HX 4000 and Xydar SRT500 are given in Tables 8,9,10,11,12 and 13 respectively.

B. FLEXURAL PROPERTIES

EQUIPMENT

1. Flexural testing machine
   Manufacturer: Instron Inc., U.S.A.
   Model: 1137
   Serial Number: 9138

2. Vernier caliper

TESTING:

Procedure: ASTM
Number: D790
Atmospheric conditions of the test room:
Temperature: 73 deg.F
Relative Humidity: 50%
Number of specimens tested: Five
Speed of testing: 0.1 in/min.

RESULTS:

The Flexural properties for Polyetherimide, Polyphenylene Sulfide, Vectra A950, Vectra B950, HX 4000 and Xydar SRT500 are given in Tables 14,15,16,17,18 and 19 respectively.

C. COMPRESSIVE PROPERTIES

EQUIPMENT

1. Tensile testing machine
   Manufacturer: Instron Inc., U.S.A.
   Model: 6025
   Serial Number: H-1081

2. Vernier caliper

3. Routing machine
   Manufacturer: Tensilkut Engineering, U.S.A.
   Model:10/31
   Serial Number:115663

TESTING:

Procedure: ASTM
Number: D695
Atmospheric conditions of the test room:
Temperature: 73 deg.F
Relative Humidity: 50%
Number of specimens tested: Five
Speed of testing: 0.05 in/min.
Preparation of samples: Samples were cut from injection molded discs, using a rotory cutter and appropriate fixtures to the dimensions recommended by ASTM.

RESULTS:

The Compressive properties for Polyetherimide, Polyphenylene Sulfide, Vectra A950, and Vectra B950 and Xydar SRT500 are given in Tables 20,21,22,23 and 24 respectively. Compression test for HX 4000 was not conducted due to warpage in the part.

V. DISCUSSION OF RESULTS

The objectives of this research were to injection mold four liquid crystal polymers, Vectra A950, Vectra B950, HX 4000, Xydar SRT500 and two high temperature engineering polymers Polyetherimide(Ultem) and Polyphenylene Sulfide(Fortron), and to test for their mechanical properties, tensile, flexural and compression.

Tables 1 to 7 list the processing conditions used to mold test specimens from of these materials. Table 1 and 2 list the processing conditions for polyetherimide. As noted in section III.C., Injection molding of all three test specimens was not possible in one shot. Table 1 lists the processing conditions for tensile and flexural specimens and Table 2 lists the processing conditions for compression(4 inch diameter disc) and flexural specimens. Tables 3, 4, 5, 6 and 7 list the processing conditions for Polyphenylene Sulfide, Vectra A950, Vectra B950 and HX 4000 and Xydar SRT500 respectively.

Tables 8 to 13 list the Tensile properties of Polyetherimide, Polyphenylene Sulfide, Vectra A950, Vectra B950, HX 4000 and Xydar SRT 500 respectively. Tables 14 to 19 list the Flexural prcperties of Polyetherimide, Polyphenylene Sulfide, Vectra A950, Vectra B950, HX 4000 and Xydar SRT500 respectively. Tables 20 to 24 list the Compression properties of Polyetherimide, Polyphenylene Sulfide, Vectra A950, Vectra B950 and Xydar SRT500. The compression test for

HX 4000 was not possible due to the warpage in the specimen. Figures 1 and 2 show the Tensile modulus and Tensile strength for the materials. Figures 3 and 4 show the Flexural modulus and maximum fiber stress for the materials. Figures 5 and 6 show the Compressive modulus and the Compressive strength of the materials. As seen from Figure 1, the tensile modulus of Vectra B950 is the highest compared to other materials. Since it is self reinforcing in nature, it cannot be directly compared to unreinforced Polyetherimide and Polyphenylene Sulfide. The tensile modulus of Vectra A950 is lower than Vectra B950, but higher than the other materials. Since Vectra B950 is a copolyester-amide, it has more strength and stiffness. The tensile moduli of Polyetherimide, Polyphenylene Sulfide, HX 4000 and Xydar SRT 500 are in the same range. HX 4000 and Xydar SRT500 should have higher tensile moduli than Polyetherimide and polyphenylene Sulfide, since they are self reinforcing polymers, but the difficulties in processing and the poor quality of the parts are likely to have given reduced values. From Figures 3 and 4, it can be seen that the flexural modulus and maximum fiber stress for Vectra B950 is higher than for the other materials. Though the tensile properties for HX 4000 are almost the same as Polyetherimide, Polyphenylene Sulfide and Xydar SRT500, the flexural modulus is very high compared to these materials (note: the flexural properties for Polyetherimide are reported at 5% strain, since the samples did not break).

From Figures 5 and 6 it can be seen that the compressive modulus of SRT 500 is higher than the other materials, though the compressive strength is lower. Polyetherimide has a higher compressive strength than the other materials, and the samples did not break for this material under compression. The values for compression properties might have been reduced, for all the materials, because the samples were machined from 4 inch diameter discs. Although the samples were all cut from the same location (in the flow direction) for all materials, the stresses and microcracks induced during machining might have reduced the properties.

Comparison of published and evaluated values for the materials are shown in Table 25. Properties for XYDAR SRT500 were not available from the manufacturers. The properties for Polyphenylene Sulfide and Vectra B950 were also not available, though these materials were compared with other materials, relatively in the manufacturers catalog. Properties for Ultem were available and some properties for Vectra A950 and HX 4000 were available. The evaluated values when compared to the manufacturer's value are comparable or lower. Table 26 show the empirical value of shear moduli and bulk moduli of the materials. These properties were arrived at, by empirical relations with their Poisson's ratio (ref no:10, table 1.4, pg.6). The Poisson's ratio for Ultem and Polyphenylene Sulfide were obtained from the manufacturer's catalog as 0.36 and 0.38 respectively. The Poisson's ratio for other materials (Vectra A950, Vectra B950, HX 4000 and Xydar SRT500) were not available, so for

these materials it was assumed to be 0.4 (general rule of thumb for engineering plastic materials).

Figure 7 show the toughness of the materials. The toughness is not an absolute value, since the area considered was under the curve with load and elongation as y-axis and x-axis respectively, and not stress and strain respectively. The toughness indicates that Polyetherimide is tougher than other materials and that it has more elongation. The least tough material was HX 4000. The tensile properties of HX 4000 are low as shown in Table 25.

TABLE 1: Processing Conditions for Polyetherimide.

Tensile and Flexural.

Drying	6 hours at 300 deg.F
Barrel Temperatures:	
Rear	575 deg.F
Center	602 deg.F
Front	630 deg.F
Nozzle	625 deg.F
Melt Temperature	610 deg.F
Screw Speed	204 rpm
Shot Size	1.89 inches
Decompression	0.1 inches
Injection Velocity	0.8 in/sec
Injection Pressure (hydraulic)	1552 psi
Injection Time	1.6 sec
Hold Pressure (hydraulic)	900 psi
Hold Time	8 sec
Mold Coolant Temperature	210 deg.F
Cooling Time	20 sec
Cycle Time	34.5 - 35 sec

TABLE 2: Processing Conditions for Polyetherimide. Disc and Flexural.

Drying	6 hours at 300 deg.F
Barrel Temperatures:	
Rear	575 deg.F
Center	602 deg.F
Front	630 deg.F
Nozzle	625 deg.F
Melt Temperature	610 deg.F
Screw Speed	204 rpm
Shot Size	1.85 inches
Decompression	0.1 inches
Injection Velocity	0.7 in/sec
Injection Pressure (hydraulic)	1653 psi
Injection Time	1.4 sec
Hold Pressure (hydraulic)	900 psi
Back Pressure	0 psi
Hold Time	8 sec
Mold Coolant Temperature	210 deg.F
Cooling Time	20 sec
Cycle Time	33.5 - 34 sec

TABLE 3: Processing Conditions for Polyphenylene Sulfide

Drying	6 hours at 275 deg.F
Barrel Temperatures:	
Rear	579 deg.F
Center	618 deg.F
Front	624 deg.F
Nozzle	630 deg.F
Melt Temperature	618 deg.F
Screw Speed	132 rpm
Shot Size	1.80 inches
Decompression	0.1 inches
Injection Velocity	0.3 in/sec
Injection Pressure (hydraulic)	900 psi
Injection Time	0.9 sec
Hold Pressure (hydraulic)	500 psi
Back Pressure	0 psi
Hold Time	4 sec
Mold Coolant Temperature	300 deg.F
Cooling Time	18 sec
Cycle Time	28 - 29 sec

TABLE 4: Processing Conditions for Vectra A950.

Drying	10 hours at 300 deg.F
Barrel Temperatures:	
Rear	536 deg.F
Center	543 deg.F
Front	548 deg.F
Nozzle	565 deg.F
Melt Temperature	552 deg.F
Screw Speed	108 rpm
Shot Size	1.75 inches
Decompression	0.1 inches
Injection Velocity	0.7 in/sec
Injection Pressure (hydraulic)	900 psi
Injection Time	1.3 sec
Hold Pressure (hydraulic)	500 psi
Back Pressure	0 psi
Hold Time	5.4 sec
Mold Coolant Temperature	220 deg.F
Cooling Time	10 sec
Cycle Time	21 - 22 sec

TABLE 5: Processing Conditions for Vectra B950.

Drying	8 hours at 300 deg.F
Barrel Temperatures:	
Rear	554 deg.F
Center	571 deg.F
Front	572 deg.F
Nozzle	565 deg.F
Melt Temperature	558 deg.F
Screw Speed	168 rpm
Shot Size	1.80 inches
Decompression	0.1 inches
Injection Velocity	0.4 in/sec
Injection Pressure (hydraulic)	900 psi
Injection Time	2.0 sec
Hold Pressure (hydraulic)	500 psi
Back Pressure	0 psi
Hold Time	7.0 sec
Mold Coolant Temperature	190 deg.F
Cooling Time	19 sec
Cycle Time	32 - 33 sec

TABLE 6: Processing Conditions for HX 4000.

Drying	8 hours at 300 deg.F
Barrel Temperatures:	
Rear	652 deg.F
Center	664 deg.F
Front	665 deg.F
Nozzle	642 deg.F
Melt Temperature	635 deg.F
Screw Speed	204 rpm
Shot Size	1.75 inches
Decompression	0.15 inches
Injection Velocity	0.9 in/sec
Injection Pressure (hydraulic)	1494 psi
Injection Time	1.1 sec
Hold Pressure (hydraulic)	855 psi
Back Pressure	0 psi
Hold Time	4.5 sec
Mold Coolant Temperature	250 deg.F
Cooling Time	15 sec
Cycle Time	32.6 - 33.3 sec

TABLE 7: Processing Conditions for Xydar SRT500.

Drying	10 hours at 250 deg.F
Barrel Temperatures:	
Rear	651 deg.F
Center	694 deg.F
Front	726 deg.F
Nozzle	662 deg.F
Melt Temperature	705 deg.F
Screw Speed	204 rpm
Shot Size	1.79 inches
Decompression	0.1 inches
Injection Velocity	0.9 in/sec
Injection Pressure (hydraulic)	1452 psi
Injection Time	1.1 sec
Hold Pressure (hydraulic)	1000 psi
Back Pressure	0 psi
Hold Time	5.0 sec
Mold Coolant Temperature	300 deg.F
Cooling Time	15 sec
Cycle Time	25 - 26 sec

TABLE 8: Tensile Properties for Polyetherimide.

Sample Number	Strength at break $x10^4$ psi	% elongn. at break	Yield strength $x10^4$ psi	% elongn. at yield	Elastic Modulus $x10^4$ psi
1	1.300	64.37	1.721	32.99	38.99
2	1.309	60.83	1.734	32.95	39.97
3	1.284	77.99	1.696	33.54	40.08
4	1.306	75.67	1.723	32.24	38.85
5	1.298	62.48	1.719	32.01	39.28
Mean	1.299	68.27	1.718	32.75	39.43
Std. Dev.	0.009	7.96	0.013	0.62	0.562

TABLE 9: Tensile Properties for Polyphenylene Sulfide.

Sample Number	Strength at break $x10^4$ psi	% elongn. at break	Elastic Modulus $x10^4$ psi
1	0.820	9.48	40.980
2	0.956	10.94	41.600
3	0.931	11.14	41.760
4	0.873	10.04	42.78
5	1.000	12.91	40.510
Mean	0.916	10.90	41.520
Std. Dev.	0.070	1.31	0.860

TABLE 10: Tensile Properties for Vectra A950.

Sample Number	Strength at break x10^4 psi	% elongn. at break	Elastic Modulus x10^4 psi
1	1.191	13.27	86.940
2	1.655	15.20	85.940
3	2.025	20.51	96.270
4	1.917	19.80	87.690
5	2.077	20.75	87.880
Mean	1.773	17.91	88.94
Std. Dev.	0.416	3.44	3.637

TABLE 11: Tensile Properties for Vectra B950.

Sample Number	Strength at break x10^4 psi	% elongn. at break	Elastic Modulus x10^4 psi
1	1.590	9.56	138.400
2	1.396	6.89	139.900
3	1.471	6.45	140.900
4	1.282	7.63	133.100
5	1.442	7.04	137.900
Mean	1.436	7.52	138.000
Std. Dev.	0.112	1.22	0.300

TABLE 12: Tensile Properties for HX 4000.

Sample Number	Strength at break $x10^4$ psi	% elongn. at break	Elastic Modulus $x10^4$ psi
1	0.328	2.44	50.760
2	0.388	3.89	44.580
3	0.502	6.53	46.250
4	0.489	0.65	40.910
5	0.386	0.32	40.100
Mean	0.419	2.76	44.520
Std. Dev.	0.074	0.27	4.315

TABLE 13: Tensile Properties for Xydar SRT500.

Sample Number	Strength at break $x10^4$ psi	% elongn. at break	Elastic Modulus $x10^4$ psi
1	1.156	23.11	38.130
2	1.258	23.86	51.470
3	0.892	15.55	43.370
4	0.905	14.25	32.870
5	0.762	15.26	34.890
Mean	0.995	18.39	40.146
Std. Dev.	0.204	4.67	7.470

TABLE 14: Flexural Properties for Polyetherimide.

Flexural properties for Polyetherimide are reported at 5% strain.

Sample Number	Maximum fiber stress $x10^4$ psi	Tangent Modulus $x10^4$ psi
1	1.228	43.110
2	1.228	43.680
3	1.305	43.110
4	1.267	45.700
5	1.228	42.100
Mean	1.251	41.540
Std. Dev.	0.034	4.591

TABLE 15: Flexural Properties for Polyphenylene Sulfide.

Sample Number	Maximum fiber stress $x10^4$ psi	Maximum Strain in/in	Tangent Modulus $x10^4$ psi
1	1.380	0.037	59.210
2	1.380	0.034	49.340
3	1.400	0.043	55.430
4	1.380	0.048	59.210
5	1.380	0.039	49.150
Mean	1.384	0.042	54.460
Std. Dev.	0.008	0.005	5.011

TABLE 16: Flexural Properties for Vectra A950.

Sample Number	Maximum fiber stress $x10^4$ psi	Maximum Strain in/in	Tangent Modulus $x10^4$ psi
1	1.689	0.040	131.000
2	1.704	0.045	114.600
3	1.612	0.042	118.700
4	1.651	0.040	122.800
5	1.704	0.035	122.800
Mean	1.672	0.040	121.900
Std. Dev.	0.039	0.003	6.081

TABLE 17: Flexural Properties for Vectra B950.

Sample Number	Maximum fiber stress $x10^4$ psi	Maximum Strain in/in	Tangent Modulus $x10^4$ psi
1	2.918	0.018	271.000
2	2.764	0.021	218.400
3	2.803	0.017	234.000
4	2.611	0.017	218.400
5	2.764	0.017	206.900
Mean	2.772	0.018	229.700
Std. Dev.	0.109	0.001	24.490

TABLE 18: Flexural Properties for HX 4000.

Sample Number	Maximum fiber stress $x10^4$ psi	Maximum Strain in/in	Tangent Modulus $x10^4$ psi
1	2.707	0.022	182.040
2	2.810	0.023	204.800
3	2.534	0.015	204.800
4	2.649	0.022	189.030
5	2.361	0.023	163.840
Mean	2.612	0.021	188.902
Std. Dev.	0.172	0.003	17.181

TABLE 19: Flexural Properties for Xydar SRT500.

Sample Number	Maximum fiber stress $x10^4$ psi	Maximum Strain in/in	Tangent Modulus $x10^4$ psi
1	1.580	0.012	19.660
2	1.663	0.014	19.660
3	1.612	0.012	18.020
4	1.520	0.012	19.660
5	1.617	0.011	21.129
Mean	1.598	0.012	19.658
Std. Dev.	0.528	0.001	1.156

TABLE 20: Compressive Properties for Polyetherimide.

Sample Number	Compressive Strength $x10^4$ psi	Compression at break in	Modulus of Elasticity $x10^4$ psi
1	1.993	0.168	25.880
2	1.678	0.133	22.700
3	1.913	0.183	23.840
4	1.982	0.181	24.450
5	1.908	0.187	24.020
Mean	1.896	0.170	24.170
Std. Dev.	0.123	0.022	1.150

TABLE 21: Compressive Properties for Polyphenylene Sulfide.

Sample Number	Compressive Strength $x10^4$ psi	Compression at break in	Modulus of Elasticity $x10^4$ psi
1	1.624	0.122	27.280
2	1.624	0.125	27.630
3	1.617	0.166	26.900
4	1.554	0.116	26.950
5	1.704	0.129	28.100
Mean	1.624	0.131	27.370
Std. Dev.	0.053	0.019	0.501

TABLE 22: Compressive Properties for Vectra A950.

Sample Number	Compressive Strength $x10^4$ psi	Compression at break in	Modulus of Elasticity $x10^4$ psi
1	0.778	0.071	22.060
2	0.893	0.120	22.530
3	0.867	0.140	22.250
4	0.928	0.148	26.440
5	0.930	0.189	20.100
Mean	0.879	0.134	22.720
Std. Dev.	0.062	0.043	2.303

TABLE 23: Compressive Properties for Vectra B950.

Sample Number	Compressive Strength $x10^4$ psi	Compression at break in	Modulus of Elasticity $x10^4$ psi
1	1.413	0.139	53.770
2	1.591	0.160	52.590
3	1.240	0.121	45.330
4	1.267	0.112	44.500
5	1.418	0.143	50.500
Mean	1.385	0.135	49.330
Std. Dev.	0.140	0.018	4.214

TABLE 21: Compressive Properties for Xydar SRT500.

Sample Number	Compressive Strength $x10^4$ psi	Compression at break in	Modulus of Elasticity $x10^4$ psi
1	0.838	0.115	76.840
2	0.732	0.143	61.990
3	0.771	0.137	77.870
4	0.939	0.185	67.660
5	0.796	0.126	79.300
Mean	0.815	0.141	72.730
Std. Dev.	0.116	0.079	23.840

TABLE 25: Comparision of Evaluated Properties to Published Properties

		Ultem		Vectra A950		HX 4000	
Prop.	Units	Manuf.	Eval.	Manuf.	Eval.	Manuf.	Eval.
Ten.St	psi. x 10^4	1.52	1.299	2.30	1.773	1.30	0.419
Ten. Mod	psi x 10^4	----	39.43	160.00	88.94	310.00	44.52
Elong.	%	60	68.27	------	-----	0.5	0.22
Flex. Mod.	psi x 10^4	48.00	41.54	------	-----	230.00	188.9
Flex. St.	psi x 10^4	2.20	1.251	------	------	3.310	2.612
Comp. St.	psi x 10^4	2.19	1.896	-----	-----	-----	----
Comp. Mod.	psi x 10^4	48.00	24.17	-----	-----	----	----

note1: the properties of Vectra B950, Fortron and Xydar SRT500 are not available.
note2: ---- indicates, that particular value was not available.

TABLE 26: Empircal Values of Shear modulus and Bulk Modulus

Material	Poisson's Ratio	Shear Modulus psi x 10^4	Bulk Modulus psi x 10^4
Ultem	0.36[i]	14.603	106.46
Fortron	0.38[i]	14.828	116.256
Vectra A950	0.4[ii]	31.76	249.032
Vectra B950	0.4[ii]	49.285	386.400
Xydar SRT500	0.4[ii]	14.337	112.408
HX 4000	0.4[ii]	15.90	124.650

[i] published values

[ii] assumed values

Fig 1: Tensile Modulus

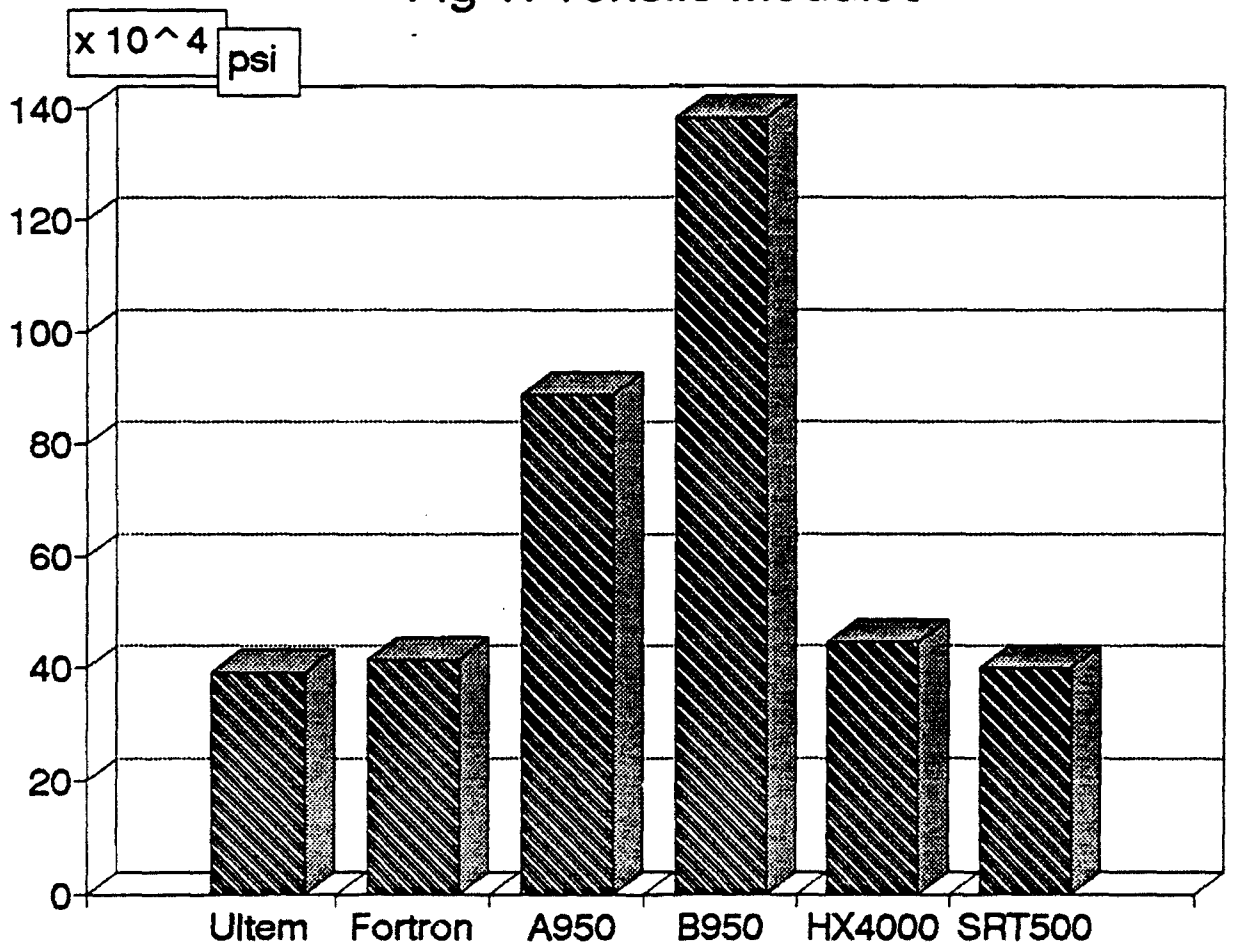


Fig 2: Tensile Strength

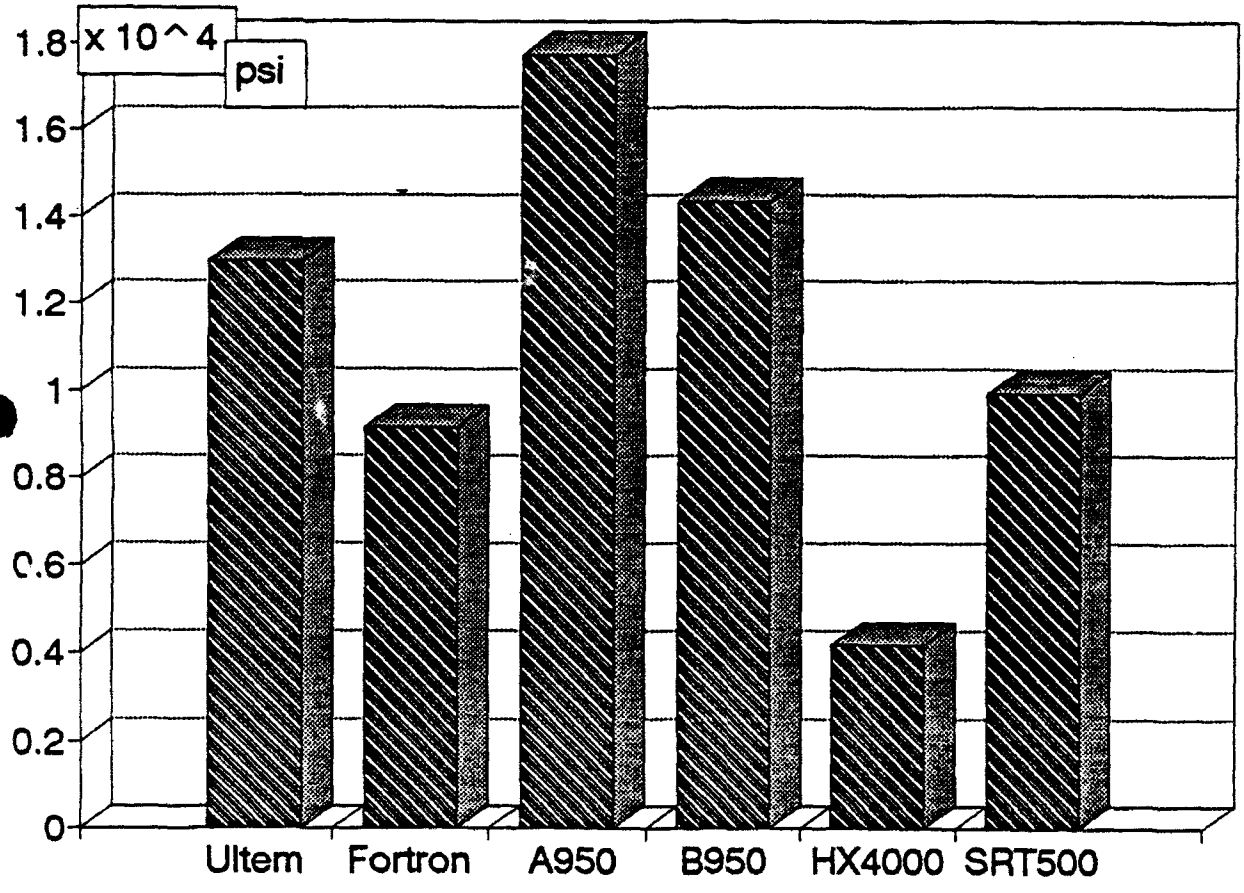


Fig 3: Flexural Modulus

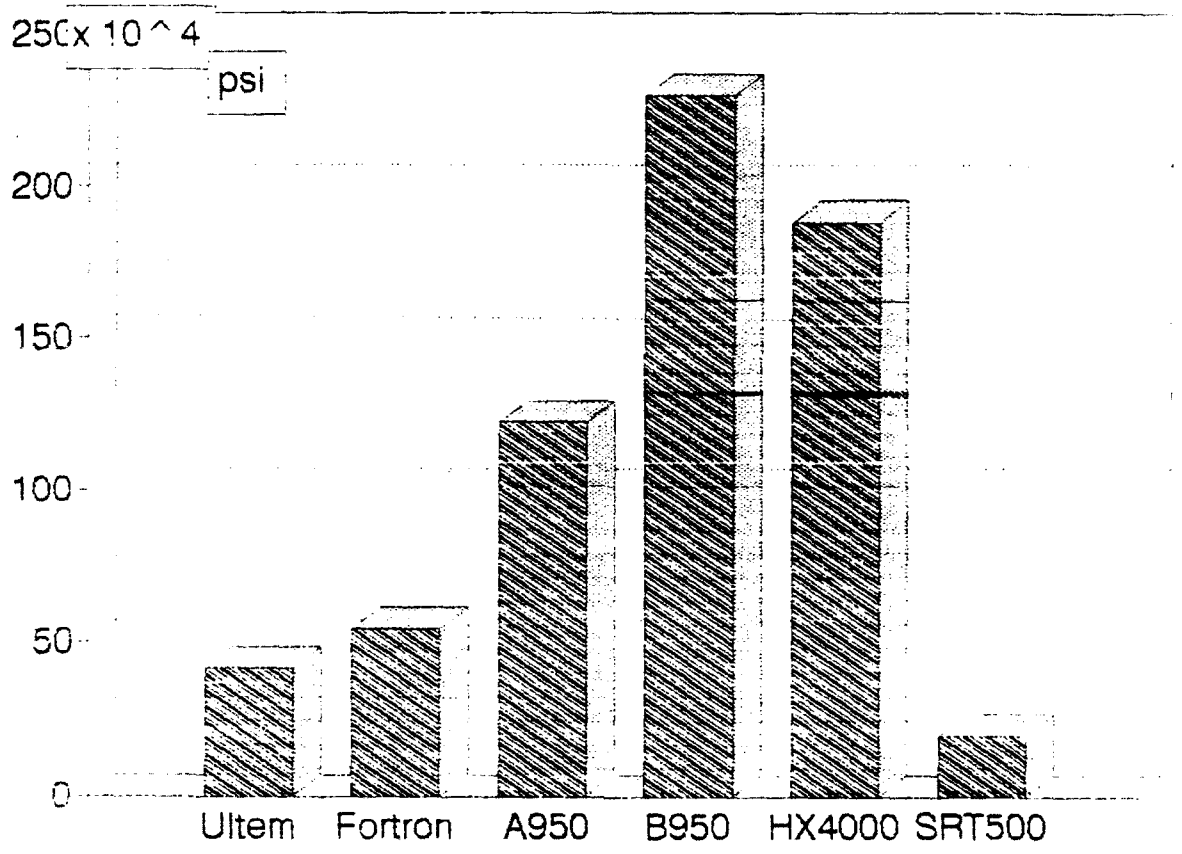


Fig 4: Maximum Flexural Fiber Stress

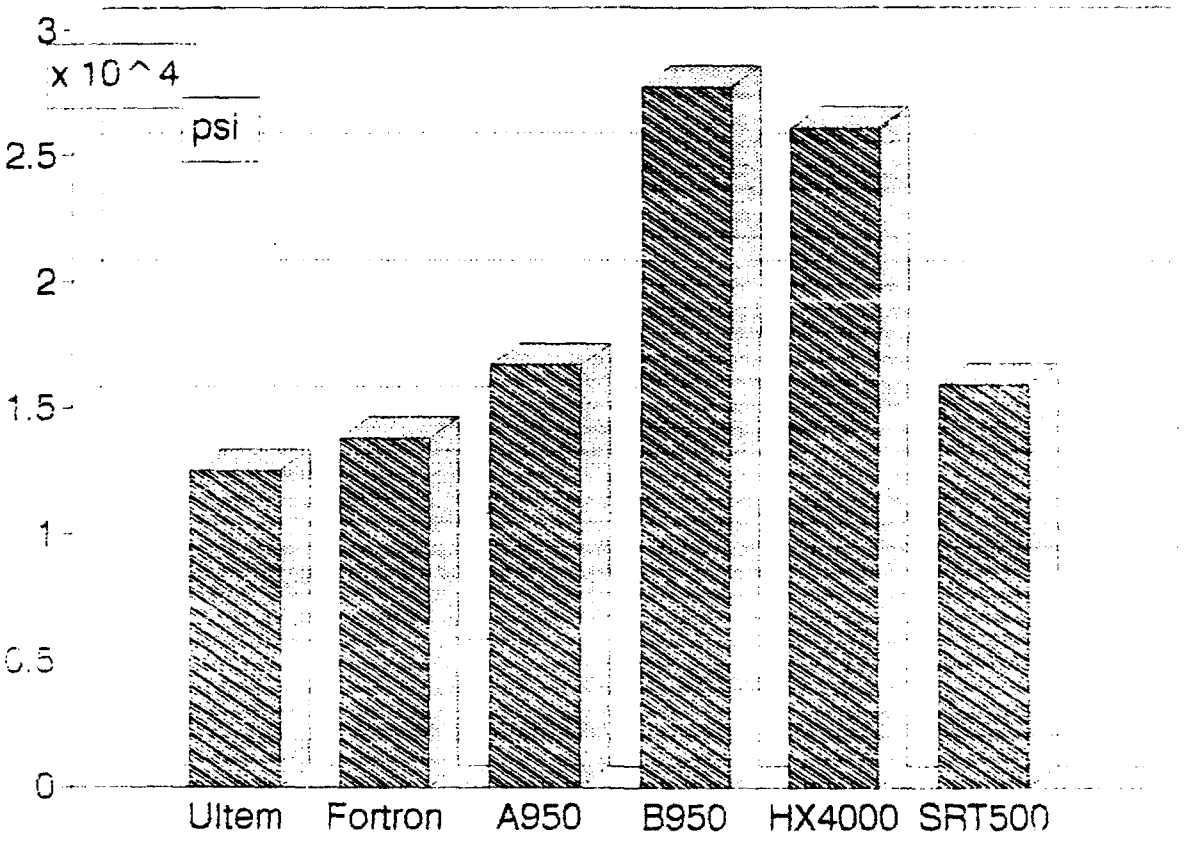


Fig 5: Compressive Modulus

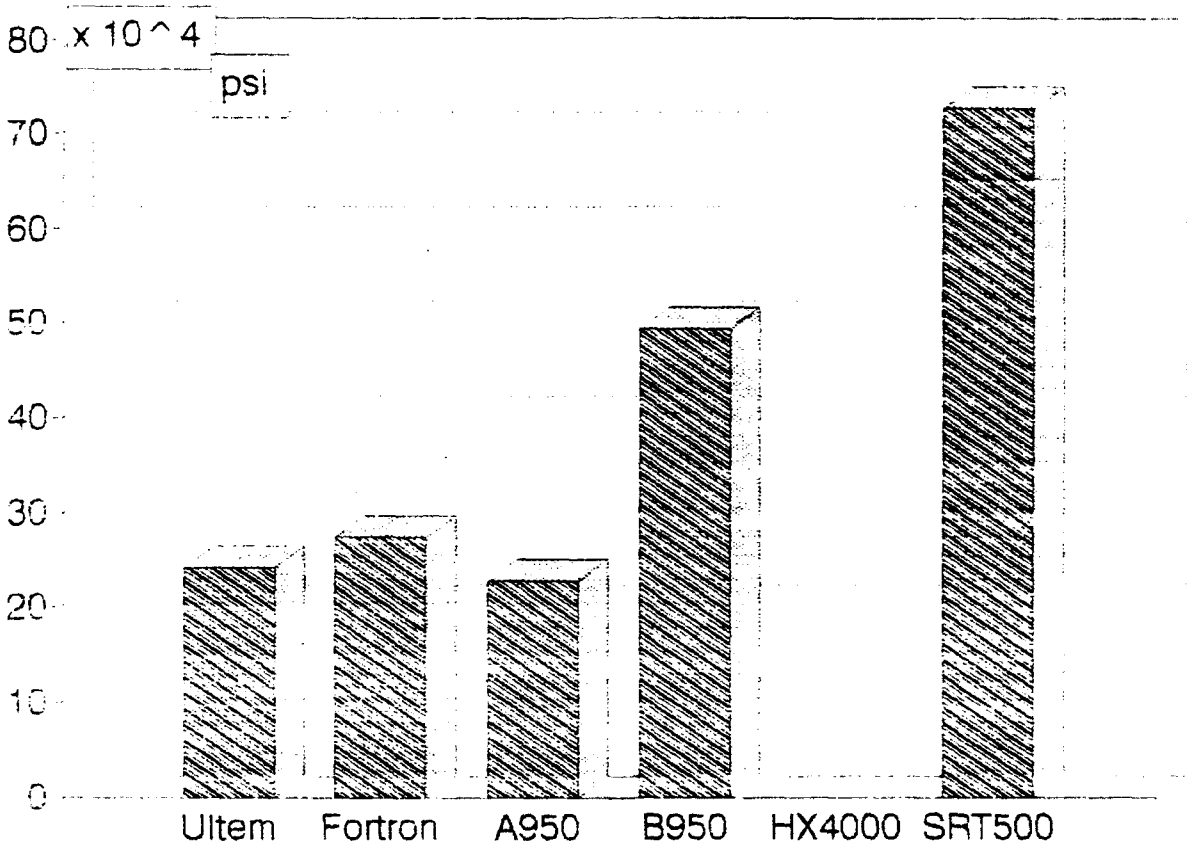


Fig 6: Compressive Strength

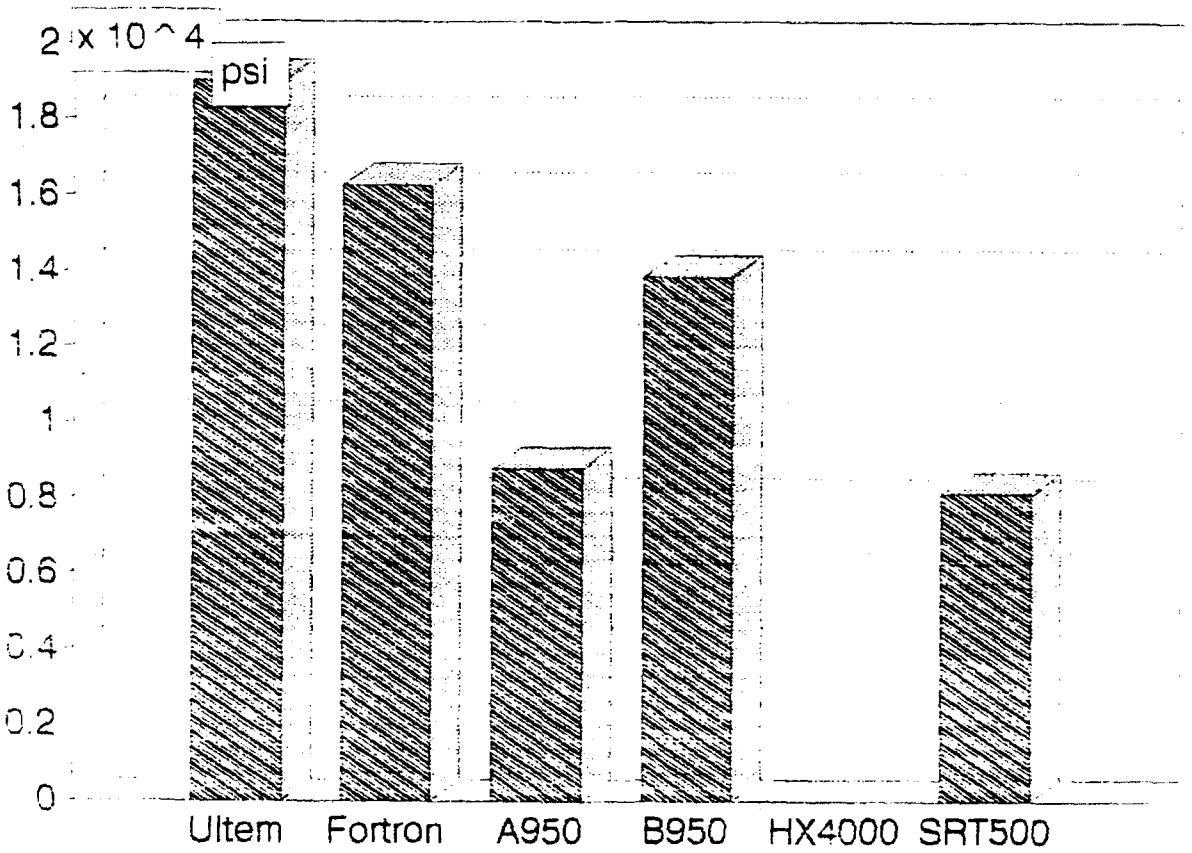
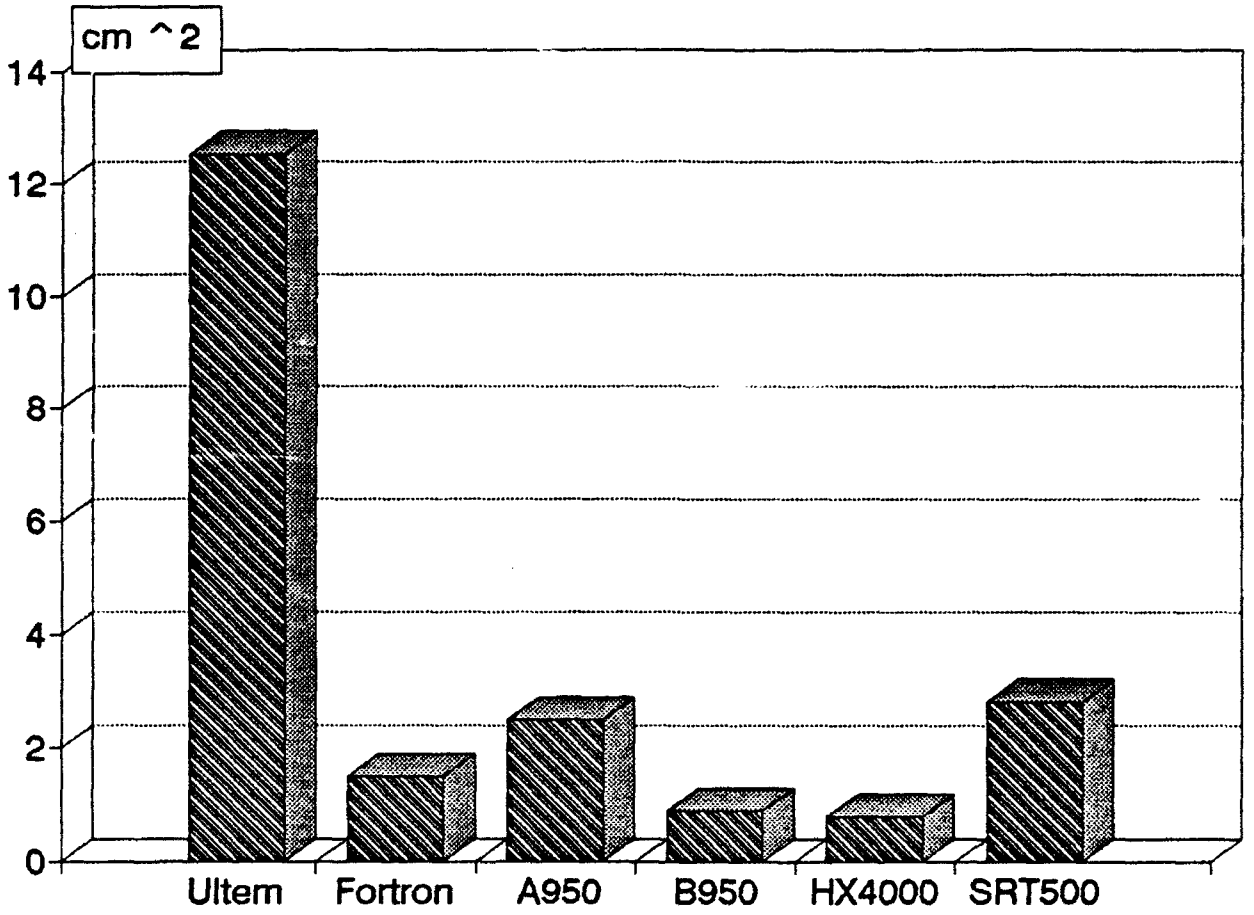


Fig 7: Toughness



VI. CONCLUSIONS

From the above experimental work done in molding and testing samples of Polyetherimide, Polyphenylene Sulfide, Vectra A950, Vectra B950, HX 4000 and Xydar SRT500, it is concluded that,

(i) The Polyetherimide, Polyphenylene Sulfide, Vectra A950 and Vectra B950 materials could be molded satisfactorily on conventional equipment to produce satispactory specimens for testing,

(ii) Problems were encountered in molding samples from the HX 4000 and Xydar SRT500 materials. Machine modifications including high temperature controllers and possibly a different screw design may be required for satisfactory processing.

(iii) Warpage of the 4 inch diameter disc for HX 4000 was a major problem, which could not be corrected,

(iv) The injection molded samples of Xydar SRT500 and HX4000 were not satisfactory due to non-uniformity of the melt. This problem may affect the measured property values,

(v) The measured tensile modulus for Vectra A950 is higher than for the other tested materials,

(vi) The measured flexural modulus for HX 4000 is higher than for the other materials, although the maximum fiber stress is lower than other materials,

(vii) The measured compressive modulus for Xydar SRT500 is higher than other materials although the compressive strength is lower for the other materials.

VII. RECOMMENDATIONS FOR FUTURE WORK

After completing the above experimental work and analyzing the results, it is recommended that,

(i) The materials should be processed under different operating conditions and their properties analyzed,

(ii) Future research work should be done to evaluate the reasons for warpage in injection molding of HX 4000,

(iii) Since the mechanical properties of liquid crystal polymers are greatly dependent on gate designs, different types of gates should be evaluated,

(iv) A machine which is capable of reaching the barrel temperatures up to 800 deg.F should be used to process Xydar SRT500 to obtain good melt homogenity,

(v) The size and shape of pellets for HX 4000 and Xydar SRT500 should be given consideration in future work for this affects the melt homogenity.

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APPENDIX A

Short Shot Method

SHORT SHOT METHOD

NOTES:

1. Assumes mold temperature is preset
2. Assumes melt temperature is preset
3. Only use this method if mold can accept a short shot without damage
4. Steps must be followed in the order given

STEPS:

1. SETTING SHOT SIZE
   a. Set holding pressure to ZERO
   b. Set holding time to ZERO
   c. Set Injection speed to MEDIUM TO FAST
   d. Set Injection (1st stage) time to a value GREATER than will be necessary to fill the mold
   e. Set Injection (1st stage) pressure to a value GREATER than will be necessary to fill the mold
   f. Set shot size to a value SMALLER than will be necessary to fill the mold
   g. Make a shot--the product should be SHORT
   h. Continue making shots, gradually INCREASING shot size--when the part is 95-98% filled, the shot size is OK. (Note: The screw must be bottomming out at this stage. There must be NO CUSHION)

2. CHECKING INJECTION SPEED
   a. Run some shots with the conditions as in 1.h--check if:
      (i) Jetting/burning or discoloration near gate/dieseling--if so, REDUCE injection speed until problems go away
      (ii) Cold flow marks--if so INCREASE injection speed until problems go away

3. SETTING INJECTION PRESSURE
   a. Continuing from step 2.a, set injection (1st stage) pressure to LOW
   b. Make a shot-- the product should be SHORT
   c. Continue making shots, gradually INCREASING injection pressure--when the part is 95-98% filled, matching the appearance in step 2.a, the injection pressure is OK. (Note: The screw must be bottomming out at this stage. There must be NO CUSHION)

4. SETTING INJECTION TIME
   a. Continuing from step 3.c, set injection (1st stage) time to LOW
   b. Make a shot-- the product should be SHORT
   c. Continue making shots, gradually INCREASING injection time--when the part is 95-98% filled, matching the appearance in step 3.c, the injection (1st stage) pressure is OK. (Note: The screw must be bottomming out at this stage. There must be NO CUSHION)

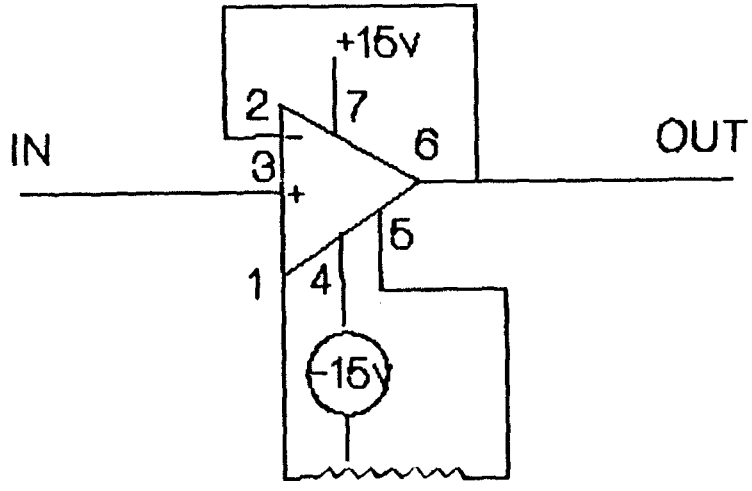
5. SETTING HOLDING TIME
   a. Continuing from step 4.c, increase shot size by 5 - 10%.
   b. Make a shot--the part should look like 4.c, but now a CUSHION is present
   c. Adjust holding (2nd stage) pressure to 50 - 60% of injection (1st stage) value. Check that holding time is still ZERO.
   d. Make a shot--the part should still look the same
   e. Continue making shots, gradually INCREASING holding time. Weigh the product at each time increment, until the weight stops increasing significantly. The holding time is now OK

R. E. Nunn 3/16/91

APPENDIX B

Machine Modification

The maximum barrel temperatures for the injection molding machine is 690 deg.F. This limit is set in the microprocessor control. If the temperature increases beyond this limit, the heater bands shuts off. With this temperature setting, it was not possible to process Xydar SRT500, which needs barrel temperature profile of 725 deg.F to 800 deg.F. This machine had three heating zones in the barrel. In order to increase the barrel temperature to the required value, we had to connect a potentiometer in between the microprocessor and the outlet of middle zone thermocouple. This potentiometer reduces the temperature reading from the thermocouple and fed the reduced value to the microprocessor. By varying the resistance in the potentiometer we could vary the barrel middle zone temperature. So, the microprocessor would actually read lower values than actual values. But this type of controller was not stable for long times (15 - 20 mins). The temperature used to vary by +/- 25 deg.F. By using this type of potentiometer we were able to process Xydar SRT500, though the samples were not satisfactory. Figure 8 shows the circuit diagram of the potentiometer.



10 K POT. 10 tURNS

offset nul = +/- 13 millivolt

Fig 8: Modification Circuit

APPENDIX C

ASTM Test Procedures

Designation: D 790 – 84a

Standard Test Methods for FLEXURAL PROPERTIES OF UNREINFORCED AND REINFORCED PLASTICS AND ELECTRICAL INSULATING MATERIALS[1]

This standard is issued under the fixed designation D 790; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This method has been approved for use by agencies of the Department of Defense to replace Method 1031 of Federal Test Method Standard 406 and for listing in the DoD Index of Specifications and Standards.

1. Scope

1.1 These test methods cover the determination of flexural properties of unreinforced and reinforced plastics, including high-modulus composites, and electrical insulating materials in the form of rectangular bars molded directly or cut from sheets, plates, or molded shapes. These test methods are generally applicable to rigid and semirigid materials. However, flexural strength cannot be determined for those materials that do not break or that do not fail in the outer fibers. Two methods of test are described as follows:

1.1.1 *Method I*—A three-point loading system utilizing center loading on a simply supported beam.

1.1.2 *Method II*—A four-point loading system utilizing two load points equally spaced from their adjacent support points, with a distance between load points of either one-third or one-half of the support span.

1.2 Either test method can be used with the two procedures that follow:

1.2.1 *Procedure A*, designed principally for materials that break at comparatively small deflections.

1.2.2 *Procedure B*, designed particularly for those materials that undergo large deflections during testing.

1.3 Comparative tests may be run according to either test method or procedure, provided that test method or procedure is found satisfactory for the material being tested.

1.4 The values stated in SI units are to be regarded as the standard.

NOTE 1—A complete metric companion to Test Method D 790 has been developed—D 790M.

1.5 *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of whoever uses this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Applicable Documents

2.1 *ASTM Standards:*

D 618 Methods of Conditioning Plastics and Electrical Insulating Materials for Testing[2]

D 638 Test Method for Tensile Properties of Plastics[2]

D 4066 Specification for Nylon Injection and Extrusion Materials[3]

E 4 Methods of Load Verification of Testing Machines[4]

3. Summary of Methods

3.1 A bar of rectangular cross section is tested in flexure as a beam as follows:

3.1.1 *Method I*—The bar rests on two supports and is loaded by means of a loading nose midway between the supports (see Fig. 1).

3.1.2 *Method II*—The bar rests on two supports and is loaded at two points (by means of

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[1] These test methods are under the jurisdiction of ASTM Committee D-20 on Plastics and are the direct responsibility of Subcommittee D20.10 on Mechanical Properties.

Current edition approved May 25 and July 27, 1984. Published September 1984. Originally published as D 790 – 70. Last previous edition D 790 – 81.

[2] *Annual Book of ASTM Standards*, Vol 08.01.

[3] *Annual Book of ASTM Standards*, Vol 08.03.

[4] *Annual Book of ASTM Standards*, Vol 03.01.

two loading noses), each an equal distance from the adjacent support point. The distance between the loading noses (that is, the load span) is either one-third or one-half of the support span (see Fig. 2).

3.2 The specimen is deflected until rupture occurs in the outer fibers or until the maximum fiber strain (see 11.9) of 5 % is reached, whichever occurs first.

4. Significance and Use

4.1 Flexural properties determined by Method I are especially useful for quality control and specification purposes.

4.2 Materials that do not fail at the point of maximum stress under Method I should be tested by Method II. Flexural properties determined by Method II are also useful for quality control and specification purposes. The basic difference between the two test methods is in the location of the maximum bending moment and maximum axial fiber stresses. The maximum axial fiber stresses occur on a line under the loading nose in Method I and over the area between the loading noses in Method II.

4.3 Flexural properties may vary with specimen depth, temperature, atmospheric conditions, and the difference in rate of straining specified in Procedures A and B (see also Note 7).

5. Apparatus

5.1 *Testing Machine*—A properly calibrated testing machine that can be operated at constant rates of crosshead motion over the range indicated, and in which the error in the load measuring system shall not exceed ± 1 % of maximum load expected to be measured. It shall be equipped with a deflection-measuring device. The stiffness of the testing machine shall be such that the total elastic deformation of the system does not exceed 1 % of the total deflection of the test specimen during test, or appropriate corrections shall be made. The load-indicating mechanism shall be essentially free from inertial lag at the crosshead rate used. The accuracy of the testing machine shall be verified in accordance with Methods E 4.

5.2 *Loading Noses and Supports*—The loading nose or noses and supports shall have cylindrical surfaces. In order to avoid excessive indentation, or failure due to stress concentration directly under the loading nose or noses, the radius of the nose or noses and supports shall be at least 3.2 mm (⅛ in.) for all specimens. For specimens 3.2 mm (⅛ in.) or greater in depth the radius of the supports may be up to 1.5 times the specimen depth. They shall be this large if significant indentation or compressive failure occurs. The arc of the loading nose in contact with the specimen shall be sufficiently large to prevent contact of the specimen with the sides of the nose or noses (see Fig. 1 for Method I, Fig. 3 for Method II).

6. Test Specimens

6.1 The specimens may be cut from sheets, plates, or molded shapes, or may be molded to the desired finished dimensions.

NOTE 2—Any necessary polishing of specimens shall be done only in the lengthwise direction of the specimen.

6.2 *Sheet Materials* (except laminated thermosetting materials and certain materials used for electrical insulation, including vulcanized fiber and glass bonded mica):

6.2.1 *Materials 1.6 mm (1/16 in.) or Greater in Thickness*—For flatwise tests the depth of the specimen shall be the thickness of the material. For edgewise tests, the width of the specimen shall be the thickness of the sheet and the depth shall not exceed the width (see Notes 3 and 4). For all tests, the support span shall be 16 (tolerance +4 or −2) times the depth of the beam. Specimen width shall not exceed one-fourth of the support span for specimens greater than 3.2 mm (⅛ in.) in depth. Specimens 3.2 mm (⅛ in.) or less in depth shall be 12.7 mm (½ in.) in width. The specimen shall be long enough to allow for overhanging on each end of at least 10 % of the support span, but in no case less than 6.4 mm (¼ in.) on each end. Overhang shall be sufficient to prevent the specimen from slipping through the supports.

NOTE 3—Whenever possible, the original surface of the sheet shall be unaltered. However, where testing machine limitations make it impossible to follow the above criterion on the unaltered sheet, one or both surfaces shall be machined to provide the desired dimensions, and the location of the specimens with reference to the total depth shall be noted. The value obtained on specimens with machined surfaces may differ from those obtained on specimens with original surfaces. Consequently, any specifications for flexural properties on the thicker sheets must state whether the original surfaces are to be retained or not. When only one surface was machined, it must be stated whether the machined surface was on the tension or compression side of the beam.

NOTE 4—Edgewise tests are not applicable for sheets that are so thin that specimens meeting these requirements cannot be cut. If specimen depth exceeds the width, buckling may occur.

6.2.2 *Materials Less than 1.6 mm (1/16 in.) in Thickness*—The specimen shall be 50.8 mm (2 in.) long by 12.7 mm (½ in.) wide, tested flatwise on a 25.4-mm (1-in.) support span.

NOTE 5—Use of the formulas for simple beams cited in these test methods for calculating results presumes that beam width is small in comparison with the support span. Therefore, the formulas do not apply rigorously to these dimensions.

NOTE 6—Where machine sensitivity is such that specimens of these dimensions cannot be measured, wider specimens or shorter support spans, or both may be used, provided the support span-to-depth ratio is at least 14 to 1. All dimensions must be stated in the report (see also Note 5).

6.3 *Laminated Thermosetting Materials and Sheet and Plate Materials Used for Electrical Insulation, Including Vulcanized Fiber and Glass-Bonded Mica*—Test the specimens in accordance with Table 1 for Method I, and Table 2 or 3 for Method II. For paper-base and fabric-base grades over 25.4 mm (1 in.) in nominal thickness, the specimens shall be machined on both surfaces to a depth of 25.4 mm (1 in.). For glass-base and nylon-base grades, specimens over 12.7 mm (½ in.) in nominal depth shall be machined on both surfaces to a depth of 12.7 mm (½ in.). The support span-to-depth ratio shall be chosen such that failures occur in the outer fibers of the specimens, due only to the bending moment (Note 7). Three recommended support span-to-depth ratios are 16, 32 and 40 to 1. When laminated materials exhibit low compressive strength perpendicular to the laminations, they shall be loaded with a large radius loading nose (up to 4 times the specimen depth for Method I and 1.5 times the specimen depth for Method II) to prevent premature damage to the outer fibers.

6.4 *Molding Materials (Thermoplastics and Thermosets)*—The recommended specimen for molding materials is 127 by 12.7 by 3.2 mm (5 by ½ by ⅛ in.) tested flatwise on a support span, resulting in a support span-to-depth ratio of 16 (tolerance +4 or −2). Thicker specimens should be avoided if they exhibit significant shrink marks or bubbles when molded.

6.5 *High-Strength Reinforced Composites, Including Highly Orthotropic Laminates*—Specimens shall be tested in accordance with Table 1 for Method I, and Table 2 or 3 for Method II. The support span-to-depth ratio shall be chosen such that failures occur in the outer fibers of the specimens, due only to the bending moment (Note 7). Three recommended support span-to-depth ratios are 16:1, 32:1, and 4 However, for some highly anisotropic composites, shear deformation can significantly influence modulus measurements, even at span-to depth ratios as high as 40:1. Hence, for these materials, an increase in span-to-depth ratio to 60:1 is recommended to eliminate shear effects when modulus data are required. It should also be noted that the flexural modulus of highly anisotropic laminates is a strong function of ply-stacking sequence and will not necessarily correlate with tensile modulus, which is not stacking-sequence dependent.

NOTE 7—As a general rule, support span-to-depth ratios of 16 are satisfactory when the ratio of the tensile strength to shear strength is less than 8 to 1, but the support span-to-depth ratio must be increased for composite laminates having relatively low shear strength in the plane of the laminate and relatively high tensile strength parallel to the support span.

7. Number of Test Specimens

7.1 At least five specimens shall be tested for each sample in the case of isotropic materials or molded specimens.

7.2 For each sample of anisotropic material in sheet form, at least five specimens shall be tested for each of the following conditions. Recommended conditions are flatwise and edgewise tests on specimens cut in lengthwise and crosswise directions of the sheet. For purposes of this test, "lengthwise" shall designate the principal axis of anisotropy and shall be interpreted to mean the direction of the sheet known to be stronger in flexure. "Crosswise" shall be the sheet direction known to be the weaker in flexure, and shall be at 90° to the lengthwise direction.

8. Conditioning

8.1 *Conditioning*—Condition the test specimens at 23 ± 2°C (73.4 ± 3.6°F) and 50 ± 5 % relative humidity for not less than 40 h prior to test in accordance with Procedure A of Methods D 618 for those tests where conditioning is required. In cases of disagreement, the tolerances shall be ±1°C (±1.8°F) and ±2 % relative humidity.

8.1.1 Note that for some hygroscopic materials, such as nylons, the material specifications (for example, Specification D 4066) call for testing "dry as-molded specimens". Such requirements take precedence over the above routine preconditioning to 50 % RH and require sealing the specimens in water vapor-impermeable con-

tainers as soon as molded and not removing them until ready for testing.

8.2 *Test Conditions*—Conduct tests in the Standard Laboratory Atmosphere of 23 ± 2°C (73.4 ± 3.6°F) and 50 ± 5 % relative humidity, unless otherwise specified in the test methods or in this specification. In cases of disagreement, the tolerances shall be ±1°C (±1.8°F) and ±2 % relative humidity.

9. Procedure

9.1 *Method I—Procedure A:*

9.1.1 Use an untested specimen for each measurement. Measure the width and depth of the specimen to the nearest 0.03 mm (0.001 in.) at the center of the support span. For specimens less than 2.54 mm (0.100 in.) in depth, measure the depth to the nearest 0.003 mm (0.0001 in.).

9.1.2 Determine the support span to be used as described in Section 6 and set the support span to within 1 % of the determined value.

9.1.3 If Table 1 is used, set the machine to the specified rate of crosshead motion, or as near as possible to it. If Table 1 is not used, calculate the rate of crosshead motion as follows and set the machine for the calculated rate, or as near as possible to it:

$$R = ZL^2/6d \quad (1)$$

where:

R = rate of crosshead motion, mm (in.)/min,
L = support span, mm (in.),
d = depth of beam, mm (in.), and
Z = rate of straining of the outer fiber, mm/mm·min (in./in.·min). Z shall equal 0.01.

In no case shall the actual crosshead rate differ from that specified by Table 1, or that calculated from Eq 1, by more than ±50 %.

9.1.4 Align the loading nose and supports so that the axes of the cylindrical surfaces are parallel and the loading nose is midway between the supports. The parallelism may be checked by means of a plate with parallel grooves into which the loading nose and supports will fit when properly aligned. Center the specimen on the supports, with the long axis of the specimen perpendicular to the loading nose and supports.

9.1.5 Apply the load to the specimen at the specified crosshead rate, and take simultaneous load-deflection data. Measure deflection either by a gage under the specimen in contact with it at the center of the support span, the gage being mounted stationary relative to the specimen supports, or by measurement of the motion of the loading nose relative to the supports. In either case, make appropriate corrections for indentation in the specimens and deflections in the weighing system of the machine. Load-deflection curves may be plotted to determine the flexural yield strength, secant or tangent modulus of elasticity, and the total work measured by the area under the load-deflection curve.

9.1.6 Terminate the test if the maximum strain in the outer fibers has reached 0.05 mm/mm (in./in.) (Notes 8 and 9). The deflection at which this strain occurs may be calculated by letting r equal 0.05 mm/mm (in./in.) as follows:

$$D = rL^2/6d \quad (2)$$

where:

D = midspan deflection, mm (in.),
r = strain, mm/mm (in./in.),
L = support span, mm (in.), and
d = depth of beam, mm (in.).

NOTE 8—For some materials the increase in strain rate provided under Procedure B may induce the specimen to yield or rupture, or both, within the required 5 % strain limit.

NOTE 9—Beyond 5 % strain, these test methods are not applicable, and some other property might be measured (for example Test Method D 638 may be considered).

9.2 *Method II—Procedure A:*

9.2.1 See 9.1.1

9.2.2 See 9.1.2.

9.2.3 If Table 2 or 3 is used, set the machine as close as possible to the specified rate of crosshead motion. If Table 2 or 3 is not used, calculate the rate of crosshead motion as follows, and set the machine as near as possible to that calculated rate for a load span of one-third of the support span:

$$R = 0.185ZL^2/d \quad (1a)$$

For a load span of one-half of the support span:

$$R = 0.167ZL^2/d \quad (1b)$$

where:

R = rate of crosshead motion, mm (in.)/min,
L = support span, mm (in.),
d = depth of beam, mm (in.), and
Z = rate of straining of the outer fibers, mm/mm (in./in.)·min, Z shall equal 0.01.

In no case shall the actual crosshead rate differ from that specified by Table 2 or 3, or that

calculated from Eq. 1a or 1b, by more than ±50 %.

9.2.4 Align the loading noses and supports so that the axes of the cylindrical surfaces are parallel and the load span is either one-third or one-half of the support span. This parallelism may be checked by means of a plate containing parallel grooves into which the loading noses and supports will fit when properly aligned. Center the specimen on the supports, with the long axis of the specimen perpendicular to the loading noses and supports. The loading nose assembly shall be of the type which will not rotate.

9.2.5 Apply the load to the specimen at the specified crosshead rate, and take simultaneous load-deflection data. Measure deflection by a gage under the specimen in contact with it at the common center of the spans, the gage being mounted stationary relative to the specimen supports. Make appropriate corrections for indentation in the specimens and deflections in the weighing system of the machine. Load-deflection curves may be plotted to determine the flexural yield strength, secant or tangent modulus of elasticity, and the total work measured by the area under the load-deflection curve.

9.2.6 If no break has occurred in a specimen by the time the maximum strain in the outer fibers has reached 0.05 mm/mm (in./in.), discontinue the test (Notes 8 and 9). The deflection at which this strain occurs may be calculated by letting r equal 0.05 mm/mm (in./in.) as follows for a load span of one-third of the support span:

$$D = 0.21rL^2/d \quad (2a)$$

For a load span of one-half of the support span:

$$D = 0.23rL^2/d \quad (2b)$$

where:

D = midspan deflection, mm (in.),
r = strain, mm per mm (in. per in.),
L = support span, mm (in.), and
d = depth of beam, mm (in.).

9.3 *Methods I and II, Procedure B:*

9.3.1 Use an untested specimen for each measurement.

9.3.2 Test conditions shall be identical to those described in 9.1 or 9.2, except that the rate of straining of the outer fibers shall be 0.10 mm/mm (in./in.)/min.

9.3.3 If no break has occurred in the specimen by the time the maximum strain in the outer fibers has reached 0.05 mm/mm (in./in.), discontinue the test (Note 9).

10. Retests

10.1 Values for properties at rupture shall not be calculated for any specimen that breaks at some obvious, fortuitous flaw, unless such flaws constitute a variable being studied. Retests shall be made for any specimen on which values are not calculated.

11. Calculations

11.1 *Maximum Fiber Stress, Method I*—When a beam of homogeneous, elastic material is tested in flexure as a simple beam supported at two points and loaded at the midpoint, the maximum stress in the outer fibers occurs at midspan. This stress may be calculated for any point on the load-deflection curve by the following equation (Notes 10 and 11):

$$S = 3PL/2bd^2 \quad (3)$$

where:

S = stress in the outer fibers at midspan, N/m^2 (psi),
P = load at a given point on the load-deflection curve, N (lbf),
L = support span, m (in.),
b = width of beam tested, m (in.), and
d = depth of beam tested, m (in.).

NOTE 10—Equation 3 applies strictly to materials for which the stress is linearly proportional to strain up to the point of rupture and for which the strains are small. Since this is not always the case, a slight error will be introduced in the use of this equation. The equation will, however, be valid for comparison data and specification values up to the maximum fiber strain of 5 % for specimens tested by the procedure herein described. It should be noted that the maximum stress may not occur in the outer fibers for a highly orthotropic laminate[5]. Laminated beam theory must be applied to determine the maximum tensile stress at failure. Thus, Eq 3 yields an apparent strength based on homogeneous beam theory. This apparent strength is highly dependent on the ply-stacking sequence for highly orthotropic laminates.

NOTE 11—The above calculation is not valid if the specimen is slipping excessively between the supports.

11.2 *Maximum Fiber Stress for Beams Tested*

[5] For the theoretical details, see Whitney, J. M., Browning, C. E., and Mair, A., "Analysis of the Flexure Test for Laminated Composite Materials," *Composite Materials: Testing and Design (Third Conference)*, ASTM STP 546, 1974, pp. 30–45.

at Large Support Spans, Method I—If support span-to-depth ratios greater than 16 to 1 are used such that deflections in excess of 10 % of the support span occur, the maximum stress for a simple beam can be reasonably approximated with the following equation (Note 12):

$$S = (3PL/2bd^2) \cdot [1 + 6(D/L)^2 - 4(d/L)(D/L)] \quad (3a)$$

where S, P, L, b, and d are the same as for Eq 3 and D is the deflection in m (in.) of the centerline of the specimen at the middle of the support span.

NOTE 12—When large support span-to-depth ratios are used, significant end forces are developed at the supports which affect the moment in a simply supported beam. An approximate correction factor is given in Eq 3a to correct for these end forces in large support span-to-depth ratio beams where relatively large deflections exist.

11.3 *Maximum Fiber Stress, Method II*—When a beam is loaded in flexure at two central points and supported at two outer points, the maximum stress in the outer fibers occurs between the two central loading points that define the load span (Fig. 2). This stress may be calculated for any point on the load-deflection curve for relatively small deflections by the following equation for a load span of one-third of the support span (Note 13):

$$S = PL/bd^2 \quad (3b)$$

For a load span of one-half of the support span:

$$S = 3PL/4bd^2 \quad (3c)$$

where:

S = stress in the outer fiber throughout the load span, N/m^2 (psi),
P = load at a given point on the load-deflection curve, N (lbf),
L = support span, m (in.),
b = width of beam, m (in.), and
d = depth of beam, m (in.).

NOTE 13—The limitations defined for Eq 3 in Notes 10 and 11 apply also to Eq 3a, 3b, 3c, 3d, and 3e.

11.4 *Maximum Fiber Stress—Method II—for Beams Tested at Large Support Spans*—If support span-to-depth ratios greater than 16 to 1 are used with resultant deflections in excess of 10 % of the support span occuring, the maximum stress may be reasonably approximated with the following formula for a load span of one-third of the support span:

$$S = (PL/bd^2) \cdot [1 + (4.70D^2/L^2) - (7.04Dd/L^2)] \quad (3d)$$

For a load span of one-half of the support span:

$$S = (3PL/4bd^2) \cdot [1-(10.91Dd/L^2)] \quad (3e)$$

where S, P, L, b, and d are the same as for Eq 3b and D = maximum deflection of the center of the beam in m (in.).

11.5 *Flexural Strength (Modulus of Rupture)*—The flexural strength is equal to the maximum stress in the outer fibers at the moment of break (for highly orthotropic laminates, see Note 10). It is calculated in accordance with Eq 3, 3a, 3b, 3c, 3d, and 3e by letting P equal the load at the moment of break. If the material does not break, this part of the test is not applicable. In this case, it is suggested that yield strength, if applicable, be calculated and that the corresponding strain be reported also (see 11.6, 11.8, and 11.9).

11.6 *Flexural Yield Strength*—Some materials that do not break at outer fiber strains up to 5 % may give load-deflection curves that show a point, Y, at which the load does not increase with an increase in deflection. In such cases, the flexural yield strength may be calculated in accordance with Eq 3, 3a, 3b, or 3c by letting P equal the load at point Y.

11.7 *Flexural Offset Yield Strength*—Offset yield strength is the stress at which the stress-strain curve deviates by a given strain (offset) from the tangent to the initial straight line portion of the stress-strain curve. The value of the offset must be given whenever this property is calculated.

NOTE 14—This value may differ from flexural yield strength defined in 11.6. Both methods of calculation are described in the Annex to Test Method D 638.

11.8 *Stress at a Given Strain*—The maximum fiber stress at any given strain may be calculated in accordance with Eq 3, 3a, 3b, 3c, 3d, and 3e by letting P equal the load read from the load-deflection curve at the deflection corresponding to the desired strain (for highly orthotropic laminates, see Note 10).

11.9 *Maximum Strain, Method I*—The maximum strain in the outer fibers also occurs at midspan, and may be calculated as follows:

$$r = 6Dd/L^2 \quad (4)$$

where:

r = maximum strain in the outer fibers, mm/mm (in./in.),
D = maximum deflection of the center of the beam, mm (in.),
L = support span, mm (in.), and
d = depth, mm (in.).

11.10 *Maximum Strain, Method II*—The maximum strain in the outer fibers also occur at midspan, and may be calculated as follows for a load span of one-third of the support span:

$$r = 4.70Dd/L^2 \quad (4a)$$

For load span of one-half of the support span:

$$r = 4.36Dd/L^2 \quad (4b)$$

where D, d, L, and r are the same as for Eq 2a.

11.11 *Modulus of Elasticity:*

11.11.1 *Tangent Modulus of Elasticity, Method I*—The tangent modulus of elasticity, often called the "modulus of elasticity," is the ratio, within the elastic limit of stress to corresponding strain and shall be expressed in newtons per square meter (pounds per square inch). It is calculated by drawing a tangent to the steepest initial straight-line portion of the load-deflection curve and using Eq 5 (for highly anisotropic composites, see Note 15).

$$E_B = L^3m/4bd^3 \quad (5)$$

where:

E_B = modulus of elasticity in bending, N/m^2 (psi),
L = support span, m (in.),
b = width of beam tested, m (in.),
d = depth of beam tested, m (in.), and
m = slope of the tangent to the initial straight-line portion of the load-deflection curve, N/m (lbf/in.) of deflection.

NOTE 15—Shear deflections can seriously reduce the apparent modulus of highly anisotropic composites when they are tested at low span-to-depth ratios[6]. For this reason, a span-to-depth ratio of 60 to 1 is recommended for flexural modulus determinations. Flexural strength should be determined on a separate set of replicate specimens at a lower span-to-depth ratio that induces tensile failures in the outer fibers of the beam along its lower face. Since the flexural modulus of highly anisotropic laminates is a critical function of ply-stacking sequence, it will not necessarily correlate with tensile modulus, which is not stacking-sequence dependent.

11.11.2 *Tangent Modulus of Elasticity, Method II*—The tangent modulus of elasticity is the ratio, within the elastic limit, of stress to corresponding strain and shall be expressed in newtons per square meter (pounds per square inch). It is calculated by drawing a tangent to the steepest initial straight-line portion of the load-deflection curve and using Eq 5a for a load span of one-third the support span, and Eq 5b for a load span of one-half of the support span, as follows:

$$E_B = 0.21L^3m/bd^3 \quad (5a)$$

$$E_B = 0.17L^3m/bd^3 \quad (5b)$$

where E_B, m, L, b, and d are the same as for Eq 5 (for highly anisotropic composites, see Note 15).

11.11.3 *Secant Modulus of Elasticity*—The secant modulus of elasticity is the ratio of stress to corresponding strain at any given point on the stress-strain curve, or the slope of the straight line that joins the origin and a selected point on the actual stress-strain curve. It shall be expressed in newtons per square meter (pounds per square inch). The selected point is generally chosen at a specified stress or strain. It is calculated in accordance with Eq 5 or 5a by letting m equal the slope of the secant to the load-deflection curve.

11.12 *Arithmetic Mean*—For each series of tests, the arithmetic mean of all values obtained shall be calculated to three significant figures and reported as the "average value" for the particular property in question.

11.13 *Standard Deviation*—The standard deviation (estimated) shall be calculated as follows and reported in two significant figures:

$$s = \sqrt{\frac{\Sigma X^2 - n\bar{X}^2}{n-1}}$$

where:

s = estimated standard deviation,
X = value of single observation,
n = number of observations, and
$\bar{X}$ = arithmetic mean of the set of observations.

11.14 See Appendix X1 for information on toe compensation.

12. Report

12.1 The report shall include the following:

[6] For a discussion of these effects, see Zweben, C., Smith, W. S., and Wardle, M. W., "Test Methods for Fiber Tensile Strength, Composite Flexural Modulus, and Properties of Fabric-Reinforced Laminates," *Composite Materials: Testing and Design (Fifth Conference)*, ASTM STP 674, 1979, pp. 228–262.

12.1.1 Complete identification of the material tested, including type, source, manufacturer's code number, form, principal dimensions, and previous history. For laminated materials, ply-stacking sequence shall be reported.

12.1.2 Direction of cutting and loading specimens.

12.1.3 Conditioning procedure.

12.1.4 Depth and width of specimen.

12.1.5 Method used.

12.1.6 Procedure used.

12.1.7 Support span length.

12.1.8 Support span-to-depth ratio.

12.1.9 Radius of supports and loading noses.

12.1.10 Rate of crosshead motion.

12.1.11 Maximum strain in the outer fibers of the specimen.

12.1.12 Flexural strength (if applicable), average value, and standard deviation.

12.1.13 Tangent or secant modulus of elasticity in bending, average value, standard deviation, and the strain level used if secant modulus.

12.1.14 Flexural yield strength (if desired), average value, and standard deviation.

12.1.15 Flexural offset yield strength (if desired), with offset or strain used, average value, and standard deviation.

12.1.16 Stress at any given strain up to and including 5 % (if desired), with strain used, average value, and standard deviation.

13. Precision

13.1 Reproducibility between specimens is approximately ±5 % for homogeneous materials tested.

13.2 Round-robin test data on flexural method comparisons are on file at ASTM Headquarters as RR 67:D-20.

TABLE 1 Recommended Dimensions for Test Specimens of Sections 6.3 and 6.5 for Various Support Span-to-Depth Ratios (See Note 7)

Method I (3-Point Loading)

Nominal Specimen Depth, mm (in.)	Specimen Width mm (in.)	Support Span-to-Depth Ratio (See Note 7)											
		L/d = 16 to 1			L/d = 32 to 1			L/d = 40 to 1			L/d = 60 to 1		
		Specimen Length, mm (in.)	Support Span, mm (in.)	Rate of Cross-head Motion (Procedure A), mm (in.)/min[A]	Specimen Length, mm (in.)	Support Span, mm (in.)	Rate of Cross-head Motion (Procedure A), mm (in.)/min[A]	Specimen Length, mm (in.)	Support Span, mm (in.)	Rate of Cross-head Motion (Procedure A), mm (in.)/min[A]	Specimen Length, mm (in.)	Support Span, mm (in.)	Rate of Cross-head Motion (Procedure A) mm (in.)/min[A]
0.8 (1/32)	25 (1)	50 (2)	16 (5/8)[B]	0.5 (0.02)	50 (2)	25 (1)	1.3 (0.05)	60 (2 1/4)	30 (1 1/4)	2.0 (0.08)	60 (2 3/8)	48 (1 7/8)	4.8 (0.19)
1.6 (1/16)	25 (1)	50 (2)	25 (1)	0.8 (0.03)	80 (3)	50 (2)	2.8 (0.11)	90 (3 1/2)	60 (2 1/2)	4.3 (0.17)	124 (4 7/8)	95 (3 3/4)	9.4 (0.37)
2.4 (3/32)	25 (1)	60 (2 1/2)	40 (1 1/2)	1.0 (0.04)	100 (4)	80 (3)	4.1 (0.16)	120 (4 1/4)	95 (3 1/4)	6.4 (0.25)	185 (7 9/32)	143 (5 5/8)	14.2 (0.56)
3.2 (1/8)	25 (1)	80 (3)	50 (2)	1.3 (0.05)	130 (5)	100 (4)	5.3 (0.21)	180 (7)	130 (5)	8.4 (0.33)	247 (9 3/4)	190 (7 1/2)	18.8 (0.74)
4.8 (3/16)	13 (1/2)	100 (4)	80 (3)	2.0 (0.08)	191 (7 1/2)	150 (6)	8.1 (0.32)	240 (9 1/2)	191 (7 1/2)	12.7 (0.50)	372 (14 5/8)	286 (11 1/4)	28.4 (1.12)
6.4 (1/4)	13 (1/2)	130 (5)	100 (4)	2.8 (0.11)	250 (10)	200 (8)	10.9 (0.43)	330 (13)	250 (10)	17.0 (0.67)	495 (19 1/2)	381 (15)	37.8 (1.49)
9.6 (3/8)	13 (1/2)	191 (7 1/2)	150 (6)	4.1 (0.16)	380 (15)	300 (12)	16.3 (0.64)	480 (19)	380 (15)	25.4 (1.00)	744 (29 5/16)	572 (22 1/2)	56.8 (2.24)
12.7 (1/2)	13 (1/2)	250 (10)	200 (8)	5.3 (0.21)	495 (19 1/2)	410 (16)	21.6 (0.85)	640 (25)	510 (20)	34.0 (1.34)	991 (39)	762 (30)	76.2 (3.00)
19.1 (3/4)	19 (3/4)	380 (15)	300 (12)	8.1 (0.32)	740 (29)	610 (24)	32.5 (1.28)	940 (37)	760 (30)	50.8 (2.00)	1486 (58 1/2)	1143 (45)	114 (4.49)
25.4 (1)	25 (1)	495 (19 1/2)	410 (16)	10.9 (0.43)	990 (39)	810 (32)	43.4 (1.71)	1240 (49)	1020 (40)	67.8 (2.67)	1981 (78)	1524 (60)	152 (5.98)

[A] Rates indicated are for Procedure A where strain rate is 0.01 mm/mm/min (0.01 in./in./min). To obtain rates for Procedure B where strain rate is 0.10 mm/mm/min (0.10 in./in./min), multiply these values by 10. Procedure A is to be used for all specification purposes unless otherwise stated in the specifications. See 9.1.3 for the method of calculation.

[B] This support span-to-depth ratio is greater than 16 to 1 in order to give clearance between moving head and specimen support.

TABLE 2 Recommended Dimensions for Test Specimens of Sections 6.3 and 6.5 for Various Support Span-to-Depth Ratios (See Note 7)

Method II [4-Point Loading at ⅓ Points, Fig. 2(A)]

Nominal Specimen Depth, mm (in.)	Specimen Width, mm (in.)	Specimen Length, mm (in.)	Support Span, mm (in.)	Load Span, mm (in.)	Rate of Crosshead Motion (Procedure A) mm (in.)/min[A]
		L/d = 16 to 1			
1.6 (1/16)	25 (1)	51 (2)	25 (1)	8.4 (0.33)	0.7 (0.03)
2.4 (3/32)	25 (1)	64 (2½)	38 (1½)	12.7 (0.50)	1.1 (0.04)
3.2 (⅛)	25 (1)	76 (3)	51 (2)	17.0 (0.67)	1.5 (0.06)
4.8 (3/16)	13 (½)	102 (4)	76 (3)	25.4 (1.00)	2.2 (0.09)
6.4 (¼)	13 (½)	127 (5)	102 (4)	33.8 (1.33)	3.0 (0.11)
9.6 (⅜)	13 (½)	190 (7½)	152 (6)	50.8 (2.00)	4.5 (0.18)
12.7 (½)	13 (½)	254 (10)	203 (8)	67.8 (2.67)	6.0 (0.24)
19.1 (¾)	19 (¾)	381 (15)	305 (12)	102 (4.00)	9.0 (0.35)
25.4 (1)	25 (1)	495 (19½)	406 (16)	135 (5.33)	12.0 (0.48)
		L/d = 32 to 1			
1.6 (1/16)	25 (1)	76 (3)	51 (2)	17.0 (0.67)	3.0 (0.11)
2.4 (3/32)	25 (1)	102 (4)	76 (3)	25.4 (1.00)	4.5 (0.18)
3.2 (⅛)	25 (1)	127 (5)	102 (4)	33.8 (1.33)	6.0 (0.24)
4.8 (3/16)	13 (½)	190 (7½)	165 (6½)	55.1 (2.17)	10.5 (0.41)
6.4 (¼)	13 (½)	254 (10)	203 (8)	67.8 (2.67)	11.9 (0.48)
9.6 (⅜)	13 (½)	381 (15)	305 (12)	102 (4)	17.9 (0.71)
12.7 (½)	13 (½)	495 (19½)	406 (16)	135 (5.3)	24.1 (0.95)
19.1 (¾)	19 (¾)	737 (29)	610 (24)	204 (8.0)	36.0 (1.42)
25.4 (1)	25 (1)	991 (39)	813 (32)	271 (10.7)	48.1 (1.89)
		L/d = 40 to 1			
1.6 (1/16)	25 (1)	89 (3½)	63 (2½)	21.2 (0.83)	4.6 (0.19)
2.4 (3/32)	25 (1)	121 (4¾)	95 (3¾)	31.8 (1.25)	7.0 (0.27)
3.2 (⅛)	25 (1)	178 (7)	127 (5)	42.4 (1.67)	9.3 (0.37)
4.8 (3/16)	13 (½)	241 (9½)	190 (7½)	63.5 (2.50)	13.9 (0.56)
6.4 (¼)	13 (½)	330 (13)	254 (10)	84.6 (3.33)	18.7 (0.74)
9.6 (⅜)	13 (½)	483 (19)	381 (15)	127 (5.0)	28.0 (1.11)
12.7 (½)	13 (½)	635 (25)	508 (20)	169 (6.7)	37.6 (1.48)
19.1 (¾)	19 (¾)	940 (37)	762 (30)	254 (10.0)	56.2 (2.22)
25.4 (1)	25 (1)	1245 (49)	1016 (40)	338 (13.3)	75.1 (2.96)
		L/d = 60 to 1			
1.6 (1/16)	25 (1)	124 (4⅞)	95 (3¾)	31.7 (1¼)	10.4 (0.41)
2.4 (3/32)	25 (1)	185 (7 9/32)	143 (5⅝)	47.6 (1⅞)	15.8 (0.62)
3.2 (⅛)	25 (1)	247 (9¾)	190 (7½)	63.3 (2½)	20.9 (0.82)
4.8 (3/16)	13 (½)	372 (14⅝)	286 (11¼)	95.3 (3¾)	31.5 (1.24)
6.4 (¼)	13 (½)	495 (19½)	381 (15)	127 (5)	41.9 (1.65)
9.6 (⅜)	13 (½)	744 (29 5/16)	572 (22½)	191 (7½)	63.1 (2.48)
12.7 (½)	13 (½)	991 (39)	762 (30)	254 (10)	84.6 (3.33)
19.1 (¾)	19 (¾)	1486 (58½)	1143 (45)	381 (15)	127 (5.00)
25.4 (1)	25 (1)	1981 (78)	1524 (60)	508 (20)	169 (6.66)

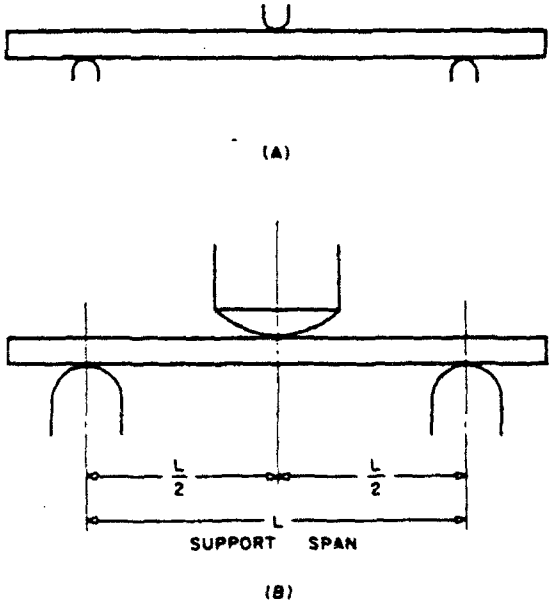
[A] Rates indicated are for Procedure A where strain rate is 0.01 mm/mm·min (0.01 in./in.·min). To obtain rates for Procedure B where strain rate is 0.10 mm/mm·min (0.10 in./in.·min), multiply these values by 10. Procedure A is to be used for all specification purposes, unless otherwise stated in the specifications. See 9.2.3 for the method of calculation.

TABLE 3 Recommended Dimensions for Test Specimens of Sections 6.3 and 6.5 for Various Support Span-to-Depth Ratios (See Note 8)

Method II [4-Point Loading at ¼ Points, Fig. 2(B)]

Nominal Specimen Depth, mm (in.)	Specimen Width, mm (in.)	Specimen Length, mm (in.)	Support Span, mm (in.)	Load Span, mm (in.)	Rate of Crosshead Motion (Procedure A) mm (in.)/min[A]
		L/d = 16 to 1			
1.6 (1/16)	25 (1)	51 (2)	25 (1)	12.5 (0.50)	0.8 (0.03)
2.4 (3/32)	25 (1)	64 (2½)	38 (1½)	19.0 (0.75)	1.0 (0.04)
3.2 (⅛)	25 (1)	76 (3)	51 (2)	25.5 (1)	1.3 (0.05)
4.8 (3/16)	13 (½)	102 (4)	76 (3)	38 (1.50)	2.0 (0.08)
6.4 (¼)	13 (½)	127 (5)	102 (4)	51 (2)	2.8 (0.11)
9.6 (⅜)	13 (½)	190 (7½)	152 (6)	76 (3)	4.1 (0.16)
12.7 (½)	13 (½)	254 (10)	203 (8)	102 (4)	5.3 (0.21)
19.1 (¾)	19 (¾)	381 (15)	305 (12)	153 (6)	8.1 (0.32)
25.4 (1)	25 (1)	495 (19½)	406 (16)	203 (8)	10.9 (0.43)
		L/d = 32 to 1			
1.6 (1/16)	25 (1)	76 (3)	51 (2)	25.5 (1)	2.8 (0.11)
2.4 (3/32)	25 (1)	102 (4)	76 (3)	38 (1.50)	4.1 (0.16)
3.2 (⅛)	25 (1)	127 (5)	102 (4)	51 (2)	5.3 (0.21)
4.8 (3/16)	13 (½)	190 (7½)	165 (6½)	82.5 (3.25)	8.1 (0.32)
6.4 (¼)	13 (½)	254 (10)	203 (8)	102 (4)	10.9 (0.43)
9.6 (⅜)	13 (½)	381 (15)	305 (12)	153 (6)	16.3 (0.64)
12.7 (½)	13 (½)	495 (19½)	406 (16)	203 (8)	21.6 (0.85)
19.1 (¾)	19 (¾)	737 (29)	610 (24)	305 (12)	32.5 (1.28)
25.4 (1)	25 (1)	991 (39)	813 (32)	407 (16)	43.4 (1.71)
		L/d = 40 to 1			
1.6 (1/16)	25 (1)	89 (3½)	63 (2½)	31.5 (1.25)	4.3 (0.17)
2.4 (3/32)	25 (1)	121 (4¾)	95 (3¾)	47.5 (1.88)	6.4 (0.25)
3.2 (⅛)	25 (1)	178 (7)	127 (5)	63.5 (2.50)	8.4 (0.33)
4.8 (3/16)	13 (½)	241 (9½)	190 (7½)	95.0 (3.75)	12.7 (0.50)
6.4 (¼)	13 (½)	330 (13)	254 (10)	127 (5.0)	17.0 (0.67)
9.6 (⅜)	13 (½)	483 (19)	381 (15)	191 (7.5)	25.4 (1.00)
12.7 (½)	13 (½)	635 (25)	508 (20)	254 (10.0)	34.0 (1.34)
19.1 (¾)	19 (¾)	940 (37)	762 (30)	381 (15.0)	50.8 (2.00)
25.4 (1)	25 (1)	1245 (49)	1016 (40)	508 (20.0)	67.8 (2.67)
		L/d = 60 to 1			
1.6 (1/16)	25 (1)	124 (4⅞)	95 (3¾)	47.5 (1⅞)	9.4 (0.37)
2.4 (3/32)	25 (1)	185 (7 9/32)	143 (5⅝)	71.5 (2 13/16)	14.2 (0.56)
3.2 (⅛)	25 (1)	247 (9¾)	190 (7½)	95.0 (3¾)	18.8 (0.74)
4.8 (3/16)	13 (½)	372 (14⅝)	286 (11¼)	143 (5⅝)	28.4 (1.12)
6.4 (¼)	13 (½)	495 (19½)	381 (15)	191 (7½)	37.8 (1.49)
9.6 (⅜)	13 (½)	744 (29 5/16)	572 (22½)	286 (11¼)	56.8 (2.24)
12.7 (½)	13 (½)	991 (39)	762 (30)	381 (15)	76.2 (3.00)
19.1 (¾)	19 (¾)	1486 (58½)	1143 (45)	572 (22.5)	114 (4.49)
25.4 (1)	25 (1)	1981 (78)	1524 (60)	762 (30)	152 (5.98)

[A] Rates indicated are for Procedure A where strain rate is 0.01 mm/mm·min (0.01 in./in.·min). To obtain rates for Procedure B where strain rate is 0.10 mm/mm·min (0.10 in./in.·min), multiply these values by 10. Procedure A is to be used for all specification purposes, unless otherwise stated in the specifications. See 9.2.3 for the method of calculation.



NOTE—(*a*) Minimum radius = 3.2 mm (⅛ in.). (*b*) Maximum radius supports = 1.5 times specimen depth, maximum radius loading nose = 4 times specimen depth.

FIG. 1 Allowable Range of Loading Nose and Support Radii for Specimen 6.4 mm (0.25 in.) Thick

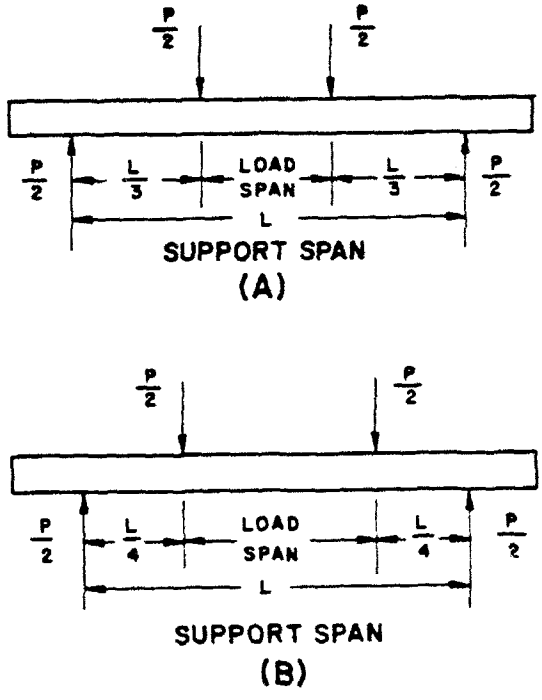
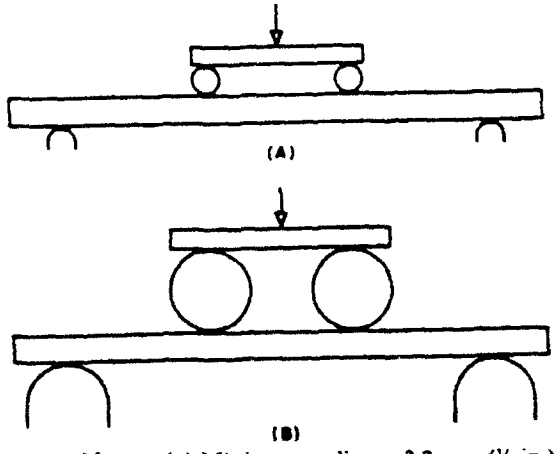


FIG. 2 Loading Diagram



NOTE—(*a*) Minimum radius = 3.2 mm (⅛ in.). (*b*) Maximum radius = 1.5 times specimen depth.

FIG. 3 Allowable Range of Loading and Support Noses Radii for Specimen 6.4 mm (0.25 in.) Thick

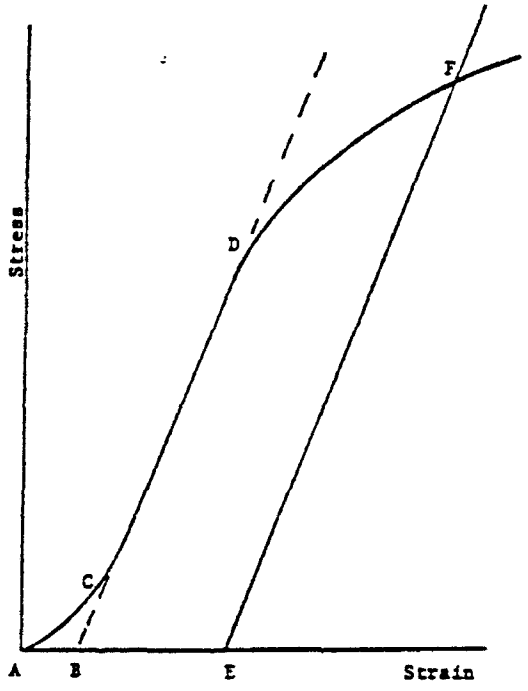
APPENDIX

(Nonmandatory Information)

specimen. In order to obtain correct values of such parameters as modulus, strain, and offset yield point, this artifact must be compensated for to give the corrected zero point on the strain or extension axis.

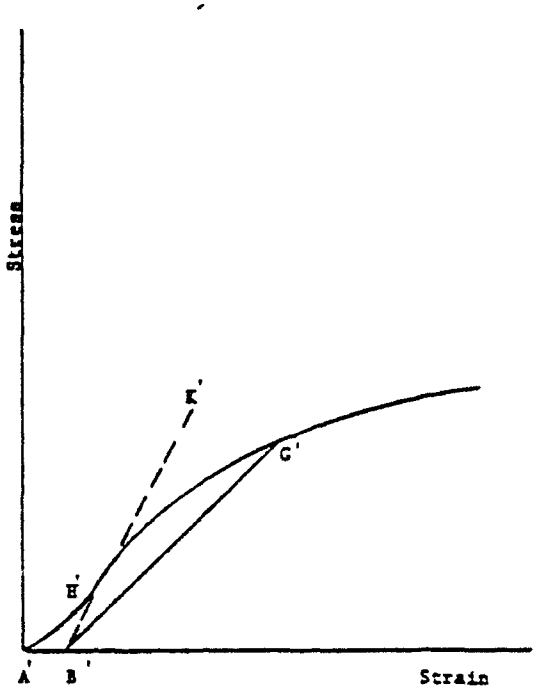
X1.2 In the case of a material exhibiting a region of Hookean (linear) behavior (Fig. X1.1), a continuation of the linear (*CD*) region of the curve is constructed through the zero-stress axis. This intersection (*B*) is the corrected zero-strain point from which all extensions or strains must be measured, including the yield offset (*BE*), if applicable. The elastic modulus can be determined by dividing the stress at any point along the line *CD* (or its extension) by the strain at the same point (measured from point *B*, defined as zero-strain).

X1.3 In the case of a material that does not exhibit any linear region (Fig. X1.2), the same kind of toe correction of the zero-strain point can be made by constructing a tangent to the maximum slope at the inflecion point (*H'*). This is extended to intersect the strain axis at point *B'*, the corrected zero-strain point. Using point *B'* as zero strain, the stress at any point (*G'*) on the curve can be divided by the strain at that point to obtain a secant modulus (slope of line *B' G'*). For those materials with no linear region, any attempt to use the tangent through the inflection point as a basis for determination of an offset yield point may result in unacceptable error.



NOTE—Some chart recorders plot the mirror image of this graph.

FIG. X1.1 Material with Hookean Region



NOTE—Some chart recorders plot the mirror image of this graph.

FIG. X1.2 Material with No Hookean Region

Designation: D 638 – 84

Standard Test Method for TENSILE PROPERTIES OF PLASTICS[1]

This standard is issued under the fixed designation D 638; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This method has been approved for use by agencies of the Department of Defense and for listing in the DoD Index of Specifications and Standards.

1. Scope

1.1 This test method covers the determination of the tensile properties of plastics in the form of standard dumbbell-shaped test specimens when tested under defined conditions of pretreatment, temperature, humidity, and testing machine speed.

1.2 This test method can be used for testing materials of any thickness up to 14 mm (0.55 in.). However, for testing specimens in the form of thin sheeting, including film less than 1.0 mm (0.04 in.) in thickness, Test Method D 882 is the preferred test method. Materials with a thickness greater than 14 mm (0.55 in.) must be reduced by machining.

NOTE 1—A complete metric companion to Test Method D 638 has been developed—D 638 M.

NOTE 2—This test method is not intended to cover precise physical procedures. It is recognized that the constant-rate-of-crosshead-movement type of test leaves much to be desired from a theoretical standpoint, that wide differences may exist between rate of crosshead movement and rate of strain between gage marks on the specimen, and that the testing speeds specified disguise important effects characteristic of materials in the plastic state. Further, it is realized that variations in the thicknesses of test specimens, which are permitted by these procedures, produce variations in the surface-volume ratios of such specimens, and that these variations may influence the test results. Hence, where directly comparable results are desired, all samples should be of equal thickness. Special additional tests should be used where more precise physical data are needed.

NOTE 3—This test method may be used for testing phenolic molded resin or laminated materials. However, where these materials are used as electrical insulation, such materials should be tested in accordance with ASTM Method D 229, Testing Rigid Sheet and Plate Materials Used for Electrical Insulation,[2,3] and ASTM Method D 651, Test for Tensile Strength of Molded Electrical Insulating Materials.[3]

1.3 *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of whoever uses this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Applicable Documents

2.1 *ASTM Standards:*

D 374 Test Methods for Thickness of Solid Electrical Insulation[2,4]

D 618 Methods of Conditioning Plastics and Electrical Insulating Materials for Testing[2]

D 882 Test Methods for Tensile Properties of Thin Plastic Sheeting[2]

D 883 Definitions of Terms Relating to Plastics[2]

D 4066 Specification for Nylon Injection and Extrusion Materials (PA)[5]

E 4 Methods of Load Verification of Testing Machines[5,6]

E 83 Method of Verification and Classification of Extensometers[6]

3. Significance and Use

3.1 This test method is designed to produce

[1] This test method is under the jurisdiction of ASTM Committee D-20 on Plastics and is the direct responsibility of Subcommittee D 20.10 on Mechanical Properties.

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[2] *Annual Book of ASTM Standards*, Vol 08.01.

[3] *Annual Book of ASTM Standards*, Vol 10.01.

[4] *Annual Book of ASTM Standards*, Vol 10.02.

[5] *Annual Book of ASTM Standards*, Vol 08.03.

[6] *Annual Book of ASTM Standards*, Vol 03.01.

tensile property data for the control and specification of plastic materials. These data are also useful for qualitative characterization and for research and development.

3.2 Tensile properties may vary with specimen preparation and with speed and environment of testing. Consequently, where precise comparative results are desired, these factors must be carefully controlled.

3.2.1 It is realized that a material cannot be tested without also testing the method of preparation of that material. Hence, when comparative tests of materials per se are desired, the greatest care must be exercised to ensure that all samples are prepared in exactly the same way, unless the test is to include the effects of sample preparation. Similarly, for referee purposes or comparisons within any given series of specimens, care must be taken to secure the maximum degree of uniformity in details of preparation, treatment, and handling.

3.3 Tensile properties may provide useful data for plastics engineering design purposes. However, because of the high degree of sensitivity exhibited by many plastics to rate of straining and environmental conditions, data obtained by this test method cannot be considered valid for applications involving load-time scales or environments widely different from those of this test method. In cases of such dissimilarity, no reliable estimation of the limit of usefulness can be made for most plastics. This sensitivity to rate of straining and environment necessitates testing over a broad load-time scale (including impact and creep) and range of environmental conditions if tensile properties are to suffice for engineering design purposes.

NOTE 4—Since the existence of a true elastic limit in plastics (as in many other organic materials and in many metals) is debatable, the propriety of applying the term "elastic modulus" in its quoted generally accepted definition to describe the "stiffness" or "rigidity" of a plastic has been seriously questioned. The exact stress-strain characteristics of plastic materials are highly dependent on such factors as rate of application of stress, temperature, previous history of specimen, etc. However, stress-strain curves for plastics, determined as described in this test method, almost always show a linear region at low stresses, and a straight line drawn tangent to this portion of the curve permits calculation of an elastic modulus of the usually defined type. Such a constant is useful if its arbitrary nature and dependence on time, temperature, and similar factors are realized.

4. Definitions

4.1 Definitions of terms applying to this test method appear in Definitions D 883 and Annex A1.

5. Apparatus

5.1 *Testing Machine*—A testing machine of the constant-rate-of-crosshead-movement type and comprising essentially the following:

5.1.1 *Fixed Member*—A fixed or essentially stationary member carrying one grip.

5.1.2 *Movable Member*—A movable member carrying a second grip.

5.1.3 *Grips*—Grips for holding the test specimen between the fixed member and the movable member. The grips shall be self-aligning, that is, they shall be attached to the fixed and movable member, respectively, in such a manner that they will move freely into alignment as soon as any load is applied, so that the long axis of the test specimen will coincide with the direction of the applied pull through the center line of the grip assembly. The specimens should be aligned as perfectly as possible with the direction of pull so that no rotary motion that may induce slippage will occur in the grips; there is a limit to the amount of misalignment self-aligning grips will accommodate.

5.1.3.1 The test specimen shall be held in such a way that slippage relative to the grips is prevented insofar as possible. Grip surfaces that are deeply scored or serrated with a pattern similar to those of a coarse single-cut file, serrations about 2.4 mm (3/32 in.) apart and about 1.6 mm (1/16 in.) deep, have been found satisfactory for most thermoplastics. Finer serrations have been found to be more satisfactory for harder plastics, such as the thermosetting materials. The serrations should be kept clean and sharp. Breaking in the grips may occur at times, even when deep serrations or abraded specimen surfaces are used; other techniques must be used in these cases. Other techniques that have been found useful, particularly with smooth-faced grips, are abrading that portion of the surface of the specimen that will be in the grips, and interposing thin pieces of abrasive cloth, abrasive paper, or plastic or rubber-coated fabric, commonly called hospital sheeting, between the specimen and the grip surface. No. 80 double-sided abrasive paper has been found effective in many cases. An open-

mesh fabric, in which the threads are coated with abrasive, has also been effective. Reducing the cross-sectional area of the specimen may also be effective. The use of special types of grips is sometimes necessary to eliminate slippage and breakage in the grips.

5.1.4 *Drive Mechanism*—A drive mechanism for imparting to the movable member a uniform, controlled velocity with respect to the stationary member, this velocity to be regulated as specified in Section 9.

5.1.5 *Load Indicator*—A suitable load-indicating mechanism capable of showing the total tensile load carried by the test specimen when held by the grips. This mechanism shall be essentially free of inertia lag at the specified rate of testing and shall indicate the load with an accuracy of ±1 % of the indicated value, or better. The accuracy of the testing machine shall be verified in accordance with Methods E 4.

NOTE 5—Experience has shown that many testing machines now in use are incapable of maintaining accuracy for as long as the periods between inspection recommended in Methods E 4. Hence, it is recommended that each machine be studied individually and verified as often as may be found necessary. It frequently will be necessary to perform this function daily.

5.1.6 The fixed member, movable member, drive mechanism, and grips shall be constructed of such materials and in such proportions that the total elastic longitudinal strain of the system constituted by these parts does not exceed 1 % of the total longitudinal strain between the two gage marks on the test specimen at any time during the test and at any load up to the rated capacity of the machine.

5.2 *Extension Indicator*—A suitable instrument for determining the distance between two designated points located within the gage length of the test specimen as the specimen is stretched. It is desirable, but not essential, that this instrument automatically record this distance (or any change in it) as a function of the load on the test specimen or of the elapsed time from the start of the test, or both. If only the latter is obtained, load-time data must also be taken. This instrument shall be essentially free of inertia lag at the specified speed of testing and shall be accurate to ±1 % of strain or better.

NOTE 6—Reference is made to Method E 83.

5.3 *Micrometers*—Suitable micrometers for measuring the width and thickness of the test specimen to an incremental discrimination of at least 0.025 mm (0.001 in.) should be used. All width and thickness measurements of rigid and semirigid plastics may be measured with a hand micrometer with ratchet. A suitable instrument for measuring the thickness of nonrigid test specimens shall have: *(1)* a contact measuring pressure of 25 ± 2.5 kPa (3.6 ± 0.36 psi), *(2)* a movable circular contact foot 6.35 ± 0.025 mm (0.250 ± 0.001 in.) in diameter, and *(3)* a lower fixed anvil large enough to extend beyond the contact foot in all directions and being parallel to the contact foot within 0.005 mm (0.0002 in.) over the entire foot area. Flatness of foot and anvil shall conform to Test Methods D 374, 5.1.3. An optional instrument equipped with a circular contact foot 15.88 ± 0.08 mm (0.625 ± 0.003 in.) in diameter is recommended for thickness measuring of process samples or larger specimens at least 15.88 mm (0.625 in.) in minimum width.

6. Test Specimens

6.1 *Sheet, Plate, and Molded Plastics:*

6.1.1 *Rigid and Semirigid Plastics*—The test specimen shall conform to the dimensions shown in Fig. 1. The Type I specimen is the preferred specimen and shall be used where sufficient material having a thickness of 7 mm (0.28 in.) or less is available. The Type II specimen may be used when a material does not break in the narrow section with the preferred Type I specimen. The Type V specimen shall be used where only limited material having a thickness of 4 mm (0.16 in.) or less is available for evaluation, or where a large number of specimens are to be exposed in a limited space (thermal and environmental stability tests, etc.). The Type IV specimen should be used when direct comparisons are required between materials in different rigidity cases (that is, nonrigid and semirigid). The Type III specimen must be used for all materials with a thickness of greater than 7 mm (0.28 in.) but not more than 14 mm (0.55 in.)

6.1.2 *Nonrigid Plastics*—The test specimen shall conform to the dimensions shown in Fig. 1. The Type IV specimen shall be used for testing nonrigid plastics with a thickness of 4 mm (0.16 in.) or less. The Type III specimen must be used for all materials with a thickness greater than 7 mm (0.28 in.) but not more than 14 mm (0.55 in.)

6.1.3 *Preparation*—Test specimens shall be prepared by machining operations, or die cutting, from materials in sheet, plate, slab, or similar form. Materials thicker than 14 mm (0.55 in.) must be machined to 14 mm (0.55 in.) for use as Type III specimens. Specimens can also be prepared by molding the material to be tested.

NOTE 7—Specimens prepared by injection molding may have different tensile properties than specimens prepared by machining or die-cutting because of the orientation induced. This effect may be more pronounced in specimens with narrow sections.

6.2 The test specimen for rigid tubes shall be as shown in Fig. 2. The length, *L*, shall be as shown in the table in Fig. 2. A groove shall be machined around the outside of the specimen at the center of its length so that the wall section after machining shall be 60 % of the original nominal wall thickness. This groove shall consist of a straight section 57.2 mm (2¼ in.) in length with a radius of 76 mm (3 in.) at each end joining it to the outside diameter. Steel or brass plugs having diameters such that they will fit snugly inside the tube and having a length equal to the full jaw length plus 25 mm (1 in.) shall be placed in the ends of the specimens to prevent crushing. They can be located conveniently in the tube by separating and supporting them on a threaded metal rod. Details of plugs and test assembly are shown in Fig. 2.

6.3 The test specimen for rigid rods shall be as shown in Fig. 3. The length, *L*, shall be as shown in the table in Fig. 3. A groove shall be machined around the specimen at the center of its length so that the diameter of the machined portion shall be 60 % of the original nominal diameter. This groove shall consist of a straight section 57.2 mm (2¼ in.) in length with a radius of 76 mm (3 in.) at each end joining it to the outside diameter.

6.4 All surfaces of the specimen shall be free of visible flaws, scratches, or imperfections. Marks left by coarse machining operations shall be carefully removed with a fine file or abrasive, and the filed surfaces shall then be smoothed with abrasive paper (No. 00 or finer). The finishing sanding strokes shall be made in a direction parallel to the long axis of the test specimen. All flash shall be removed from a molded specimen, taking great care not to disturb the molded surfaces. In machining a specimen, undercuts that would exceed the dimensional tolerances shown in Fig. 1 shall be scrupulously avoided. Care shall also be taken to avoid other common machining errors.

6.5 If it is necessary to place gage marks on the specimen, this shall be done with a wax crayon or India ink that will not affect the material being tested. Gage marks shall not be scratched, punched, or impressed on the specimen.

6.6 When testing materials that are suspected of anisotropy, duplicate sets of test specimens shall be prepared, having their long axes respectively parallel with, and normal to, the suspected direction of anisotropy.

7. Conditioning

7.1 *Conditioning*—Condition the test specimens at 23 ± 2°C (73.4 ± 3.6°F) and 50 ± 5 % relative humidity for not less than 40 h prior to test in accordance with Procedure A of Methods D 618, for those tests where conditioning is required. In cases of disagreement, the tolerances shall be ±1°C (1.8°F) and ±2 % relative humidity.

7.1.1 Note that for some hygroscopic materials, such as nylons, the material specifications (for example, Specification D 4066) call for testing "dry as-molded specimens." Such requirements take precedence over the above routine preconditioning to 50 % RH and require sealing the specimens in water vapor-impermeable containers as soon as molded and not removing them until ready for testing.

7.2 *Test Conditions*—Conduct tests in the Standard Laboratory Atmosphere of 23 ± 2°C (73.4 ± 3.6°F) and 50 ± 5 % relative humidity, unless otherwise specified in the test methods. In cases of disagreements, the tolerances shall be ± 1°C (1.8°F) and ±2 % relative humidity.

NOTE 8—The tensile properties of some plastics change rapidly with small changes in temperature. Since heat may be generated as a result of straining the specimen at high rates, conduct tests without forced cooling to ensure uniformity of test conditions. Measure the temperature in the reduced section of the specimen and record it for materials where self-heating is suspected.

8. Number of Test Specimens

8.1 Test at least five specimens for each sample in the case of isotropic materials.

8.2 Test ten specimens, five normal to, and five parallel with the principal axis of anisotropy,

for each sample in the case of anisotropic materials.

8.3 Discard specimens that break at some obvious fortuitous flaw, or that do not break between the predetermined gage marks, and make retests, unless such flaws constitute a variable to be studied.

NOTE 9—Before testing, all transparent specimens should be inspected in a polariscope. Those which show atypical or concentrated strain patterns should be rejected, unless the effects of these residual strains constitute a variable to be studied.

9. Speed of Testing

9.1 Speed of testing shall be the relative rate of motion of the grips or test fixtures during the test. Rate of motion of the driven grip or fixture when the testing machine is running idle may be used, if it can be shown that the resulting speed of testing is within the limits of variation allowed.

9.2 Choose the speed of testing from Table 1. Determine this chosen speed of testing by the specification for the material being tested, or by agreement between those concerned. When the speed is not specified, use the lowest speed shown in Table 1 for the specimen geometry being used, which gives rupture within ½ to 5 min testing time.

9.3 Modulus determinations may be made at the speed selected for the other tensile properties when the recorder response and resolution are adequate.

10. Procedure

10.1 Measure the width and thickness of rigid flat specimens (Fig. 1) with a suitable micrometer to the nearest 0.025 mm (0.001 in.) at several points along their narrow sections. Measure the thickness of nonrigid specimens (produced by a Type IV die) in the same manner with the required dial micrometer. Take the width of this specimen as the distance between the cutting edges of the die in the narrow section. Measure the diameter of rod specimens, and the inside and outside diameters of tube specimens, to the nearest 0.025 mm (0.001 in.) at a minimum of two points 90° apart; make these measurements along the groove for specimens so constructed. Use plugs in testing tube specimens, as shown in Fig. 2.

10.2 Place the specimen in the grips of the testing machine, taking care to align the long axis of the specimen and the grips with an imaginary line joining the points of attachment of the grips to the machine. The distance between the ends of the gripping surfaces, when using flat specimens, shall be as indicated in Fig. 1. On tube and rod specimens, the location for the grips shall be as shown in Figs. 2 and 3. Tighten the grips evenly and firmly to the degree necessary to prevent slippage of the specimen during the test, but not to the point where the specimen would be crushed.

10.3 Attach the extensometer indicator.

10.4 Set the speed of testing at the proper rate as required in Section 9, and start the machine.

10.5 Record the load-extension curve of the specimen.

10.6 Record the load and extension at the yield point (if one exists) and the load and extension at the moment of rupture.

NOTE 10—If it is desired to measure both modulus and failure properties (yield or break, or both), it may be necessary, in the case of highly extensible materials to run two independent tests. The high magnification extensometer normally used to determine properties up to the yield point may not be suitable for tests involving high extensibility. If allowed to remain attached to the specimen, the extensometer could be permanently damaged. A broad range incremental extensometer or hand rule technique may be needed when such materials are taken to rupture.

11. Calculations

11.1 *Tensile Strength*—Calculate the tensile strength by dividing the maximum load in newtons (or pounds-force) by the original minimum cross-sectional area of the specimen in square metres (or square inches). Express the result in pascals (or pounds-force per square inch) and report it to three significant figures as "Tensile Strength at Yield" or "Tensile Strength at Break," whichever term is applicable. When a nominal yield or break load less than the maximum is present and applicable, it may be desirable also to calculate, in a similar manner, the corresponding "Tensile Stress at Yield" or "Tensile Stress at Break" and report it to three significant figures (Annex Note A1.1).

11.2 *Percent Elongation*—If the specimen gives a yield load that is larger than the load at break, calculate "Percent Elongation at Yield." Otherwise, calculate "Percent Elongation at Break." Do this by reading the extension (change in gage length) at the moment the applicable load is reached. Divide that extension by the original gage length and multiply by 100. Report "Percent

Elongation at Yield" or "Percent Elongation at Break" to two significant figures. When a yield or breaking load less than the maximum is present and of interest, it is desirable to calculate and report both "Percent Elongation at Yield" and "Percent Elongation at Break" (Annex Note A1.2).

11.3 *Modulus of Elasticity*—Calculate the modulus of elasticity by extending the initial linear portion of the load-extension curve and dividing the difference in stress corresponding to any segment of section on this straight line by the corresponding difference in strain. All elastic modulus values shall be computed using the average initial cross-sectional area of the test specimens in the calculations. The result shall be expressed in pascals (or pounds-force per square inch) and reported to three significant figures.

11.4 For each series of tests, calculate the arithmetic mean of all values obtained and report it as the "average value" for the particular property in question.

11.5 Calculate the standard deviation (estimated) as follows and report it to two significant figures:

$$s = \sqrt{(\Sigma X^2 - n\bar{X}^2)/(n - 1)}$$

where:

s = estimated standard deviation,
X = value of single observation,
n = number of observations, and
$\bar{X}$ = arithmetic mean of the set of observations.

11.6 See Appendix X1 for information on toe compensation.

12. Report

12.1 The report shall include the following:

12.1.1 Complete identifications of the material tested, including type, source, manufacturer's code numbers, form, principal dimensions, previous history, etc.,

12.1.2 Method of preparing test specimens,

12.1.3 Type of test specimen and dimensions,

12.1.4 Conditioning procedure used,

12.1.5 Atmospheric conditions in test room,

12.1.6 Number of specimens tested,

12.1.7 Speed of testing,

12.1.8 Tensile strength at yield or break, average value, and standard deviation,

12.1.9 Tensile stress at yield or break, if applicable, average value, and standard deviation,

12.1.10 Percentage elongation at yield or break (or both, as applicable), average value, and standard deviation,

12.1.11 Modulus of elasticity, average value, and standard deviation, and

12.1.12 Date of test.

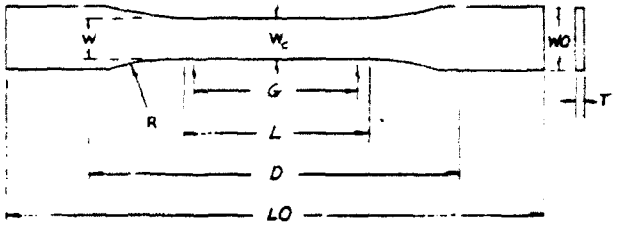
TABLE 1 Designations for Speed of Testing[A]

Classification[B]	Specimen Type	Speed of Testing, mm/min (in./min)		Nominal Strain[C] Rate at Start of Test, mm/mm·min
Rigid and Semirigid	I, II, III rods and tubes	5	(0.2) ± 25 %	0.1
		50	(2) ± 10 %	1
		500	(20) ± 10 %	10
	IV	5	(0.2) ± 25 %	0.15
		50	(2) ± 10 %	1.5
		500	(20) ± 10 %	15
	V	1	(0.05) ± 25 %	0.1
		10	(0.5) ± 25 %	1
		100	(5) ± 25 %	10
Nonrigid	III	50	(2) ± 10 %	1
		500	(20) ± 10 %	10
	IV	50	(2) ± 10 %	1.5
		500	(20) ± 10 %	15

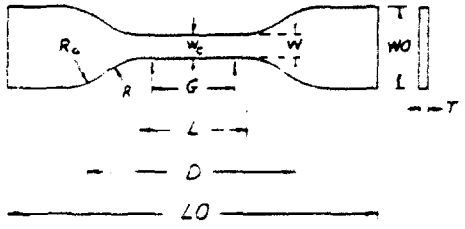
[A] Select the lowest speed that produces rupture in ½ to 5 min for the specimen geometry being used (see 9.2).

[B] See Definitions D 883 for definitions.

[C] The initial rate of straining cannot be calculated exactly for dumbbell-shaped specimens because of extension, both in the reduced section outside the gage length and in the fillets. This initial strain rate can be measured from the initial slope of the tensile strain-versus-time diagram.



TYPES I, II, III & V



TYPE IV

Specimen Dimensions for Thickness, *T*, mm[D]

Dimensions (see drawings)	7 or under		Over 7 to 14 incl.	4 or under		Tolerances
	Type I	Type II	Type III	Type IV[G]	Type V[I]	
W—Width of narrow section[A,B]	13	6	19	6	3.18	±0.5[G,J]
L—Length of narrow section	57	57	57	33	9.53	±0.5[J]
WO—Width over-all, min[E]	19	19	29	19	...	+6.4
WO—Width over-all, min[E]	...	...	...	...	9.53	+3.18
LO—Length over-all, min[F]	165	183	246	115	63.5	no max
G—Gage length[C]	50	50	50	...	7.62	±0.25[J]
G—Gage length[C]	...	..	...	25	...	±0.13
D—Distance between grips	115	133	115	64[H]	25.4	±5
R—Radius of fillet	76	76	76	14	12.7	±1[J]
RO—Outer radius (Type IV)	...	...	...	25	...	±1

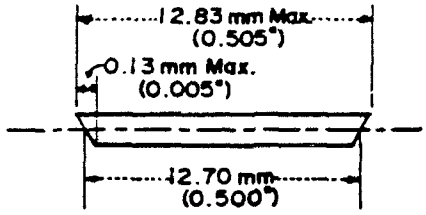
Specimen Dimensions for Thickness, *T*, in.[D]

Dimensions (see drawings)	0.28 or under		Over 0.28 to 0.55 incl.	0.16 or under		Tolerances
	Type I	Type II	Type III	Type IV[G]	Type V[I]	
W—Width of narrow section[A,B]	0.50	0.25	0.75	0.25	0.125	±0.02[G,J]
L—Length of narrow section	2.25	2.25	2.25	1.30	0.375	±0.02[J]
WO—Width over-all, min[E]	0.75	0.75	1.13	0.75	...	+0.25
WO—Width over-all, min[E]	...	...	...	...	0.375	+0.125
LO—Length over-all, min[F]	6.5	7.2	9.7	4.5	2.5	no max
G—Gage length[C]	2.00	2.00	2.00	...	0.300	±0.010[J]
G—Gage length[C]	...	...	...	1.00	...	±0.005
D—Distance between grips	4.5	5.3	4.5	2.5[H]	1.0	±0.2
R—Radius of fillet	3.00	3.00	3.00	0.56	0.5	±0.04[J]
RO—Outer radius (Type IV)	...	...	...	1.00	...	±0.04

FIG. 1 Tension Test Specimens for Sheet, Plate, and Molded Plastics

[A] The width at the center W_c shall be plus 0.00 mm, minus 0.10 mm (+0.000 in., −0.004 in.) compared with width *W* at other parts of the reduced section. Any reduction in *W* at the center shall be gradual, equally on each side so that no abrupt changes in dimension result.

[B] For molded specimens, a draft of not over 0.13 mm (0.005 in.) may be allowed for either Type I or II specimens 3.2 mm (0.13 in.) in thickness, and this should be taken into account when calculating width of the specimen. Thus a typical section of a molded Type I specimen, having the maximum allowable draft, could be as follows:



[C] Test marks or initial extensometer span.

[D] Thickness, T, shall be 3.2 ± 0.4 mm (0.13 ± 0.02 in.) for all types of molded specimens, and for other Types I and II specimens where possible. If specimens are machined from sheets or plates, thickness, T, may be the thickness of the sheet or plate provided this does not exceed the range stated for the intended specimen type. For sheets of nominal thickness greater than 14 mm (0.55 in.) the specimens shall be machined to 14 ± 0.4 mm (0.55 ± 0.02 in.) in thickness, for use with the Type III specimen. For sheets of nominal thickness between 14 and 51 mm (0.55 and 2 in.) approximately equal amounts shall be machined from each surface. For thicker sheets both surfaces of the specimen shall be machined and the location of the specimen with reference to the original thickness of the sheet, shall be noted. Tolerances on thickness less than 14 mm (0.55 in.) shall be those standard for the grade of material tested.

[E] Overall widths greater than the minimum indicated may be desirable for some materials in order to avoid breaking in the grips.

[F] Overall lengths greater than the minimum indicated may be desirable either to avoid breaking in the grips or to satisfy special test requirements.

[G] For the Type IV specimen, the internal width of the narrow section of the die shall be 6.00 ± 0.05 mm (0.250 ± 0.002 in.). The dimensions are essentially those of Die C in ASTM Test Method D 412, for Rubber Properties in Tension (*Annual Book of ASTM Standards*, Vols 08.01 and 09.01).

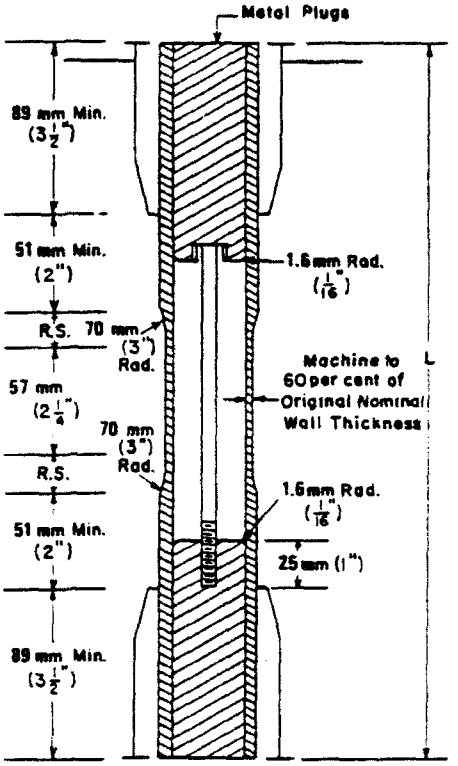
[H] When self-tightening grips are used, for highly extensible polymers, the distance between grips will depend upon the types of grips used and may not be critical if maintained uniform once chosen.

[I] The Type V specimen shall be machined or die cut to the dimensions shown, or molded in a mold whose cavity has these dimensions. The dimensions shall be:

W = 3.18 ± 0.03 mm (0.125 ± 0.001 in.),
L = 9.53 ± 0.08 mm (0.375 ± 0.003 in.),
G = 7.62 ± 0.02 mm (0.300 ± 0.001 in.), and
R = 12.7 ± 0.08 mm (0.500 ± 0.003 in.).

The other tolerances are those in the table. Supporting data on the introduction of the L specimen of Test Method D 1822 as the Type V specimen may be obtained from ASTM Headquarters, 1916 Race St., Philadelphia, PA 19103, by requesting RR:D-20-1038.

FIG. 1 *Continued.*

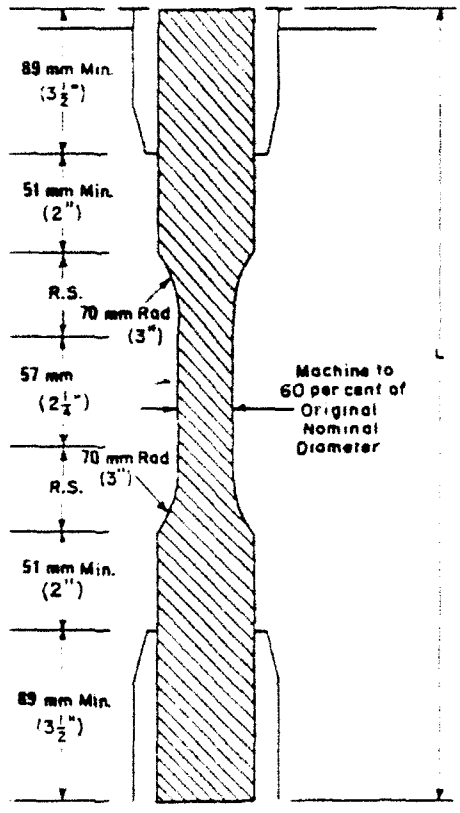


DIMENSIONS OF TUBE SPECIMENS

Nominal Wall Thickness	Length of Radial Sections, 2R.S.	Total Calculated Minimum Length of Specimen	Standard Length, *L*, of Specimen to be Used for 89-mm (3½-in.) Jaws[4]
mm(in.)	mm(in.)	mm(in.)	mm(in.)
0.79(1/32)	13.9(0.547)	350(13.80)	381(15)
1.2(3/64)	17.0(0.670)	354(13.92)	381(15)
1.6(1/16)	19.6(0.773)	356(14.02)	381(15)
2.4(3/32)	24.0(0.946)	361(14.20)	381(15)
3.2(1/8)	27.7(1.091)	364(14.34)	381(15)
4.8(3/16)	33.9(1.333)	370(14.58)	381(15)
6.4(1/4)	39.0(1.536)	376(14.79)	400(15.75)
7.9(5/16)	43.5(1.714)	380(14.96)	400(15.75)
9.5(3/8)	47.6(1.873)	384(15.12)	400(15.75)
11.1(7/16)	51.3(2.019)	388(15.27)	400(15.75)
12.7(1/2)	54.7(2.154)	391(15.40)	419(16.5)

[4] For other jaws greater than 89 mm (3½ in.), the standard length shall be increased by twice the length of the jaws minus 178 mm (7 in.). The standard length permits a slippage of approximately 6.4 to 12.7 mm (¼ to ½ in.) in each jaw while maintaining maximum length of jaw grip.

FIG. 2 Diagram Showing Location of Tube Tension Test Specimens in Testing Machine



DIMENSIONS OF ROD SPECIMENS

Nominal Diameter	Length of Radial Sections, 2R.S.	Total Calculated Minimum Length of Specimen	Standard Length, *L*, of Specimen to be Used for 89-mm (3½-in.) Jaws[A]
mm (in.)	mm (in.)	mm (in.)	mm (in.)
3.2 (⅛)	19.6 (0.773)	356 (14.02)	381 (15)
4.7 (⅜₁₆)	24.0 (0.946)	361 (14.20)	381 (15)
6.4 (¼)	27.7 (1.091)	364 (14.34)	381 (15)
9.5 (⅜)	33.9 (1.333)	370 (14.58)	381 (15)
12.7 (½)	39.0 (1.536)	376 (14.80)	400 (15.75)
15.9 (⅝)	43.5 (1.714)	380 (14.96)	400 (15.75)
19.0 (¾)	47.6 (1.873)	384 (15.12)	400 (15.75)
22.2 (⅞)	51.5 (2.019)	388 (15.27)	400 (15.75)
25.4 (1)	54.7 (2.154)	391 (15.40)	419 (16.5)
31.8 (1¼)	60.9 (2.398)	398 (15.65)	419 (16.5)
38.1 (1½)	66.4 (2.615)	403 (15.87)	419 (16.5)
42.5 (1¾)	71.4 (2.812)	408 (16.06)	419 (16.5)
50.8 (2)	76.0 (2.993)	412 (16.24)	432 (17)

[A] For jaws greater than 89 mm (3½ in.), the standard length shall be increased by twice the length of the jaws minus 178 mm (7 in.). The standard length permits a slippage of approximately 6.4 to 12.7 mm (¼ to ½ in.) in each jaw while maintaining maximum length of jaw grip.

FIG. 3 Diagram Showing Location of Rod Tension Test Specimen in Testing Machine

ANNEX

(Mandatory Information)

A1. DEFINITIONS OF TERMS AND SYMBOLS RELATING TO TENSION TESTING OF PLASTICS

A1.1 *tensile stress (nominal)*—the tensile load per unit area of minimum original cross-section, within the gage boundaries, carried by the test specimen at any given moment. It is expressed in force per unit area, usually megapascals (or pounds-force per square inch).

NOTE A1.1—The expression of tensile properties in terms of the minimum original cross-section is almost universally used in practice. In the case of materials exhibiting high extensibility, or "necking", or both, (A1.11) nominal stress calculations may not be meaningful beyond the yield point (A1.10) due to the extensive reduction in cross-sectional area that ensues. Under some circumstances it may be desirable to express the tensile properties per unit of minimum prevailing cross-section. These properties are called "true" tensile properties (that is, true tensile stress, etc.).

A1.2 *tensile strength (nominal)*—the maximum tensile stress (nominal) sustained by the specimen during a tension test. When the maximum stress occurs at the yield point (A1.10), it shall be designated Tensile Strength at Yield. When the maximum stress occurs at break, it shall be designated Tensile Strength at Break.

A1.3 *gage length*—the original length of that portion of the specimen over which strain or change in length is determined.

A1.4 *elongation*—the increase in length produced in the gage length of the test specimen by a tensile load. It is expressed in units of length, usually millimetres (or inches). (Also known as *extension*.)

NOTE A1.2—Elongation and strain values are valid only in cases were uniformity of specimen behavior within the gage length is present. In the case of materials exhibiting "necking phenomena," such values are only of qualitative utility after attainment of "yield" point. This is due to inability to assure that necking will encompass the entire length between the gage marks prior to specimen failure.

A1.5 *percentage elongation*—the elongation of a test specimen expressed as a percentage of the gage length.

A1.6 *percentage elongation at yield and break*:

A1.6.1 *percentage elongation at yield*—the percentage elongation at the moment the yield point (A1.10) is attained in the test specimen.

A1.6.2 *percentage elongation at break*—the percentage elongation at the moment of rupture of the test specimen.

A1.7 *strain*—the ratio of the elongation to the gage length of the test specimen, that is, the change in length per unit of original length. It is expressed as a dimensionless ratio.

A1.8 *true strain* (see Fig. A1.1) is defined by the following equation for ϵ_T:

$$\epsilon_T = \int_{L_o}^{L} dL/L = \ln L/L_o$$

where:

dL = the increment of elongation when the distance between the gage marks is L,
L_o = the original distance between gage marks, and
L = the distance between gage marks at any time.

A1.9 *tensile stress-strain curve*—a diagram in which values of tensile stress are plotted as ordinates against corresponding values of tensile strain as abscissas.

A1.10 *yield point*—the first point on the stress-strain curve at which an increase in strain occurs without an increase in stress (Fig. A1.2).

NOTE A1.3—Only materials whose stress-strain curves exhibit a point of zero slope may be considered as having a yield point.

NOTE A1.4—Some materials exhibit a distinct "break" or discontinuity in the stress-strain curve in the elastic region. This break is not a yield point by definition. However, this point may prove useful for material characterization in some cases.

A1.11 *necking*—the localized reduction in cross-section which may occur in a material under tensile stress.

A1.12 *yield strength*—the stress at which a material exhibits a specified limiting deviation from the proportionality of stress to strain. Unless otherwise specified, this stress will be the stress at the yield point and when expressed in relation to the Tensile Strength shall be designated either Tensile Strength at Yield or Tensile Stress at Yield as required under A1.2 (Fig. A1.2). (See *offset yield strength*.)

A1.13 *offset yield strength*—the stress at which the strain exceeds by a specified amount (the offset) an extension of the initial proportional portion of the stress-strain curve. It is expressed in force per unit area, usually megapascals (or pounds-force per square inch).

NOTE A1.5—This measurement is useful for materials whose stress-strain curve in the yield range is of gradual curvature. The offset yield strength can be derived from a stress-strain curve as follows (Fig. A1.3):

On the strain axis lay off OM equal to the specified offset.

Draw OA tangent to the initial straight-line portion of the stress-strain curve.

Through M draw a line MN parallel to OA and locate the intersection of MN with the stress-strain curve.

The stress at the point of intersection r is the "offset yield strength." The specified value of the offset must be stated as a percentage of the original gage length in conjunction with the strength value. *Example*: 0.1 % offset yield strength = ... MPa (psi), or *yield strength* at 0.1 % offset ... MPa (psi).

greatest stress which a material is capable of sustaining without any deviation from proportionality of stress to strain (Hooke's law). It is expressed in force per unit area, usually megapascals (or pounds-force per square inch).

A1.15 *elastic limit*—the greatest stress which a material is capable of sustaining without any permanent strain remaining upon complete release of the stress. It is expressed in force per unit area, usually megapascals (or pounds-force per square inch).

NOTE A1.6—Measured values of proportional limit and elastic limit vary greatly with the sensitivity and accuracy of the testing equipment, eccentricity of loading, the scale to which the stress-strain diagram is plotted, and other factors. Consequently, these values are usually replaced by yield strength.

A1.16 *modulus of elasticity*—the ratio of stress (nominal) to corresponding strain below the proportional limit of a material. It is expressed in force per unit area, usually megapascals (or pounds-force per square inch) (Also known as *elastic modulus* or *Young's modulus*).

NOTE A1.7—The stress-strain relations of many plastics do not conform to Hooke's law throughout the elastic range but deviate therefrom even at stresses well below the elastic limit. For such materials the slope of the tangent to the stress-strain curve at a low stress is usually taken as the modulus of elasticity. Since the existence of a true proportional limit in plastics is debatable, the propriety of applying the term "modulus of elasticity" to describe the stiffness or rigidity of a plastic has been seriously questioned. The exact stress-strain characteristics of plastic materials are very dependent on such factors as rate of stressing, temperature, previous specimen history, etc. However, such a value is useful if its arbitrary nature and dependence on time, temperature, and other factors are realized.

A1.17 *secant modulus*—the ratio of stress (nominal) to corresponding strain at any specified point on the stress-strain curve. It is expressed in force per unit area, usually megapascals (or pounds-force per square inch), and reported together with the specified stress or strain.

NOTE A1.8—This measurement is usually employed in place of modulus of elasticity in the case of materials whose stress-strain diagram does not demonstrate proportionality of stress to strain.

A1.18 *percentage reduction of area (nominal)*—the difference between the original cross-sectional area measured at the point of rupture after breaking and after all retraction has ceased, expressed as a percentage of the original area.

A1.19 *percentage reduction of area (true)*—the difference between the original cross-sectional area of the test specimen and the minimum cross-sectional area within the gage boundaries prevailing at the moment of rupture, expressed as a percentage of the original area.

A1.20 *rate of loading*—the change in tensile load carried by the specimen per unit time. It is expressed in force per unit time, usually newtons (or pounds-force) per minute. The initial rate of loading can be calculated from the initial slope of the load versus time diagram.

A1.21 *rate of stressing (nominal)*—the change in tensile stress (nominal) per unit time. It is expressed in force per unit area per unit time, usually megapascals (or pounds-force per square inch) per minute. The initial rate of stressing can be calculated from the initial slope of the tensile stress (nominal) versus time diagram.

NOTE A1.9—The initial rate of stressing as determined in this manner has only limited physical significance. It does, however, roughly describe the average rate at which the initial stress (nominal) carried by the test specimen is applied. It is affected by the elasticity and flow characteristics of the materials being tested. At the yield point, the rate of stressing (true) may continue to have a positive value if the cross-sectional area is decreasing.

A1.22 *rate of straining*—the change in tensile strain per unit time. It is expressed either as strain per unit time, usually metres per metre (or inches per inch) per minute, or percentage elongation per unit time, usually percentage elongation per minute. The initial rate of straining can be calculated from the initial slope of the tensile strain versus time diagram.

NOTE A1.10—The initial rate of straining is synonymous with the rate of crosshead movement divided by the initial distance between crossheads only in a machine with constant-rate-of-crosshead movement and when the specimen has a uniform original cross-section, does not "neck down," and does not slip in the jaws.

A1.23 *Symbols*—The following symbols may be used for the above terms:

SYMBOL	TERM
W	Load
ΔW	Increment of load
L	Distance between gage marks at any time
L_o	Original distance between gage marks
L_u	Distance between gage marks at moment of rupture
ΔL	Increment of distance between gage marks = elongation
A	Minimum cross-sectional area at any time
A_o	Original cross-section area
ΔA	Increment of cross-sectional area
A_u	Cross-sectional area at point of rupture measured after breaking specimen
A_T	Cross-sectional area at point of rupture, measured at the moment of rupture
t	Time
Δt	Increment of time
σ	Tensile stress
$\Delta\sigma$	Increment of stress
σ_T	True tensile stress
σ_U	Tensile strength at break (nominal)
σ_{UT}	Tensile strength at break (true)
ϵ	Strain
$\Delta\epsilon$	Increment of strain
ϵ_U	Total strain, at break
ϵ_T	True strain
$\%El$	Percentage elongation
Y.P.	Yield point
E	Modulus of elasticity

A1.24 Relations between these various terms may be defined as follows:

$$\sigma = W/A_o$$

$$\sigma_T = W/A$$

$$\sigma_U = W/A_o \text{ (where } W \text{ is breaking load)}$$

$$\sigma_{UT} = W/A_T \text{ (where } W \text{ is breaking load)}$$

$$\epsilon = \Delta L/L_o = (L - L_o)/L_o$$

$$\epsilon_U = (L_u - L_o)/L_o$$

$$\epsilon_T = \int_{L_o}^{L} dL/L = \ln L/L_o$$

$$\%El = [(L - L_o)/L_o] \times 100 = \epsilon \times 100$$

Percentage reduction of area (nominal)

$$= [(A_o - A_u)/A_o] \times 100$$

Percentage reduction of area (true)

$$= [(A_o - A_T)/A_o] \times 100$$

Rate of loading = $\Delta W/\Delta t$

Rate of stressing (nominal) = $\Delta\sigma/\Delta t = (\Delta W/A_o)/\Delta t$

Rate of straining = $\Delta\epsilon/\Delta t = (\Delta L/L_o)\Delta t$

For the case where the volume of the test specimen does not change during the test, the following three relations hold:

$$\sigma_T = \sigma(1 + \epsilon) = \sigma L/L_o$$

$$\sigma_{UT} = \sigma_U(1 + \epsilon_U) = \sigma_U L_u/L_o$$

$$A = A_o/(1 + \epsilon)$$

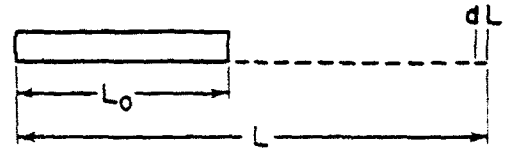


FIG. A1.1 Illustration of True Strain Equation

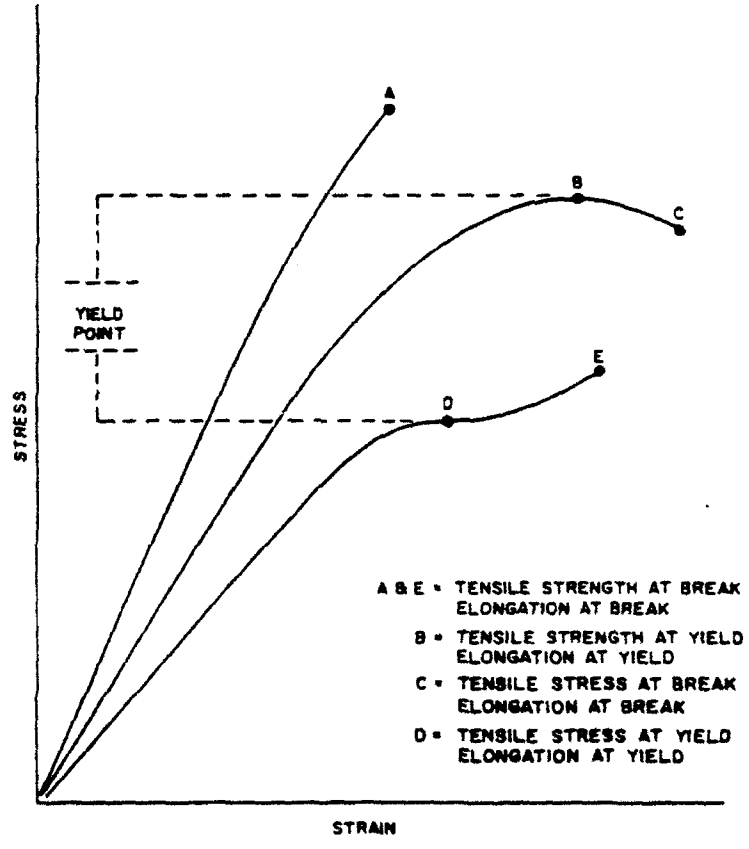


FIG. A1.2 Tensile Designations

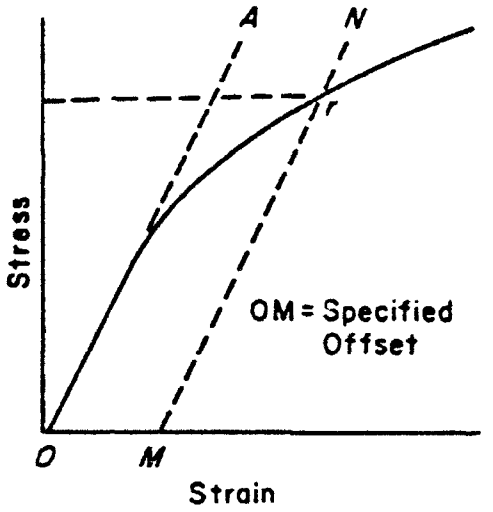


FIG. A1.3 Offset Yield Strength

APPENDIX

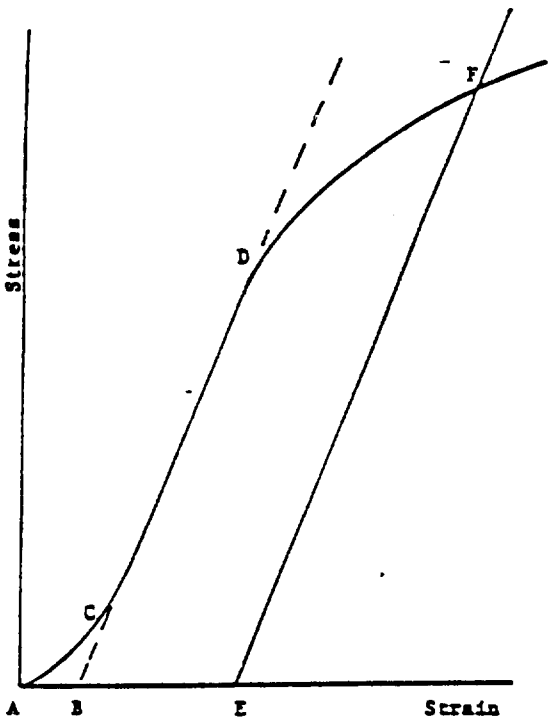
(Nonmandatory Information)

X1. TOE COMPENSATION

X1.1 In a typical stress-strain curve (Fig. X1.1) there is a toe region, *AC*, that does not represent a property of the material. It is an artifact caused by a takeup of slack, and alignment or seating of the specimen. In order to obtain correct values of such parameters as modulus, strain, and offset yield point, this artifact must be compensated for to give the corrected zero point on the strain or extension axis.

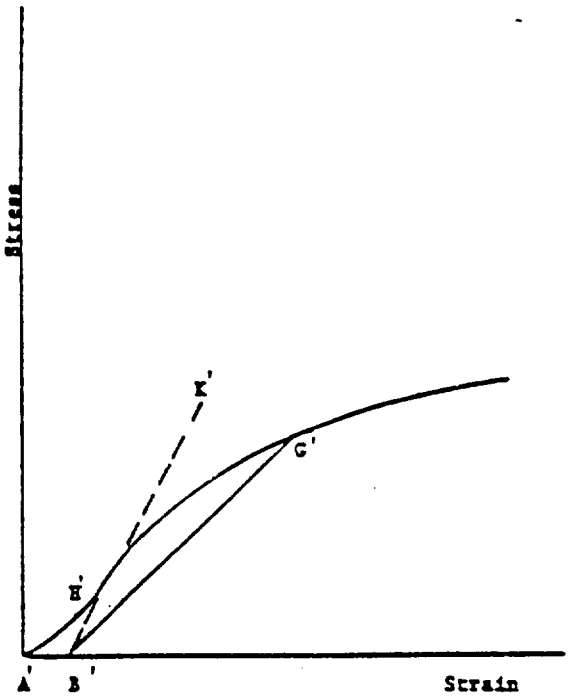
X1.2 In the case of a material exhibiting a region of Hookean (linear) behavior (Fig. X1.1), a continuation of the linear (*CD*) region of the curve is constructed through the zero-stress axis. This intersection (*B*) is the corrected zero-strain point from which all extensions or strains must be measured, including the yield offset (*BE*), if applicable. The elastic modulus can be determined by dividing the stress at any point along the line *CD* (or its extension) by the strain at the same point (measured from point *B*, defined as zero-strain).

X1.3 In the case of a material that does not exhibit any linear region (Fig. X1.2), the same kind of toe correction of the zero-strain point can be made by constructing a tangent to the maximum slope at the inflection point (*H'*). This is extended to intersect the strain axis at point *B'*, the corrected zero-strain point. Using point *B'* as zero strain, the stress at any point (*G'*) on the curve can be divided by the strain at that point to obtain a secant modulus (slope of line *B' G'*). For those materials with no linear region, any attempt to use the tangent through the inflection point as a basis for determination of an offset yield point may result in unacceptable error.



NOTE—Some chart recorders plot the mirror image of this graph.

FIG. X1.1 Material with Hookean Region



NOTE—Some chart recorders plot the mirror image of this graph.

FIG. X1.2 Material with No Hookean Region

The American Society for Testing and Materials takes no position respecting the validity of any patent rights asserted in connection with any item mentioned in this standard. Users of this standard are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, are entirely their own responsibility.

This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards, 1916 Race St., Philadelphia, Pa. 19103.

Designation: D 695 – 84

Standard Test Method for COMPRESSIVE PROPERTIES OF RIGID PLASTICS[1]

This standard is issued under the fixed designation D 695; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This test method has been approved for use by agencies of the Department of Defense to replace Method 1021 of Federal Test Method Standard 406 and for listing in the DoD Index of Specifications and Standards.

1. Scope

1.1 This test method covers the determination of the mechanical properties of rigid plastics when loaded in compression at relatively low uniform rates of straining or loading. Test specimens of standard shape are employed.

1.2 The values stated in SI units are to be regarded as the standard.

1.3 *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of whoever uses this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Applicable Documents

2.1 *ASTM Standards:*

D 618 Methods of Conditioning Plastics and Electrical Insulating Materials for Testing[2]

D 638 Test Method for Tensile Properties of Plastics[2]

D 4066 Specification for Nylon Injection and Extrusion Materials (PA)[3]

E 4 Methods of Load Verification of Testing Machines[3,4]

E 83 Method of Verification and Classification of Extensometers[4]

3. Significance and Use

3.1 Compression tests provide information about the compressive properties of plastics when employed under conditions approximating those under which the tests are made.

3.2 Compressive properties include modulus of elasticity, yield stress, deformation beyond yield point, and compressive strength (unless the material merely flattens but does not fracture). Materials possessing a low order of ductility may not exhibit a yield point. In the case of a material that fails in compression by a shattering fracture, the compressive strength has a very definite value. In the case of a material that does not fail in compression by a shattering fracture, the compressive strength is an arbitrary one depending upon the degree of distortion that is regarded as indicating complete failure of the material. Many plastic materials will continue to deform in compression until a flat disk is produced, the compressive stress (nominal) rising steadily in the process, without any well-defined fracture occurring. Compressive strength can have no real meaning in such cases.

3.3 Compression tests provide a standard method of obtaining data for research and development, quality control, acceptance or rejection under specifications, and special purposes. The tests cannot be considered significant for engineering design in applications differing widely from the load-time scale of the standard test. Such applications require additional tests such as impact, creep, and fatigue.

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[1] This test method is under the jurisdiction of ASTM Committee D-20 on Plastics and is the direct responsibility of Subcommittee D20.10 on Mechanical Properties.

Current edition approved July 27, 1984. Published September 1984. Originally published as D 695 – 42 T. Last previous edition D 695 – 80.

[2] *Annual Book of ASTM Standards*, Vol 08.01.

[3] *Annual Book of ASTM Standards*, Vol 08.03.

[4] *Annual Book of ASTM Standards*, Vol 03.01.

Institute for Plastics Innovation

University of Massachusetts Lowell
333 Aiken Street
Lowell, MA 01854
Telephone (508) 934-3445
Fax: (508) 937-9877

February 25, 94

To:
Mr. Delores Campbell
Defense Technology Information Ctr.
Cameron Station Bldg. 5
Alexandria, VA 22304-614
Tel: (703) 274-6837
Fax: (703) 274-9307

Dear Mr. Campbell:

I am enclosing ASTM D 695-89 specification on "Compressive Properties of Rigid Plastics" which you can use to replace the one with missing pages (p-243-284) in our Air Force Report #PL-TR-92-3056 on "Physical Properties of Injection Molded Liquid Crystal Polymers and High Temperature Engineering Polymers". Please also correct our names on the cover page of the report by the following:

Dr. Nick R. Schott
Dr. Robert E. Nunn
Dr. Miftahur Rahman
Mr. Sudesh Appaji

Thank you.

Sincerely,

Dr. N. R. Schott
Director, IPI

ADA 264 913

Designation: D 695 – 89

Standard Test Method for Compressive Properties of Rigid Plastics[1]

This standard is issued under the fixed designation D 695; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This test method has been approved for use by agencies of the Department of Defense to replace Method 1021. Consult the DoD Index of Specifications and Standards for the specific year of issue which has been adopted by the Department of Defense.

1. Scope

1.1 This test method covers the determination of the mechanical properties of unreinforced and reinforced rigid plastics, including high-modulus composites, when loaded in compression at relatively low uniform rates of straining or loading. Test specimens of standard shape are employed.

1.2 The values stated in SI units are to be regarded as the standard.

NOTE 1—A complete metric companion to Test Method D 695 has been developed—D 695M.

NOTE 2—For compressive properties of resin-matrix composites reinforced with oriented continuous, discontinuous, or cross-ply reinforcements, tests may be made in accordance with Test Method D 3410.

1.3 *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 618 Methods of Conditioning Plastics and Electrical Insulating Materials for Testing[2]

D 638 Test Method for Tensile Properties of Plastics[2]

D 695M Test Method for Compressive Properties of Rigid Plastics [Metric][2]

D 3410 Test Method for Compressive Properties of Unidirectional Crossply Fiber-Resin Composites[3]

D 4066 Specification for Nylon Injection and Extrusion Materials[4]

E 4 Practices for Load Verification of Testing Machines[4,5]

E 83 Practice for Verification and Classification of Extensometers[5]

E 691 Practice for Conducting an Interlaboratory Test Study to Determine the Precision of Test Methods[6]

3. Terminology

3.1 *Definitions:*

3.1.1 *compressive deformation*—the decrease in length produced in the gage length of the test specimen by a compressive load. It is expressed in units of length.

3.1.2 *compressive strain*—the ratio of compressive deformation to the gage length of the test specimen, that is, the change in length per unit of original length along the longitudinal axis. It is expressed as a dimensionless ratio.

3.1.3 *compressive strength*—the maximum compressive stress (nominal) carried by a test specimen during a compression test. It may or may not be the compressive stress (nominal) carried by the specimen at the moment of rupture.

3.1.4 *compressive strength at failure (nominal)*—the compressive stress (nominal) sustained at the moment of failure of the test specimen if shattering occurs.

3.1.5 *compressive stress (nominal)*—the compressive load per unit area of minimum original cross section within the gage boundaries, carried by the test specimen at any given moment. It is expressed in force per unit area.

NOTE 3—The expression of compressive properties in terms of the minimum original cross section is almost universally used. Under some circumstances the compressive properties have been expressed per unit of prevailing cross section. These properties are called "true" compressive properties.

3.1.6 *compressive stress-strain diagram*—a diagram in which values of compressive stress are plotted as ordinates against corresponding values of compressive strain as abscissas.

3.1.7 *compressive yield point*—the first point on the stress-strain diagram at which an increase in strain occurs without an increase in stress.

3.1.8 *compressive yield strength*—normally the stress at the yield point (see also 3.1.11).

3.1.9 *crushing load*—the maximum compressive force applied to the specimen, under the conditions of test, that produces a designated degree of failure.

3.1.10 *modulus of elasticity*—the ratio of stress (nominal) to corresponding strain below the proportional limit of a material. It is expressed in force per unit area based on the average initial cross-sectional area.

3.1.11 *offset compressive yield strength*—the stress at which the stress-strain curve departs from linearity by a specified percentage of deformation (offset).

3.1.12 *percentage compressive strain*—the compressive deformation of a test specimen expressed as a percentage of the original gage length.

3.1.13 *proportional limit*—the greatest stress that a material is capable of sustaining without any deviation from proportionality of stress to strain (Hooke's law). It is expressed in force per unit area.

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[1] This test method is under the jurisdiction of ASTM Committee D-20 on Plastics and is the direct responsibility of Subcommittee D20.10 on Mechanical Properties.

Current edition approved Jan. 27, 1989. Published March 1989. Originally published as D 695 – 42 T. Last previous edition D 695 – 88.

[2] *Annual Book of ASTM Standards*, Vol 08.01.

[3] *Annual Book of ASTM Standards*, Vol 15.03.

[4] *Annual Book of ASTM Standards*, Vol 08.03.

[5] *Annual Book of ASTM Standards*, Vol 03.01.

[6] *Annual Book of ASTM Standards*, Vol 14.02.

3.1.14 *slenderness ratio*—the ratio of the length of a column of uniform cross section to its least radius of gyration. For specimens of uniform rectangular cross section, the radius of gyration is 0.289 times the smaller cross-sectional dimension. For specimens of uniform circular cross section, the radius of gyration is 0.250 times the diameter.

4. Significance and Use

4.1 Compression tests provide information about the compressive properties of plastics when employed under conditions approximating those under which the tests are made.

4.2 Compressive properties include modulus of elasticity, yield stress, deformation beyond yield point, and compressive strength (unless the material merely flattens but does not fracture). Materials possessing a low order of ductility may not exhibit a yield point. In the case of a material that fails in compression by a shattering fracture, the compressive strength has a very definite value. In the case of a material that does not fail in compression by a shattering fracture, the compressive strength is an arbitrary one depending upon the degree of distortion that is regarded as indicating complete failure of the material. Many plastic materials will continue to deform in compression until a flat disk is produced, the compressive stress (nominal) rising steadily in the process, without any well-defined fracture occurring. Compressive strength can have no real meaning in such cases.

4.3 Compression tests provide a standard method of obtaining data for research and development, quality control, acceptance or rejection under specifications, and special purposes. The tests cannot be considered significant for engineering design in applications differing widely from the load-time scale of the standard test. Such applications require additional tests such as impact, creep, and fatigue.

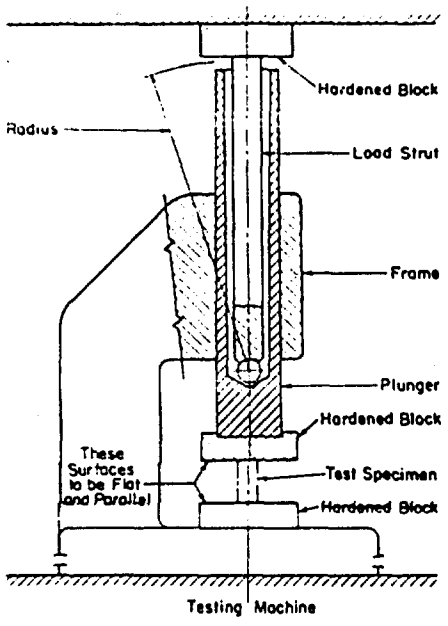
5. Apparatus

5.1 *Testing Machine*—Any suitable testing machine capable of control of constant-rate-of-crosshead movement and comprising essentially the following:

5.1.1 *Drive Mechanism*—A drive mechanism for imparting to the cross-head movable member, a uniform, controlled velocity with respect to the base (fixed member), this velocity to be regulated as specified in Section 9.

5.1.2 *Load Indicator*—A load-indicating mechanism capable of showing the total compressive load carried by the test specimen. The mechanism shall be essentially free from inertia-lag at the specified rate of testing and shall indicate the load with an accuracy of ±1 % of the maximum indicated value of the test (load). The accuracy of the testing machine shall be verified at least once a year in accordance with Practices E 4.

5.2 *Compressometer*—A suitable instrument for determining the distance between two fixed points on the test specimen at any time during the test. It is desirable that this instrument automatically record this distance (or any change in it) as a function of the load on the test specimen. The instrument shall be essentially free of inertia-lag at the specified rate of loading and shall conform to the requirements for a Class B-2 extensometer as defined in Practice E 83.



NOTE—Devices similar to the one illustrated have been successfully used in a number of different laboratories. Details of the device developed at the National Bureau of Standards are given in the paper by Aitchinson, C. S., and Miller, J. A., "A Subpress for Compressive Tests," Natl. Advisory Committee for Aeronautics, Technical Note No. 912, 1943.

FIG. 1 Subpress for Compression Tests

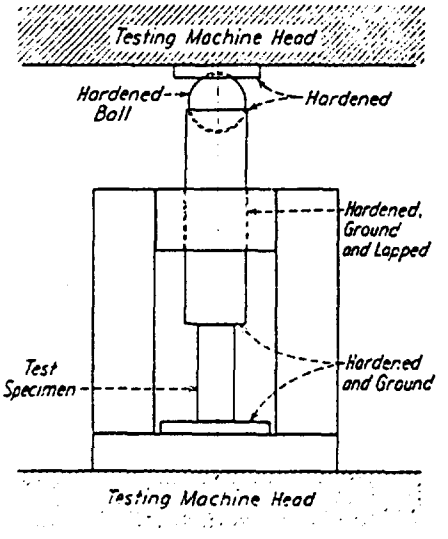


FIG. 2 Compression Tool

NOTE 4—The requirements for extensometers cited herein apply to compressometers as well.

5.3 *Compression Tool*—A compression tool for applying the load to the test specimen. This tool shall be so constructed that loading is axial within 1:1000 and applied through surfaces that are flat within 0.025 mm (0.001 in.) and parallel to each other in a plane normal to the vertical loading axis. Examples of suitable compression tools are shown in Figs. 1 and 2.

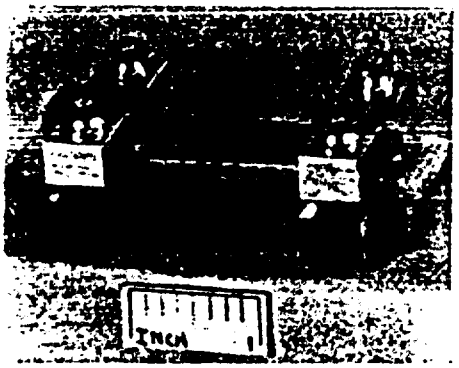


FIG. 3 Support Jig for Thin Specimen

5.4 *Supporting Jig*—A supporting jig for thin specimens is shown in Figs. 3 and 4.

5.5 *Micrometers*—Suitable micrometers, reading to 0.01 mm or 0.001 in. for measuring the width, thickness, and length of the specimens.

6. Test Specimens

6.1 Unless otherwise specified in the materials specifications, the specimens described in 6.2 and 6.7 shall be used. These specimens may be prepared by machining operations from materials in sheet, plate, rod, tube, or similar form, or they may be prepared by compression or injection molding of the material to be tested. All machining operations shall be done carefully so that smooth surfaces result. Great care shall be taken in machining the ends so that smooth, flat parallel surfaces and sharp, clean edges to within 0.025 mm (0.001 in.) perpendicular to the long axis of the specimen, result.

6.2 The standard test specimen, except as indicated in 6.3 to 6.7, shall be in the form of a right cylinder or prism whose length is twice its principal width or diameter. specimen sizes are 12.7 by 12.7 by 25.4 mm (0.50 1 in.) (prism), or 12.7 mm (0.50 in.) in diameter by (1 in.) (cylinder). Where elastic modulus and of stress data are desired, the test specimen shall h dimensions that the slenderness ratio is in the rang to 16:1. In this case, preferred specimen sizes ar 12.7 by 50.8 mm (0.50 by 0.50 by 2 in.) (prism), or (0.50 in.) in diameter by 50.8 mm (2 in.) (cylinde

6.3 For rod material, the test specimen sha diameter equal to the diameter of the rod and a length to allow a specimen slenderness ratio in from 11 to 16:1.

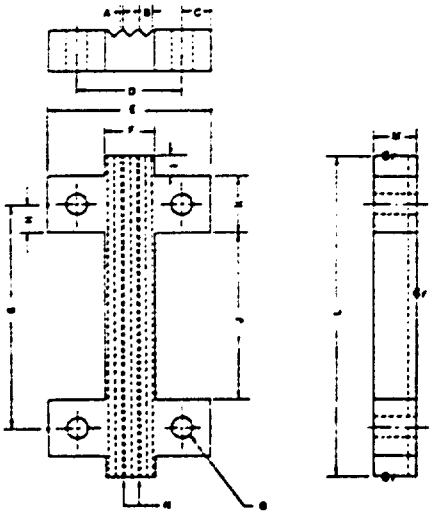
6.4 When testing tubes, the test specimen sha diameter equal to the diameter of the tube and a 25.4 mm (1 in.) (Note 5). For crushing-load deter (at right angles to the longitudinal axis), the spec shall be the same, with the diameter becoming the

NOTE 5—This specimen can be used for tubes with a wa of 1 mm (0.039 in.) or over, to inside diameters of 6.4 mm (over, and to outside diameters of 50.8 mm (2.0 in.) or less.

6.5 Where it is desired to test conventional high laminates in the form of sheets, the thickness of wh than 25.4 mm (1 in.), a pile-up of sheets 25.4 m square, with a sufficient number of layers to produce of at least 25.4 mm (1 in.), may be used.

6.6 When testing material that may be susp anisotropy, duplicate sets of test specimens shall be having their long axis respectively parallel with and to the suspected direction of anisotropy.

6.7 *Reinforced Plastics, Including High-Strength ites and High-Strength Composites and Highly Or Laminates*—The following specimens shall be reinforced materials, or for other materials when nec comply with the slenderness ratio requirements or t attachment of a deformation-measuring device.



LETTER	METRIC SYSTEM	BRITISH SYSTEM
A	40 mm	0156 in
B	318	125
C	6.35	.250
D	238	.9375
E	365	14375
F	111	4375
G	508	200
H	635	250
I	476	1875
J	38.1	1500
K	12.7	500
L	730	2875
M	9 53	375
N	358	141
O	476 d.	1875 d.

NOTE 1—Cold rolled steel.
NOTE 2—Furnished four steel machine screws and nuts, round head, slotted, length 31.75 mm (1¼ in.).
NOTE 3—Grind surfaces denoted "Gr."

FIG. 4 Support Jig, Details

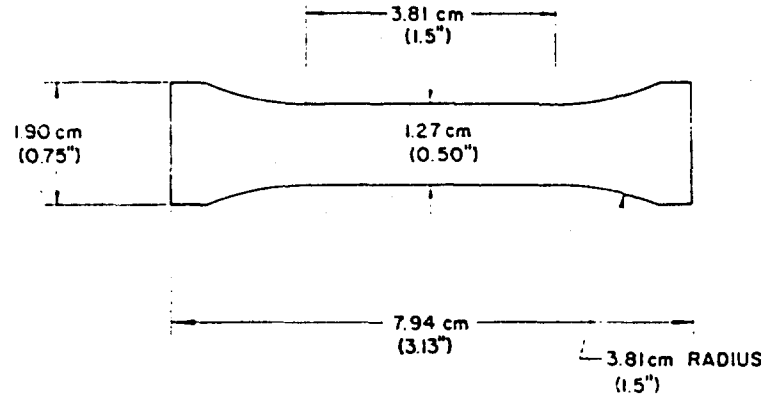


FIG. 5 Compression Test Specimen for Materials Less than 3.2 mm Thick

6.7.1 For materials 3.2 mm (⅛ in.) and over in thickness, a specimen shall consist of a prism having a cross section of 12.7 mm (½ in.) by the thickness of the material and a length such that the slenderness ratio is in the range from 11 to 16:1 (Note 6).

6.7.2 For materials under 3.2 mm (⅛ in.) thick, or where elastic modulus testing is required and the slenderness ratio does not provide for enough length for attachment of a compressometer or similar device, a specimen conforming to that shown in Fig. 6 shall be used. The supporting jig shown in Figs. 3 and 4 shall be used to support the specimen during test (Note 7).

NOTE 6—If failure for materials in the thickness range of 3.2 mm (⅛ in.) is by delamination rather than by the desirable shear plane fracture, the material may be tested in accordance with 6.7.2.

NOTE 7—Round-robin tests have established that relatively satisfactory measurements of modulus of elasticity may be obtained by applying a compressometer to the edges of the jig-supported specimen.

6.8 When testing syntactic foam, the standard test specimen shall be in the form of a right cylinder 25.4 mm (1 in.) in diameter by 50.8 mm (2 in.) in length.

7. Conditioning

7.1 *Conditioning*—Condition the test specimens at 23 ± 2°C (73.4 ± 3.6°F) and 50 ± 5 % relative humidity for not less than 40 h prior to test in accordance with Procedure A of Methods D 618, for those tests where conditioning is required. In cases of disagreement, the tolerances shall be 1°C (1.8°F) and ±2 % relative humidity.

7.1.1 Note that for some hygroscopic materials, such as nylons, the material specifications (for example, Specification D 4066) call for testing "dry as-molded specimens." Such requirements take precedence over the above routine preconditioning to 50 % RH and require sealing the specimens in water vapor-impermeable containers as soon as molded and not removing them until ready for testing.

7.2 *Test Conditions*—Conduct tests in the Standard Laboratory Atmosphere of 23 ± 2°C (73.4 ± 3.6°F) and 50 ± 5 % relative humidity, unless otherwise specified in the test methods. In cases of disagreement, the tolerances shall be 1°C (1.8°F) and ±2 % relative humidity.

8. Number of Test Specimens

8.1 At least five specimens shall be tested for each sample in the case of isotropic materials.

8.2 Ten specimens, five normal to and five parallel with the principal axis of anisotropy, shall be tested for each sample in the case of anisotropic materials.

8.3 Specimens that break at some obvious fortuitous flow shall be discarded and retests made, unless such flaws constitute a variable, the effect of which it is desired to study.

9. Speed of Testing

9.1 Speed of testing shall be the relative rate of motion of the grips or test fixtures during the test. Rate of motion of the driven grip or fixture when the machine is running idle may be used if it can be shown that the resulting speed of testing is within the limits of variation allowed.

9.2 The standard speed of testing shall be 1.3 ± 0.3 mm (0.050 ± 0.010 in.)/min, except as noted in 10.5.4.

10. Procedure

10.1 Measure the width and thickness of the specimen to the nearest 0.01 mm (0.001 in.) at several points along its length. Calculate and record the minimum value of the cross-sectional area. Measure the length of the specimen and record the value.

10.2 Place the test specimen between the surfaces of the compression tool, taking care to align the center line of its long axis with the center line of the plunger and to ensure that the ends of the specimen are parallel with the surface of the compression tool. Adjust the crosshead of the testing machine until it just contacts the top of the compression tool plunger.

NOTE 8—The compression tool may not be necessary for testing of lower modulus (for example, 100 000 to 500 000 psi) material if the loading surfaces are maintained smooth, flat, and parallel to the extent that buckling is not incurred.

10.3 Place thin specimens in the jig (Figs. 3 and 4) so that they are flush with the base and centered (Note 9). The nuts or screws on the jig shall be finger tight (Note 10). Place the assembly in the compression tool as described in 5.3.

NOTE 9—A round-robin test, designed to assess the influence of specimen positioning in the supporting jig (that is, flush versus centered mounting), showed no significant effect on compressive strength due to this variable. However, flush mounting of the specimen with the base of the jig is specified for convenience and ease of mounting. Substantiating data are filed at ASTM Headquarters (RR:D20-1061).

NOTE 10—A round-robin test on the effect of lateral pressure at the supporting jig has established that reproducible data can be obtained with the tightness of the jig controlled as indicated.

10.4 If only compressive strength or compressive yield strength, or both, are desired, proceed as follows:

10.4.1 Set the speed control at 1.3 mm/min (0.050 in./min) and start the machine.

10.4.2 Record the maximum load carried by the specimen during the test (usually this will be the load at the moment of rupture).

10.5 If stress-strain data are desired, proceed as follows:

10.5.1 Attach compressometer.

10.5.2 Set the speed control at 1.3 mm/min (0.050 in./min) and start the machine.

10.5.3 Record loads and corresponding compressive strain at appropriate intervals of strain or, if the test machine is equipped with an automatic recording device, record the complete load-deformation curve.

10.5.4 After the yield point has been reached, it may be desirable to increase the speed from 5 to 6 mm/min (0.20 to 0.25 in./min) and allow the machine to run at this speed until the specimen breaks. This may be done only with relatively ductile materials and on a machine with a weighing system with response rapid enough to produce accurate results.

11. Calculation

11.1 *Compressive Strength*—Calculate the compressive strength by dividing the maximum compressive load carried by the specimen during the test by the original minimum cross-sectional area of the specimen. Express the result in megapascals or pounds-force per square inch and report to three significant figures.

11.2 *Compressive Yield Strength*—Calculate the compressive yield strength by dividing the load carried by the specimen at the yield point by the original minimum cross-sectional area of the specimen. Express the result in megapascals or pounds-force per square inch and report to three significant figures.

11.3 *Offset Yield Strength*—Calculate the offset yield strength by the method referred to in 4.10.

11.4 *Modulus of Elasticity*—Calculate the modulus of elasticity by drawing a tangent to the initial linear portion of the load deformation curve, selecting any point on this straight line portion, and dividing the compressive stress represented by this point by the corresponding strain, measure from the point where the extended tangent line intersects the strain-axis. Express the result in gigapascals or pounds-force per square inch and report to three significant figures.

11.5 For each series of tests, calculate to three significant figures the arithmetic mean of all values obtained and report as the "average value" for the particular property in question.

11.6 Calculate the standard deviation (estimated) as follows and report to two significant figures:

$$s = \sqrt{(\Sigma X^2 - n\bar{X}^2)/(n-1)}$$

where:

s = estimated standard deviation,

X = value of single observation,

n = number of observations, and

$\bar{X}$ = arithmetic mean of the set of observations.

NOTE 11—The method for determining the offset compr strength is similar to that described in the Annex of Test Meth

11.7 See Appendix X1 for information on toe c tion.

12. Report

12.1 The report shall include the following:

12.1.1 Complete identification of the materi including type, source, manufacturer's code numb principal dimensions, previous history, etc.,

12.1.2 Method of preparing test specimens,

12.1.3 Type of test specimen and dimensions,

12.1.4 Conditioning procedure used,

12.1.5 Atmospheric conditions in test room,

12.1.6 Number of specimens tested,

12.1.7 Speed of testing,

12.1.8 Compressive strength, average value, and deviation,

12.1.9 Compressive yield strength and offset yield average value, and standard deviation, when of inte

12.1.10 Modulus of elasticity in compression (if r average value, standard deviation, and

12.1.11 Date of test.

13. Precision and Bias[7]

13.1 Tables 1 and 2 are based on a round robin c in 1987 per Practice E 691, involving three materi by six laboratories for D 695M. Since the test pa overlap within tolerances and the test values are nor the same data is used for both methods. For each all of the samples were prepared at one source. E result was the average of five individual determi Each lab obtained two test results for each material.

NOTE 12—Caution: The following explanations of r an through 13.2.3) are only intended to present a meaningf considering the *approximate* precision of this test method. T Tables 1 and 2 should not be rigorously applied to acce rejection of material, as those data are specific to the round may not be representative of other lots, conditions, m laboratories. Users of this test method should apply the outlined in Practice E 691 to generate data specific to their and materials or between specific laboratories. The princip through 13.2.3 would then be valid for such data.

13.2 *Concept of r and R*—If $S(r)$ and $S(R)$ h calculated from a large enough body of data, an results that were averages from testing five specim

13.2.1 *Repeatability, r*—Comparing two test r the same material, obtained by the same operator same equipment on the same day. The two te should be judged not equivalent if they differ by m the r value for that material.

13.2.2 *Reproducibility, R*—Comparing two result same material, obtained by different operators u ferent equipment on different days. The two tes should be judged not equivalent if they differ by mor value for that material.

[7] Supporting data are available from ASTM Headquarters, R D-20-1150.

13.2.3 Any judgement per 13.2.1 and 13.2.2 would have an approximate 95 % (0.95) probability of being correct.

13.3 There are no recognized standards by which to estimate bias of this test method.

APPENDIX

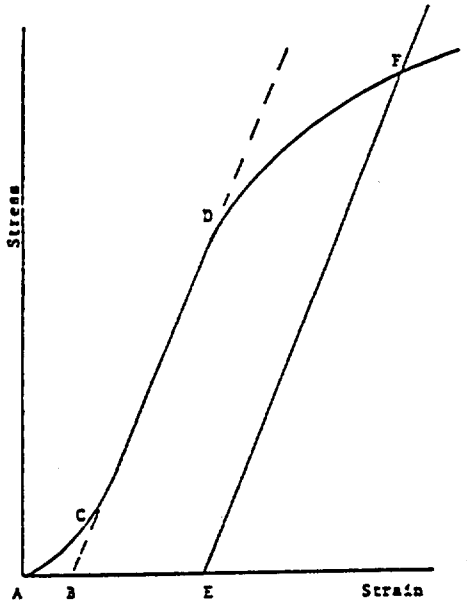
(Nonmandatory Information)

X1. TOE COMPENSATION

X1.1 In a typical stress-strain curve (Fig. X1.1) there is a toe region, AC, that does not represent a property of the material. It is an artifact caused by a takeup of slack, and alignment or seating of the specimen. In order to obtain correct values of such parameters as modulus, strain, and offset yield point, this artifact must be compensated for to give the corrected zero point on the strain or extension axis.

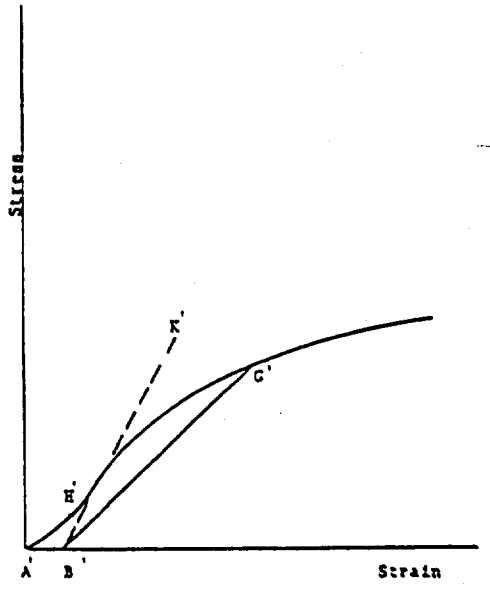
X1.2 In the case of a material exhibiting a region of Hookean (linear) behavior (Fig. X1.1), a continuation of the linear (CD) region of the curve is constructed through the zero-stress axis. This intersection (B) is the corrected zero-strain point from which all extensions or strains must be measured, including the yield offset (BE), if applicable. The elastic modulus can be determined by dividing the stress at any point along the line CD (or its extension) by the strain at the same point (measured from point B, defined as zero-strain).

X1.3 In the case of a material that does not exhibit any linear region (Fig. X1.2), the same kind of toe correction of the zero-strain point can be made by constructing a tangent to the maximum slope at the inflection point (H'). This is extended to intersect the strain axis at point B', the corrected zero-strain point. Using point B' as zero strain, the stress at any point (G') on the curve can be divided by the strain at that point to obtain a secant modulus (slope of line B' G'). For those materials with no linear region, any attempt to use the tangent through the inflection point as a basis for determination of an offset yield point may result in unacceptable error.



NOTE—Some chart recorders plot the mirror image of this graph.

FIG. X1.1 Material with Hookean Region



NOTE—Some chart recorders plot the mirror image of this graph.

FIG. X1.2 Material with No Hookean Region

4. Definitions

4.1 *compressive stress (nominal)*—the compressive load per unit area of minimum original cross section within the gage boundaries, carried by the test specimen at any given moment. It is expressed in force per unit area.

NOTE 1—The expression of compressive properties in terms of the minimum original cross section is almost universally used. Under some circumstances the compressive properties have been expressed per unit of prevailing cross section. These properties are called "true" compressive properties.

4.2 *compressive strength*—the maximum compressive stress (nominal) carried by a test specimen during a compression test. It may or may not be the compressive stress (nominal) carried by the specimen at the moment of rupture.

4.3 *compressive strength at failure (nominal)*—the compressive stress (nominal) sustained at the moment of failure of the test specimen if shattering occurs.

4.4 *compressive deformation*—the decrease in length produced in the gage length of the test specimen by a compressive load. It is expressed in units of length.

4.5 *compressive strain*—the ratio of compressive deformation to the gage length of the test specimen, that is, the change in length per unit of original length along the longitudinal axis. It is expressed as a dimensionless ratio.

4.6 *percentage compressive strain*—the compressive deformation of a test specimen expressed as a percentage of the original gage length.

4.7 *compressive stress-strain diagram*—a diagram in which values of compressive stress are plotted as ordinates against corresponding values of compressive strain as abscissas.

4.8 *compressive yield point*—the first point on the stress-strain diagram at which an increase in strain occurs without an increase in stress.

4.9 *compressive yield strength*—normally the stress at the yield point (see also 4.10).

4.10 *offset compressive yield strength*—the stress at which the stress-strain curve departs from linearity by a specified percentage of deformation (offset).

4.11 *proportional limit*—the greatest stress that a material is capable of sustaining without any deviation from proportionality of stress to strain (Hooke's law). It is expressed in force per unit area.

4.12 *modulus of elasticity*—the ratio of stress (nominal) to corresponding strain below the proportional limit of a material. It is expressed in force per unit area based on the average initial cross-sectional area.

4.13 *slenderness ratio*—the ratio of the length of a column of uniform cross section to its least radius of gyration. For specimens of uniform rectangular cross section, the radius of gyration is 0.289 times the smaller cross-sectional dimension. For specimens of uniform circular cross section, the radius of gyration is 0.250 times the diameter.

4.14 *crushing load*—the maximum compressive force applied to the specimen, under the conditions of test, that produces a designated degree of failure.

5. Apparatus

5.1 *Testing Machine*—Any suitable testing machine capable of control of constant-rate-of-crosshead movement and comprising essentially the following:

5.1.1 *Drive Mechanism*—A drive mechanism for imparting to the cross-head movable member, a uniform, controlled velocity with respect to the base (fixed member), this velocity to be regulated as specified in Section 9.

5.1.2 *Load Indicator*—A load-indicating mechanism capable of showing the total compressive load carried by the test specimen. The mechanism shall be essentially free from inertia-lag at the specified rate of testing and shall indicate the load with an accuracy of ±1 % of the maximum indicated value of the test (load). The accuracy of the testing machine shall be verified at least once a year in accordance with Methods E 4.

5.2 *Compressometer*—A suitable instrument for determining the distance between two fixed points on the test specimen at any time during the test. It is desirable that this instrument automatically record this distance (or any change in it) as a function of the load on the test specimen. The instrument shall be essentially free of inertia-lag at the specified rate of loading and shall conform to the requirements for a Class B-2 extensometer as defined in Method E 83.

NOTE 2—The requirements for extensometers cited herein apply to compressometers as well.

5.3 *Compression Tool*—A compression tool

for applying the load to the test specimen. This tool shall be so constructed that loading is axial within 1:1000 and applied through surfaces that are flat within 0.025 mm (0.001 in.) and parallel to each other in a plane normal to the vertical loading axis. Examples of suitable compression tools are shown in Figs. 1 and 2.

5.4 *Supporting Jig*—A supporting jig for thin specimens is shown in Figs. 3 and 4.

5.5 *Micrometers*—Suitable micrometers, reading to 0.01 mm or 0.001 in. for measuring the width, thickness, and length of the specimens.

6. Test Specimens

6.1 Unless otherwise specified in the materials specifications, the specimens described in 6.2 and 6.7 shall be used. These specimens may be prepared by machining operations from materials in sheet, plate, rod, tube, or similar form, or they may be prepared by compression or injection molding of the material to be tested. All machining operations shall be done carefully so that smooth surfaces result. Great care shall be taken in machining the ends so that smooth, flat parallel surfaces and sharp, clean edges to within 0.025 mm (0.001 in.) perpendicular to the long axis of the specimen, result.

6.2 The standard test specimen, except as indicated in 6.3 to 6.7, shall be in the form of a right cylinder or prism whose length is twice its principal width or diameter. Preferred specimen sizes are 12.7 by 12.7 by 25.4 mm (0.50 by 0.50 by 1 in.) (prism), or 12.7 mm (0.50 in.) in diameter by 25.4 mm (1 in.) (cylinder). Where elastic modulus and offset yield-stress data are desired, the test specimen shall be of such dimensions that the slenderness ratio is in the range from 11 to 15:1. In this case, preferred specimen sizes are 12.7 by 12.7 by 50.8 mm (0.50 by 0.50 by 2 in.) (prism), or 12.7 mm (0.50 in.) in diameter by 50.8 mm (2 in.) (cylinder).

6.3 For rod material, the test specimen shall have a diameter equal to the diameter of the rod and a sufficient length to allow a specimen slenderness ratio in the range from 11 to 15:1.

6.4 When testing tubes, the test specimen shall have a diameter equal to the diameter of the tube and a length of 25.4 mm (1 in.) (Note 4). For crushing-load determinations (at right angles to the longitudinal axis), the specimen size shall be the same, with the diameter becoming the height.

NOTE 3—This specimen can be used for tubes with a wall thickness of 1 mm (0.039 in.) or over, to inside diameters of 6.4 mm (0.25 in.) or over, and to outside diameters of 50.8 mm (2.0 in.) or less.

6.5 Where it is desired to test conventional high-pressure laminates in the form of sheets, the thickness of which is less than 25.4 mm (1 in.), a pile-up of sheets 25.4 mm (1 in.) square, with a sufficient number of layers to produce a height of at least 25.4 mm (1 in.), may be used.

6.6 When testing material that may be suspected of anisotropy, duplicate sets of test specimens shall be prepared having their long axis respectively parallel with and normal to the suspected direction of anisotropy.

6.7 The following specimens shall be used for glass-reinforced materials, or for other materials when necessary to comply with the slenderness ratio requirements or to permit attachment of a deformation-measuring device.

6.7.1 For materials 3.2 mm (⅛ in.) and over in thickness, a specimen shall consist of a prism having a cross section of 12.7 mm (½ in.) by the thickness of the material and a length such that the slenderness ratio is in the range from 11 to 15:1 (Note 4).

6.7.2 For materials under 3.2 mm (⅛ in.) thick, or where elastic modulus testing is required and the slenderness ratio does not provide for enough length for attachment of a compressometer or similar device, a specimen conforming to that shown in Fig. 5 shall be used. The supporting jig shown in Figs. 3 and 4 shall be used to support the specimen during test (Note 5).

NOTE 4—If failure for materials in the thickness range of 3.2 mm (⅛ in.) is by delamination rather than by the desirable shear plane fracture, the material may be tested in accordance with 6.7.2.

NOTE 5—Round-robin tests have established that relatively satisfactory measurements of modulus of elasticity may be obtained by applying a compressometer to the edges of the jig-supported specimen.

6.8 When testing syntactic foam, the standard test specimen shall be in the form of a right cylinder 25.4 mm (1 in.) in diameter by 50.8 mm (2 in.) in length.

7. Conditioning

7.1 *Conditioning*—Condition the test specimens at 23 ± 2°C (73.4 ± 3.6°F) and 50 ± 5 % relative humidity for not less than 40 h prior to test in accordance with Procedure A of Method D 618, for those tests where conditioning is required. In cases of disagreement, the tolerance

shall be 1°C (1.8°F) and ± 2 % relative humidity.

7.1.1 Note that for some hygroscopic materials, such as nylons, the material specifications (for example, Specification D 4066) call for testing "dry as-molded specimens". Such requirements take precedence over the above routine preconditioning to 50 % RH and require sealing the specimens in water vapor-impermeable containers as soon as molded and not removing them until ready for testing.

7.2 *Test Conditions*—Conduct tests in the Standard Laboratory Atmosphere of 23 ± 2°C (73.4 ± 3.6°F) and 50 ± 5 % relative humidity, unless otherwise specified in the test methods. In cases of disagreement, the tolerances shall be 1°C (1.8°F) and ±2 % relative humidity.

8. Number of Test Specimens

8.1 At least five specimens shall be tested for each sample in the case of isotropic materials.

8.2 Ten specimens, five normal to and five parallel with the principal axis of anisotropy, shall be tested for each sample in the case of anisotropic materials.

8.3 Specimens that break at some obvious fortuitous flow shall be discarded and retests made, unless such flaws constitute a variable, the effect of which it is desired to study.

9. Speed of Testing

9.1 Speed of testing shall be the relative rate of motion of the grips or test fixtures during the test. Rate of motion of the driven grip or fixture when the machine is running idle may be used if it can be shown that the resulting speed of testing is within the limits of variation allowed.

9.2 The standard speed of testing shall be 1.3 ± 0.3 mm (0.050 ± 0.010 in.)/min, except as noted in 10.5.4.

10. Procedure

10.1 Measure the width and thickness of the specimen to the nearest 0.01 mm (0.001 in.) at several points along its length. Calculate and record the minimum value of the cross-sectional area. Measure the length of the specimen and record the value.

10.2 Place the test specimen between the surfaces of the compression tool, taking care to align the center line of its long axis with the center line of the plunger and to ensure that the ends of the specimen are parallel with the surface of the compression tool. Adjust the crosshead of the testing machine until it just contacts the top of the compression tool plunger.

NOTE 6—The compression tool may not be necessary for testing of lower modulus (for example, 100 000 to 500 000 psi) material if the loading surfaces are maintained smooth, flat, and parallel to the extent that buckling is not incurred.

10.3 Place thin specimens in the jig (Figs. 3 and 4) so that they are flush with the base and centered (Note 7). The nuts or screws on the jig shall be finger tight (Note 8). Place the assembly in the compression tool as described in 5.3.

NOTE 7—A round-robin test, designed to assess the influence of specimen positioning in the supporting jig (that is, flush versus centered mounting), showed no significant effect on compressive strength due to this variable. However, flush mounting of the specimen with the base of the jig is specified for convenience and ease of mounting. Substantiating data are filed at ASTM Headquarters (RR:D-20-1061).

NOTE 8—A round-robin test on the effect of lateral pressure at the supporting jig has established that reproducible data can be obtained with the tightness of the jig controlled as indicated.

10.4 If only compressive strength or compressive yield strength, or both, are desired, proceed as follows:

10.4.1 Set the speed control at 1.3 mm/min (0.050 in./min) and start the machine.

10.4.2 Record the maximum load carried by the specimen during the test (usually this will be the load at the moment of rupture).

10.5 If stress-strain data are desired, proceed as follows:

10.5.1 Attach compressometer.

10.5.2 Set the speed control at 1.3 mm/min (0.050 in./min) and start the machine.

10.5.3 Record loads and corresponding compressive strain at appropriate intervals of strain or, if the test machine is equipped with an automatic recording device, record the complete load-deformation curve.

10.5.4 After the yield point has been reached, it may be desirable to increase the speed from 5 to 6 mm/min (0.20 to 0.25 in./min) and allow the machine to run at this speed until the specimen breaks. This may be done only with relatively ductile materials and on a machine with a weighing system with response rapid enough to produce accurate results.

11. Calculations

11.1 *Compressive Strength*—Calculate the

compressive strength by dividing the maximum compressive load carried by the specimen during the test by the original minimum cross-sectional area of the specimen. Express the result in megapascals or pounds-force per square inch and report to three significant figures.

11.2 *Compressive Yield Strength*—Calculate the compressive yield strength by dividing the load carried by the specimen at the yield point by the original minimum cross-sectional area of the specimen. Express the result in megapascals or pounds-force per square inch and report to three significant figures.

11.3 *Offset Yield Strength*—Calculate the offset yield strength by the method referred to in 4.10.

11.4 *Modulus of Elasticity*—Calculate the modulus of elasticity by drawing a tangent to the initial linear portion of the load deformation curve, selecting any point on this straight line portion, and dividing the compressive stress represented by this point by the corresponding strain, measure from the point where the extended tangent line intersects the strain-axis. Express the result in gigapascals or pounds-force per square inch and report to three significant figures.

11.5 For each series of tests, calculate to three significant figures the arithmetic mean of all values obtained and report as the "average value" for the particular property in question.

11.6 Calculate the standard deviation (estimated) as follows and report to two significant figures:

$$s = \sqrt{(\Sigma X^2 - n\bar{X}^2)/(n-1)}$$

where:

s = estimated standard deviation,
X = value of single observation,
n = number of observations, and
$\bar{X}$ = arithmetic mean of the set of observation

NOTE 9—The method for determining the offs compressive yield strength is similar to that describ in the Annex of Test Method D 638.

11.7 See Appendix X1 for information on tc compensation.

12. Report

12.1 The report shall include the following:

12.1.1 Complete identification of the materi tested, including type, source, manufacturer code number, form, principal dimensions, pr vious history, etc.,

12.1.2 Method of preparing test specimens,

12.1.3 Type of test specimen and dimension

12.1.4 Conditioning procedure used,

12.1.5 Atmospheric conditions in test room

12.1.6 Number of specimens tested,

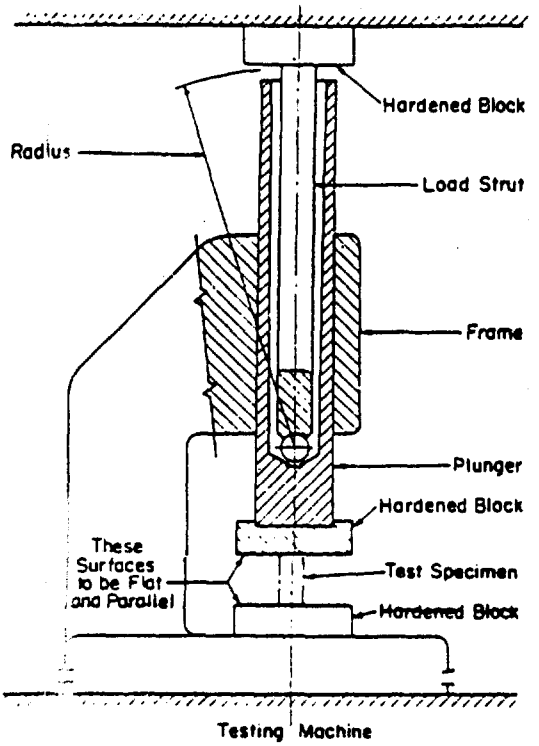
12.1.7 Speed of testing,

12.1.8 Compressive strength, average v and standard deviation,

12.1.9 Compressive yield strength and offs yield strength average value, and standard devi tion, when of interest,

12.1.10 Modulus of elasticity in compressic (if required), average value, standard deviatio and

12.1.11 Date of test.



NOTE—Devices similar to the one illustrated have been successfully used in a number of different laboratories. Details of the device developed at the National Bureau of Standards are given in the paper by Aitchison, C. S., and Miller, J. A., "A Subpress for Compressive Tests," Natl. Advisory Committee for Aeronautics, Technical Note No. 912, 1943.

FIG. 1 Subpress for Compression Tests

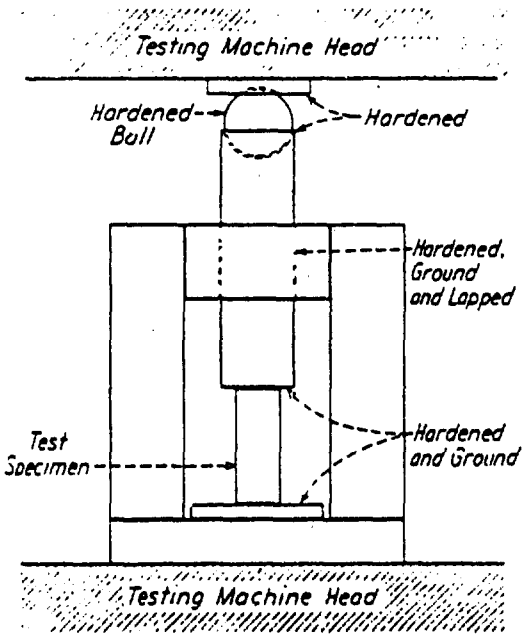


FIG. 2 Compression Tool

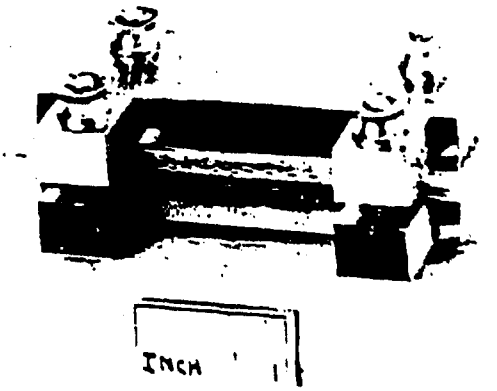
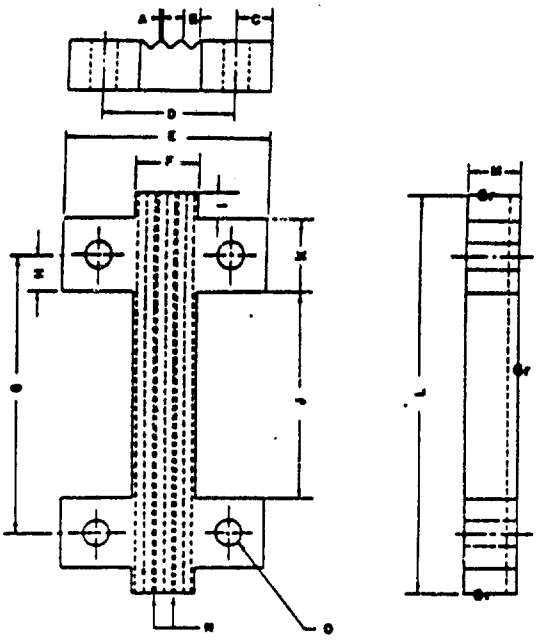


FIG. 3 Support Jig for This Specimen



LETTER	METRIC SYSTEM	BRITISH SYSTEM
A	.40 mm.	.0156 in.
B	3.18 /	.125
C	6.35	.250
D	23.8	.9375
E	38.5	1.4375
F	11.1	.4375
G	50.8	2.00
H	6.35	.250
I	4.76	.1875
J	38.1	1.500
K	12.7	.500
L	73.0	2.875
M	9.53	.375
N	3.58	.141
O	4.76 d.	.1875 d.

NOTE 1—Cold rolled steel.
NOTE 2—Furnished four steel machine screws and nuts, round head, slotted, length 31.75 mm (1¼ in.).
NOTE 3—Grind surfaces denoted "Gr."

FIG. 4 Support Jig, Details

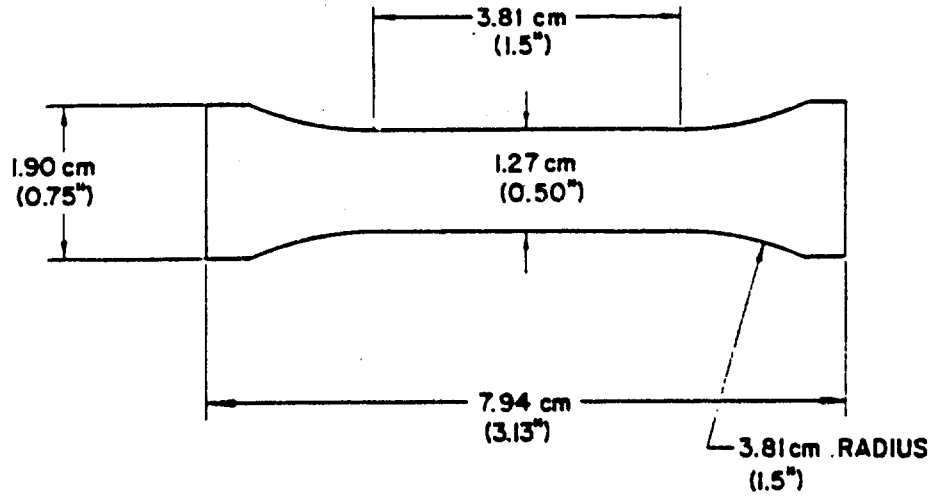


FIG. 5 Compression Test Specimen for Materials Less than 3.2 mm Thick

APPENDIX

(Nonmandatory Information)

X1. TOE COMPENSATION

X1.1 In a typical stress-strain curve (Fig. X1.1) there is a toe region, *AC*, that does not represent a property of the material. It is an artifact caused by a takeup of slack, and alignment or seating of the specimen. In order to obtain correct values of such parameters as modulus, strain, and offset yield point, this artifact must be compensated for to give the corrected zero point on the strain or extension axis.

X1.2 In the case of a material exhibiting a region of Hookean (linear) behavior (Fig. X1.1), a continuation of the linear (*CD*) region of the curve is constructed through the zero-stress axis. This intersection (*B*) is the

APPENDIX D

Material Manufacturer's Data

ULTEM® Processing Data

Polyetherimide Resin

GE Plastics
Technical Sales Service

General Electric Company
One Plastics Avenue Pittsfield, MA 01201
413 448-6341
Replex 413 448-7731

ULTEM: 1000 **AVAILABILITY: Europe, USA COMMERCIAL**

Unreinforced. 392F (200C) DTUL at 264 psi, UL94 V-0/5V rated.

EXTRUSION-USA

NOTE: Release grades (grade numbers ending in R), plate-out and/or die build-up may occur due to the internal release agent.

DRYING	4 hrs at 300F
TEMPERATURES (F)	
MELT	625-675
REAR 1	615-660
MIDDLE	625-675
FRONT	625-675
DIE PRESSURE (psi)	1200-20000
SCREW DESIGN	1.8 to 2.8:1.0 Compression Ratio 16 to 24:1 L/D
SCREW SPEED (rpm)	10-70

PURGE: HDPE or undried polycarbonate.

INJECTION MOLDING

DRYING - 4 hrs @ 300F, in trays (hopper dryer preferred while molding)

MELT TEMPERATURE (F) 640-800 (typically 675-725)

CYLINDER TEMPERATURES (F) Rear - 590-700 Front - 650-800
Center - 620-750 Nozzle - 650-775

MOLD TEMPERATURES (F) 250-350 (typically 275) increased mold temperature will increase flow, improve surface and reduce molded-in stress.

MOLDING PRESSURES (psig)

Booster (1st Stage)	1000-1800
Holding (2nd Stage)	800-1500
Back	50-200

SCREW DESIGN	1.5 to 3.0:1.0 compression ratio, 16 to 24:1 L/D
RAM SPEED	Medium to fast
CLAMP PRESSURE	2-4 tons psi -- unreinforced 4-6 tons psi -- glass reinforced
SCREW SPEED	50-200 rpm

PURGE: Fractional melt index - HDPE, glass reinforced polycarbonate. Begin purging at processing temperature and reduce barrel temperatures to about 500F while continuing to purge.

Source Eris, print date: 92/01/28, last updated: 92/01/27

THESE PROPERTY VALUES ARE NOT INTENDED FOR SPECIFICATION PURPOSES
ALL DATA SUBJECT TO STANDARD DISCLAIMER

P1PSD62 TSS

ULTEM® Product Data

Polyetherimide Resin

GE Plastics
Technical Sales Service

General Electric Company
One Plastics Avenue, Pittsfield, MA 01201
413 448-8341
Facsimile 413 448-7731

ULTEM: 1000 **AVAILABILITY: Europe, USA COMMERCIAL**

Unreinforced. 392F (200C) DTUL at 264 psi, UL94 V-0/5V rated.

PROPERTY	TYPICAL DATA	UNIT	METHOD
MECHANICAL			
Tensile Strength, yield, Type I, 0.125"	15200	psi	ASTM D 638
Tensile Elongation, yield, Type I 0.125"	7.0	%	ASTM D 638
Tensile Elongation, break, Type I 0.125"	60.0	%	ASTM D 638
Flexural Strength, yield, 0.125"	22000	psi	ASTM D 790
Flexural Modulus, 0.125"	480000	psi	ASTM D 790
Compressive Strength	21900	psi	ASTM D 695
Compressive Modulus	480000	psi	ASTM D 695
Shear Strength	15000	psi	ASTM D 732
Hardness, Rockwell M	109	-	ASTM D 785
Taber Abrasion, CS-17, 1 kg	10	mg/1000cy	ASTM D 1044
IMPACT			
Izod Impact, unnotched, 73F	25.0	ft-lb/in	ASTM D 256
Izod Impact, notched, 73F	1.0	ft-lb/in	ASTM D 256
Gardner Impact, 73F	27	ft-lbs	ASTM D 3029
THERMAL			
Vicat Softening Temp, Rate B	426	deg F	ASTM D 1525
HDT, 66 psi, 0.250", unannealed	410	deg F	ASTM D 648
HDT, 264 psi, 0.250", unannealed	392	deg F	ASTM D 648
Thermal Conductivity	0.22	W/m-C	ASTM C 177
CTE, flow, 0F to 300F	3.1 E-5	in/in-F	ASTM E 831
CTE, xflow, 0F to 300F	3.0 E-5	in/in-F	ASTM E 831
Thermal Index, Elec Prop	170	deg C	UL 746B
Thermal Index, Mech Prop with impact	170	deg C	UL 746B
Thermal Index, Mech prop without impact	170	deg C	UL 746B
PHYSICAL			
Specific Gravity, solid	1.27	-	ASTM D 792
Water Absorption, 24 hours @ 73F	0.250	%	ASTM D 570
Water Absorption, equilibrium, 73F	1.25	%	ASTM D 570
Mold Shrinkage, flow, 0.125"	7	in/in E-3	ASTM D 955
Poisson's Ratio	0.36	-	ASTM D 638
ELECTRICAL			
Volume Resistivity	1.0 E17	ohm-cm	ASTM D 257
Dielectric Strength, in air, 62 mils	831	V/mil	ASTM D 149
Dielectric Strength, in oil, 62 mils	710	V/mil	ASTM D 149
Dielectric Strength, in oil, 125 mils	500	V/mil	ASTM D 149
Dielectric Constant, 100 Hz	3.15	-	ASTM D 150
Dielectric Constant, 1 kHz	3.15	-	ASTM D 150
Dissipation Factor, 100 Hz	0.0015	-	ASTM D 150
Dissipation Factor, 1 kHz	0.0012	-	ASTM D 150
Dissipation Factor, 2450 MHz	0.0025	-	ASTM D 150
FLAME CHARACTERISTICS			
UL File Number, USA	E121562	-	-
94V-0 Rated (tested thickness)	0.016	in	UL 94
94-5VA Rating (tested thickness)	0.075	in	UL 94
CSA (See File for complete listing)	LR88480	File No.	CSA LISTED
Oxygen Index (LOI)	47.0	%	ASTM D 2863
NBS Smoke Density, flaming, Ds 4 min	0.7	-	ASTM E 662
NBS Smoke Density, flaming, Dmax 20 min	30.0	-	ASTM E 662

Source Eris, print date: 92/01/28, last updated: 92/01/27

THESE PROPERTY VALUES ARE NOT INTENDED FOR SPECIFICATION PURPOSES
ALL DATA SUBJECT TO STANDARD DISCLAIMER

P1PSD62 TSS

– Flame Characteristics – This rating is not intended to reflect hazards presented by this or any other material under actual fire conditions

Hoechst Celanese

Fortron®

Polyphenylene Sulfide (PPS)

Processing Guide (FN-6)

Table of Contents

Introduction

This is a general guide to molding FORTRON polyphenylene sulfide resins, a family of high temperature, flame retardant thermoplastics with exceptional electrical properties. While this brochure contains essential information required by molders, it is also recommended that molders discuss their particular requirements for resins and equipment with a FORTRON technical representative, prior to molding an unfamiliar formulation.

FORTRON polyphenylene sulfide resins are easy to process, and fill molds readily, since all grades are internally lubricated. Customer colors are available to order, and color concentrates are also available for molders who wish to color compound on their injection molding machines. FORTRON polyphenylene sulfide resins are available in a wide variety of grades.

General Precautions When Molding Fortron®

No particular hazards have been identified when molding FORTRON resins, provided that standard industry safety practices are followed. Like most thermoplastics, FORTRON will decompose and give off decomposition products if heated to very high temperatures. However, FORTRON is stable up to 700°F (370°C), well above the limits of most polymers. As a precaution, sufficient ventilation should always be provided.

To avoid thermal decomposition, evolution of fumes, and excessive loads on the molding machine, melt temperatures should not exceed 700°F (370°C), which is well above the normal processing range. FORTRON should not be maintained at processing temperatures for long periods of time. It is recommended that the molding machine be shutdown, if it is idle for 15 minutes or more. This is usually sufficient time to allow for process adjustments.

Upon start-up the operator should allow adequate heating up time such that the barrel zone temperatures reach the set point temperatures before feeding the FORTRON pellets, or rotating the screw. The operator should wear eye safety protection, especially during injection purging. The operator should also use proper gloves, and other appropriate garments for handling hot equipment, and to prevent exposure of the skin to molten polymer. The operator should retract the injection unit during shutdown to avoid nozzle freeze-up from contact with the mold.

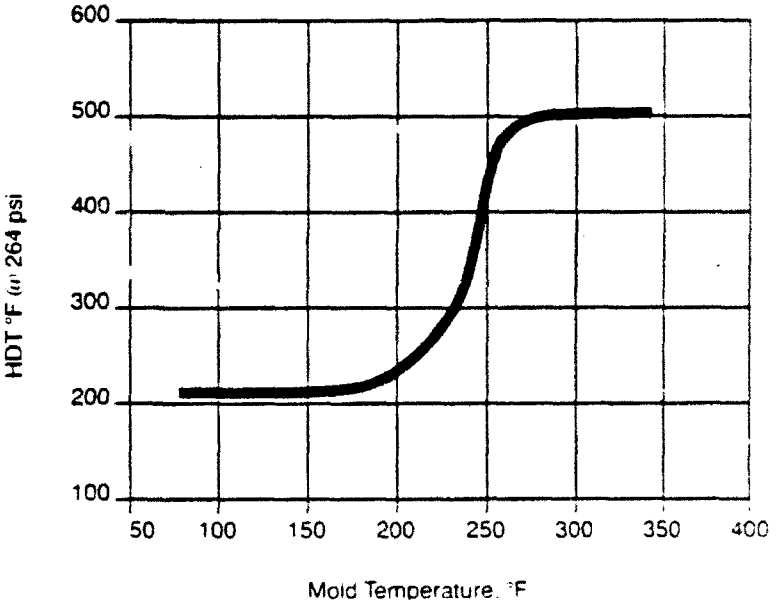
Material Safety Data Sheets (MSDS) are available for all FORTRON grades, and should be consulted prior to molding.

Molding Equipment

FORTRON polyphenylene sulfide resins are best molded on reciprocating injection-screw injection molding machines with a horizontal plasticating unit. To ensure the correct work input to melt and mix the resin a plasticating screw with a channel depth ratio from 2 to 3 is preferred.

To obtain the maximum properties from FORTRON resins the injection mold must be heated above 275°F (135°C). This will ensure adequate crystallization. The relationship of mechanical properties to mold temperature shows high sensitivity from 200°F (93°C) to 300°F (150°C), as shown in figure 1. To ensure the maximum properties the mold must therefore be heated by oil or electric cartridge heaters to maintain the 275°F (135°C) minimum temperature. Finally to ensure adequate flow, a nozzle with an orifice diameter greater than ¼ inch should be fitted to the barrel. A suck-back of up to a ½ inch may be required on the molding machine to eliminate drooling. In cases of excessive drooling (e.g. vertical press) reverse taper nozzles or nozzles with shut-off valves may also be used.

Figure 1 — Effects of Mold Temperature on Mechanical Properties



Drying Procedures

Although FORTRON resins do not absorb high percentages of atmospheric moisture, it is recommended that exposure to ambient air be kept to a minimum.

FORTRON resins should be dried before molding, to reduce the possibility of hydrolytic degradation, to minimize drooling from the nozzle, and ensure a good surface appearance. The following procedures will produce an acceptable moisture level.

Using a dehumidifying air drier, or oven, the resin should be dried for 3–4 hours at 250–275°F (121–132°C).

To limit moisture regain, a hopper drier is preferred.

Table 1 — Typical Machine Settings for FORTRON® resins

Stock (melt) temperature	590-640°F (310-338°C)
Mold temperature	275-325°F (135-163°C)
Zone temperatures	
Rear	585-635°F (307-335°C)
Middle	590-640°F (310-338°C)
Front	600-640°F (315-338°C)
Nozzle temperature	600-640°F (315-338°C)
Injection pressure	5000-15000 psi (34-104 MPa)
Screw speed	Minimum
Back pressure	Minimum
Cushion	⅛ inch (3mm)
Suck-back	Up to ½ inch (12mm), if required

Start-Up Procedure

The operator should allow the molding machine to stabilize for ½ hour at the recommended zone temperatures before rotating the screw.

The molding machine should then be purged with polypropylene at the recommended temperatures for molding FORTRON. Once purged, FORTRON may be fed to the unit and injection purged until only FORTRON is present in the plasticating unit. The melt temperature should be checked to ensure it is within the recommended range.

Molding Conditions

The machine settings required to mold satisfactory parts from FORTRON resins will vary depending upon the part design, the mold, the machine and the specific FORTRON grade being molded.

Typical settings which may be used in molding FORTRON appear in Table 1. Stock temperature should be checked with a pyrometer to ensure that it falls within the recommended range. Machine settings should be adjusted if necessary to ensure that the melt temperature remains within the recommended range of Table 1.

For optimum performance, the residence time of the molten FORTRON in the barrel should be five minutes or less. Shot sizes 30 to 70% of machine barrel capacity provide recommended residence times.

Mold Temperature

The most critical parameter for molding FORTRON resins to ensure adequate crystallization in order to obtain optimum properties, the mold temperature should exceed 275°F (135°C). This high mold temperature also provides excellent surface appearance and minimizes post-mold shrinkage. To achieve this mold temperture, oil circulating heaters or electric cartridge heaters should be employed.

Back Pressure

A minimum setting for the back pressure on the screw should be maintained. This is especially important when molding fiber-reinforced grades to minimize fiber breakage and excessive shear heating.

Cooling Times

Cooling times depend on the size, shape, wall thickness and complexity of the molded part, as well as the machine settings and mold design. For comparison purposes a part with a ⅛ inch thickness requires from 25 to 30 seconds overall cycle. Due to the relatively hot mold temperature, the high-strength Fortron parts are ejected quite hot, but without distortion.

Regrind

FORTRON is able to substantially retain its properties after several moldings. For this reason, up to 25% uncontaminated FORTRON regrind may be mixed with virgin resin, and the resultant moldings will exhibit only slight property loss (less than 10% of original mechanical properties). Drying of regrind and homogeneously mixing it back into the virgin FORTRON are recommended.

Cushion

The shot size should be adjusted to allow a cushion between ⅛ to ¼ inch at the end of the injection stroke. This will compensate for feed variations from shot-to-shot.

Shut-Down Procedure

The operator should purge the molding machine with polypropylene at FORTRON molding temperatures, immediately after molding FORTRON. This should be continued until no FORTRON remains in the plasticating unit. The zone temperatures may then be lowered.

The operator should shut down the molding machine with the screw in the forward position. This will reduce the time required to heat the residual purge material when the molding machine is restarted.

FORTRON should never be left in the barrel, since the heat required to remelt the residual FORTRON may exceed the heater band capability. The molding machine would require disassembly to remove any residual FORTRON.

It is recommended that the molding machine be shutdown, if it is to be idle for 15 minutes or more. Injection purging may be conducted intermittently to remove degrading polymer and maintain fresh charges in the plasticating unit.

Mold Design

Although FORTRON presents no unusual difficulties for mold designers, it is recommended that prior to constructing a prototype or production mold, a HOECHST CELANESE Technical Service Engineer be consulted. This will allow the mold designer to take advantage of the expertise in FORTRON mold design that has previously been developed.

Flow length

All FORTRON grades have low melt viscosities and readily fill injection molds. For comparison purposes, mold designers are referred to Table 2 where the flow length of FORTRON is presented under typical molding conditions. The spiral channel employed had dimensions of 0.125" × 0.250", and the Fortron was molded at 610°F stock temperature, 275°F mold temperature, with 8000 psi injection pressure.

Table 2 — Spiral Flow Length

Fortron® PPS Grade	Spiral Flow in inches to nearest .25 in.
1140A1 (40% glass)	16.00
1140A4 (40% glass)	24.50
1140L4 (40% glass)	17.75
6165A4 (65% min/glass)	12.00

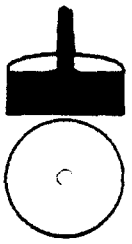
Mold materials

FORTRON polyphenylene sulfide is non-corrosive to all standard materials used in mold construction. Some reinforcements and fillers may cause abrasive wear. When molding filled grades of FORTRON it is recommended that wear resistant materials be used for surfaces which contact the resin, just as with other filled resins. Mold cavities should be hardened to RC50-55 for filled grades of FORTRON.

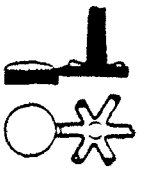
Gate location

Gates should be located to provide a flow that is uniform and uninterrupted. To minimize the weakness intrinsic to weld lines, the number of gates should be held to a minimum. When multiple gates are necessary they should be placed so that the weld lines in the product are formed in areas of minimal load. Where possible adjacent flow fronts should be forced to meet at an acute angle to form a meld line. The bonds at the meld line are inherently stronger than those at the weld line formed when the flow fronts meet from opposite directions. Venting at the weld line will also promote stronger welds.

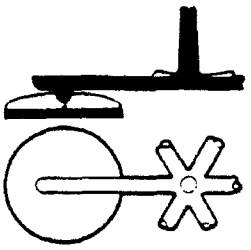
Figure 2 Various Gate Types Used in Injection Molds



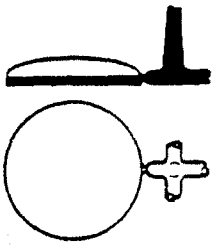
Sprue: Provides simplicity for single cavity molds and symmetry on circular shapes. Suitable for thick sections.



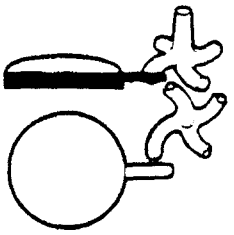
Side or Edge: Provides simplicity for multicavity molds. Suitable for medium and thick sections.



Pin (3 plate tool): Used to minimize finishing where edge gating is undesirable and for automatic degating. Only suitable for thin sections.

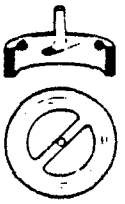


Restricted or Pin: Provides simple degating and finishing. Only suitable for thin sections.

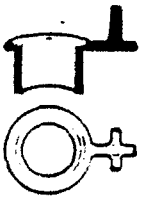


Tab: Used to stop "jetting" when other means are not available and when a restricted gate is desired. Also enables area of greatest strain to be removed from the molding.

Diaphragm: Used for single cavity concentric moldings of ring shape with medium or small internal diameter.



Internal Ring: Similar to diaphragm gate. Used for molds with large internal diameters or to reduce (sprue/runner) to molding ratio.



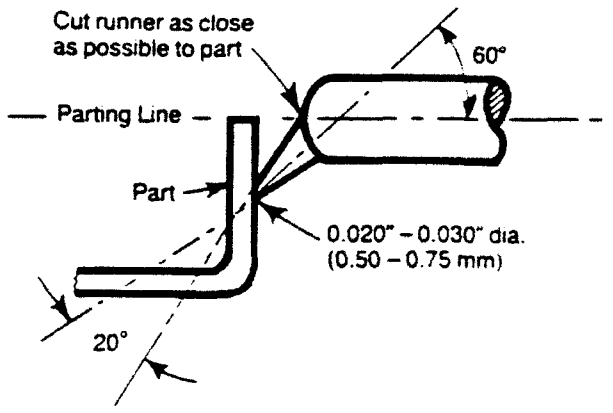
External Ring: Used for multicavity concentric moldings of ring shape or where diaphragm gate cannot be used.

Gate sizes

The size of the gate is related to the nominal wall thickness. Gates should always be at least as wide as they are deep.

The high flow of Fortron materials permits the use of very small gate sizes (as low as 0.002 sq. in.). For example, pinpoint gates are typically 0.040 to 0.070 in. in diameter. This smaller gate area minimizes gate vestige and also provides satisfactory part separation from the runner. For edge gates, a typical starting point is 50% of the nominal wall thickness. Land lengths should be as short as possible to eliminate pressure drop across the gate.

Figure 3 — Submarine Gates



Gate types

Any kind of gate may be used for molding FORTRON polyphenylene sulfide. Some examples of suitable gate types are shown in Figure 2. If a submarine gate is selected it should conform approximately to the geometry recommended in Figure 3.

Runner systems

Full round runners with diameters as small as ¼ inch (6mm) may be used for molding FORTRON. Equivalent trapezoidal runners may also be used, when only one mold half can be used for the runner system. Due to Fortron's processing sensitivity, it is imperative when using a multi-cavity mold that the runner system is balanced to ensure that all cavities finish filling simultaneously.

Vents

Vents should be located in all sections of the mold cavity where air may become trapped by the molten FORTRON, particularly in the last areas to fill. The low viscosity of FORTRON dictates that shallow vents be used. A depth of about 0.0003 inch (0.007mm) is recommended. Inadequate venting will entrap gas causing incomplete filling, burn marks, and/or poorer weld line strength.

Shrinkage

Melt temperature, mold temperature, injection pressure, hold time and part design all influence shrinkage. Due to the high filler loading, shrinkage of Fortron materials are very low and predictable. Some typical shrinkage values appear in Table 3 as a guide to the mold designer. Less shrinkage is exhibited in the flow direction than the transverse direction due to glass orientation effects. Gate location and number of gates also are an important factor in minimizing the differential shrinkage rate to prevent warpage and bowing.

Table 3 — Approximate Mold Shrinkage

	Mold shrinkage (in./in.)
Flow direction	0.001–0.003
Transverse direction	0.003–0.006

Weld lines

Weld lines are created whenever two or more flow fronts meet. Weld lines exhibit lower mechanical properties than those of the base resin. This is particularly acute when materials contain fibrous reinforcements since the reinforcing fibers cannot reinforce the weld line. If possible, a single gate is recommended. This minimizes the number of weld lines, and also provides less complicated part filling characteristics. Glass orientation, shrinkage, warpage, and vent locations are now easier to predict.

Mold heating

When molding FORTRON polyphenylene sulfide, oil circulating heaters or electric cartridge heaters should be used to allow the mold temperature to reach the recommended range of 275–325°F (135–163°C). The oil channels, and cartridge heaters should be placed about one channel/heater diameter from the surface of the mold cavity and should be placed 3–5 diameters apart. Enough channels/heaters should be used to ensure that the mold cavity reaches a uniform temperature. Insulation for the mold could also be used to reduce heat loss and energy requirements.

Trouble Shooting Guide for Molding Fortron

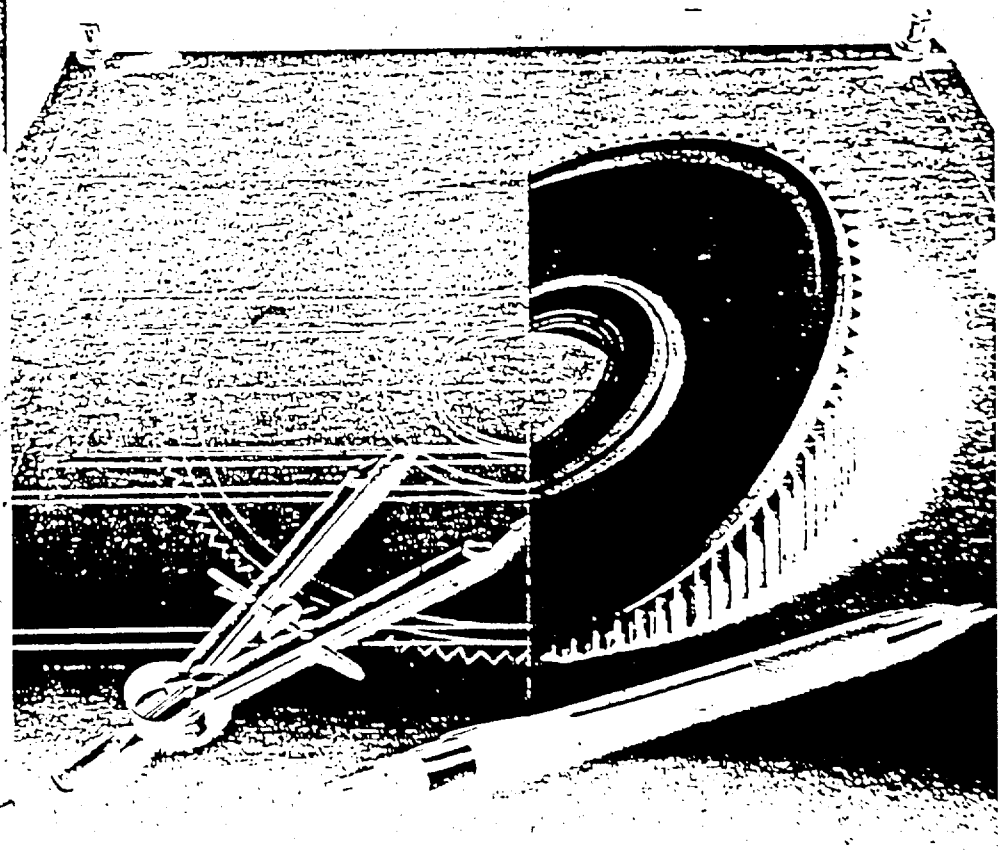
Corrective actions are suggested for the majority of the molding problems that may occur with FORTRON resins. These actions are suggested with the most likely and/or easiest remedy first. As with any problem, confirmation that the machine is operating within the recommended parameters for the specific FORTRON grade is strongly urged. The stock temperatures should also be confirmed

Problem	Suggested Corrective Action
Short Shots	1. Increase feed
	2. Increase injection pressure
	3. Use booster and increase ram speed
	4. Improve venting
	5. Raise material temperature by: a) raising cylinder temperature c) raising back pressure b) increasing screw speed
	6. Raise mold temperature
	7. Increase overall cycle
	8. Increase size of sprue and or runners and/or gates
Flashing	1. Lower material temperature by: a) lowering cylinder temperature b) decreasing screw speed c) lowering back pressure
	2. Decrease injection pressure
	3. Decrease overall cycle
	4. Decrease plunger forward time
	5. Check mold closure
	6. Improve mold venting
	7. Check press platens for parallelism
Burn Marks	1. Decrease plunger speed
	2. Decrease booster time
	3. Decrease injection time
	4. Improve venting in mold cavity
	5. Alter position and/or increase gate size
Sticking In Cavities and/or Bushing	1. Decrease injection pressure
	2. Decrease plunger forward time
	3. Decrease booster time
	4. Adjust feed for constant cushion
	5. Increase mold closed time
	6. Lower mold temperature
	7. Decrease cylinder and nozzle temperature
	8. Check mold for undercuts and/or insufficient draft
Weld Lines	1. Increase injection pressure
	2. Increase injection forward time
	3. Raise mold temperature
	4. Raise material temperature
	5. Vent the cavity in the weld area
	6. Provide an overflow well adjacent to the weld area
	7. Change gate location to alter flow pattern
Poor Surface Appearance	1. Raise mold temperature
	2. Increase injection pressure
	3. Use booster and increase ram speed
	4. Raise material temperature by: a) raising cylinder temperature b) increasing screw speed c) raising back pressure

Problem	Suggested Corrective Action
Nozzle Freeze Off	1. Raize nozzle temperature
	2. Raise mold temperature
	3. Insulate nozzle from sprue bushing
	4. Raise material temperature by: a) raising cylinder temperature b) increasing screw speed c) raising back pressure
	5. Decrease soak time
Nozzle Drool	1. Lower nozzle temperature
	2. Lower material temperature by: a) lowering cylinder temperature b) decreasing screw speed c) lowering back pressure
	3. Decrease residual pressure in cylinder by: a) reducing plunger forward time b) increasing decompress time
	4. Decrease overall cycle time
	5. Dry the material
	6. Use nozzle with smaller orifice
	7. Use reverse-taper nozzle of nozzle valve
Discoloration	1. Purge heating cylinder
	2. Lower material temperature by: a) lowering cylinder temperature b) decreasing screw speed c) lowering back pressure
	3. Lower nozzle temperature
	4. Shorten overall cycle
	5. Check hopper and feed zone for contaminants
	6. Provide additional vents in mold
	7. Move mold to smaller shot size press
Sinks and/or Voids	1. Increase injection pressure (hold)
	2. Increase injection speed
	3. Increase size of gates and/or sprue and/or runners
	4. Relocate gates nearer heavy sections
	5. Raise mold temperature (voids)
	6. Lower mold temperature (sinks)
	7. Decrease cushion
Warpage Distortion	1. Equalize temperature in both halves of mold
	2. Observe mold for uniformity of ejection
	3. Increase injection pressure
	4. Try higher and lower mold temperatures
	5. Increase die closed time
	6. Lower material temperature
Poor Dimensional Control	1. Maintain uniform feed and cushion from cycle to cycle
	2. Fill mold as rapidly as possible
	3. Balance cavities for uniform flow
	4. Increase gate size
	5. Check machine hydraulic and electrical systems for erratic performance
	6. Reduce number of cavities
	7. Maintain uniform cooling rate

Design Guide (EN-10)

Designing With Fortron®
Polyphenylene Sulfide



Engineering Plastics Division

Hoechst Celanese

Hoechst

Foreword

This first edition of the *Fortron® PPS Design Manual* represents a compilation of design information to provide general guidelines for broad classes of Fortron® PPS material. We hope that this publication enables the designer to better understand the behavior of this high-performance material. Thus, after a brief overview (Ch. 1), the following chapters deal with the behavior of Fortron® PPS with regard to its physical and thermal properties (Ch. 2), mechanical properties (Ch. 3), dimensional stability (Ch.4), its behavior in chemical environments (Ch. 5), and its electrical properties (Ch. 6). The book then discusses fundamental design criteria both for part design and for tool design (Ch. 7), recommended methods and specifications for assembly (Ch. 8), and finally, secondary operations with Fortron® PPS (Ch. 9).

For a discussion of general issues to be considered in designing for plastic parts, the reader is encouraged to study *Designing with Plastic: The Fundamentals* (TDM-1), which is also published by the Engineering Plastics Division of Hoechst Celanese Corporation. Grade-specific information is not given in the *Fortron® PPS Design Manual*, which is a product-specific publication. For grade-specific information, the reader is referred to Fortron® Material Monographs in the area of specific interest, e.g., tensile strength, stress–strain data, fatigue data, and long-term properties of specific grades of Fortron® PPS.

This layered structure of publications enables the Engineering Plastics Division of Hoechst Celanese Corporation to provide detailed, product-specific information more quickly and efficiently than incorporating all such information in one large volume, when often only small parts of such a publication are needed by the designer. Such a structure also allows for quick updates as specific product data are made available.

We hope that this manual helps you, the design engineer, to more accurately predict the behavior of Fortron® PPS, and thus, to better design with this high-performance polymer. We welcome your comments and suggestions for improving this manual in future editions.

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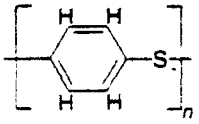
Table of Contents

Chapter 1

Overview

Chemistry of Fortron® PPS

Fortron® products are based on a linear poly(phenylene sulfide) (PPS) polymer, produced by a polycondensation reaction of *p*-dichlorobenzene and sodium sulfide. The reaction yields a PPS polymer with the following structure:



General Characteristics of Fortron® PPS

The structure of Fortron® PPS polymer contributes to the following properties:

- High thermal stability
- Excellent chemical resistance
- Inherent flame resistance in the molecule without the addition of halogens
- Excellent electrical properties
- Excellent flow

Fortron® PPS is further distinguished from highly branched PPS products by the following performance advantages:

- Higher elongation and impact strength
- Higher weld line strength
- Lower ionic impurities in base resins and filled products
- A natural color of light beige for the Fortron® PPS base resin for easier coloring

Most designers choose Fortron® PPS because it demonstrates a valuable combination of properties relative to the load-bearing capabilities and dimensional stability when exposed to chemicals and high-temperature environments.

Reinforcements and Fillers

When fillers, such as glass fibers, minerals, or mixtures of these, are added to the base resin, the load-bearing capability, represented by the heat distortion temperature (HDT), is also raised. The HDT of Fortron® unreinforced PPS is generally 221°F (105°C) at 264 psi, while that of a reinforced Fortron® PPS is 500+°F (260+°C). Because of this added value and Fortron® PPS's affinity for fillers, the majority of PPS applications use glass-reinforced or mineral/glass-filled systems.

Flash

All PPS compounds inherently exhibit some degree of flash, especially in applications requiring the filling of thin walls over long distances with relatively high pressures. Selection of the proper grade of Fortron® PPS and the use of proper injection molding conditions will aid in minimizing flash. In addition, gate location can be used to decrease the high pressures associated with flash (see "Gate Location" subsection in Chapter 7).

Product Support

Experienced field engineers and design engineers are available to assist you with product design, material specification, and molding trials. For further information or assistance, please contact your representative from the Hoechst Celanese Engineering Plastics Division offices listed on the back cover of this publication.

Agency Approvals

Fortron® PPS has been granted ratings by Underwriters Laboratories of UL-94V0 to 0.031 in. (0.79 mm) thickness and UL-94-5VA at 0.125 in. (3.18 mm) on many filled grades, as well as ratings of A00 and V0 by the CSA (Canadian Standards Agency). UL yellow cards are available upon request. Some Fortron® PPS grades have also been approved under Military Specifications M-24519 and M-46174 (ASTM D4067).

Safety and Health Information

The usual precautions employed in working with high-melting plastics should be observed in working with Fortron® polymers.

Consult the current Material Safety Data Sheet (MSDS) prior to use for detailed safety and health information concerning specific Fortron® PPS grades.

Use process controls, work practices, and protective measures described in the MSDS to control workplace exposure.

MSDSs have been developed by Hoechst Celanese Corporation, Engineering Plastics Division, to provide our customers with valuable safety, health, and environmental information. A copy of the MSDS for each specific Fortron® PPS grade is available upon request. Please contact your local sales office or call the Technical Information number given at the end of this publication.

Chapter 2

Physical and Thermal Properties

This chapter describes some of the basic characteristics of Fortron® PPS and its thermal capability. The thermal properties discussed here, and shown in Table 1, are due to short-term testing. Long-term thermal properties, such as time–temperature effects both without load (heat aging) and with a load (creep modulus), are discussed in Chapter 3.

The reader is encouraged to review sections of this manual that deal with the thermal stability of Fortron® PPS products, as well as sections that show how dimensional accuracy depends on thermal changes. Finally, a general review of Chapter 4 of *Designing with Plastic: The Fundamentals* (TDM-1) may help the designer deal with the thermal requirements of an application.

Table 1 Thermal and physical properties of Fortron® PPS

Property	Units	40% Glass	65% Mineral/ Glass	Unfilled
Specific Gravity		1.64	1.99	1.35
Melt Specific Heat	J/g°C	1.5	1.6	
Glass Transition Temperature	°C	90	90	90
Crystallization Temperature (Peak)	°C	125	125	125
Melt Recrystallization Temperature (Peak)	°C	220	215	190-250*
Melt Temperature	°C	282	282	282
Heat Deflection Temperature, @ 264 psi	°C	260+	260+	105
Thermal Conductivity	W/m°K			
@ 25°C		0.2	0.3	
@ 125°C		0.2	0.35	
@ 230°C		0.25	0.35	
@ 300°C		0.25	0.35	0.3

* Please note that this range represents the values for a number of different polymers, not a range for one polymer.

Crystallinity

Fortron® PPS is a semicrystalline polymer that consists of both amorphous and crystalline regions. The crystalline regions of neat Fortron® PPS account for 60–65% of the polymer. With the combination of a high degree of crystallinity and its aromatic structure, Fortron® PPS exhibits a high melt temperature of 285°C (545°F). The polymer crystallizes rapidly above the T_g, as indicated by an exothermic crystallization peak at 120–130°C, as seen in Table 1. From the melt, recrystallization also occurs rapidly at 215–220°C, also seen in Table 1.

Glass Transition Temperature (T_g)

The glass transition temperature, T_g, is the temperature at which the amorphous regions of the polymer become mobile. The significance of this value is that above T_g (about 90°C for Fortron® PPS products), the load-bearing capability is reduced. This is illustrated by the results from a dynamic mechanical thermal analysis (DMTA), a powerful technique used to indicate the stiffness of a molded part as a function of temperature and load. Results from the DMTA cover a range of loads and temperatures.

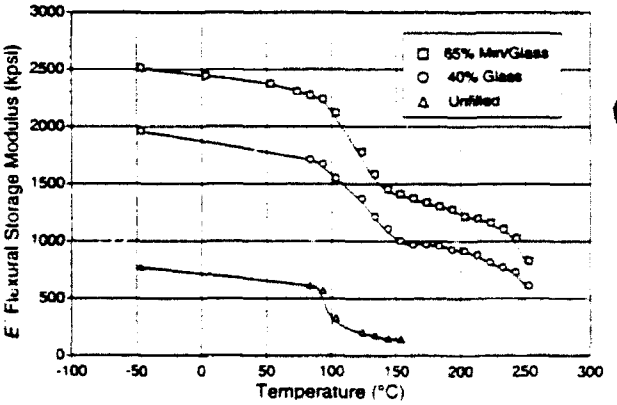


Figure 1 Flexural storage modulus vs. temperature for Fortron® PPS

The flexural storage modulus (E') is one such curve generated by a DMTA for evaluating the load-bearing capability of a material. Figure 1 illustrates the change in stiffness of Fortron® PPS at temperatures both below and above the T_g.

Thermal Degradation via Thermogravimetric Analysis (TGA)

Thermogravimetric analysis is a technique used to evaluate a material's thermal stability. In this test the material is heated until it is melted completely and finally degraded. During the heating process, the weight of the sample is measured at various exposure temperatures. The curve seen in Figure 2 shows that thermal oxidation of 40% glass-reinforced Fortron® PPS occurs well after the melt temperature.

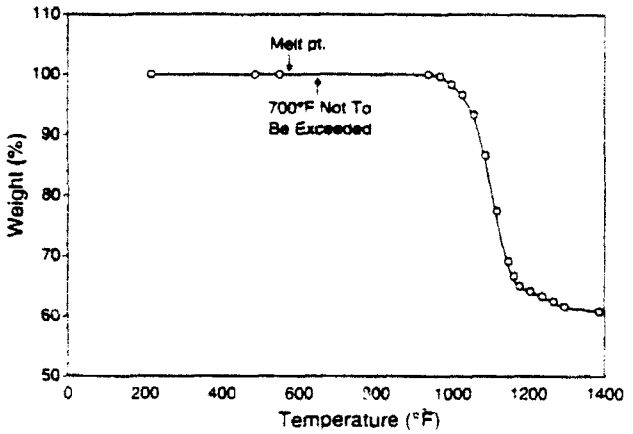


Figure 2 Weight loss vs. temperature for 40% glass-reinforced Fortron® PPS

No particular molding hazards have been identified for molding Fortron® polymers, provided that standard industry practices are followed. Like most thermoplastics, Fortron® PPS will decompose to give off decomposition products, including carbon dioxide, carbon monoxide, sulfur oxides, hydrogen, and methane, if heated to very high temperatures (>700°F). However, Fortron® PPS is stable up to 700°F (370°C), well above the limits of most polymers. As a precaution, sufficient ventilation should always be provided.

To avoid thermal decomposition and evolution of fumes, melt temperatures should not exceed 700°F (370°C), which is well above the normal processing range. Fortron® PPS should not be maintained at processing temperatures for long periods of time. It is recommended that the molding machine be shut down if it is to be idle for 15 min or more.

Oxygen Index

Since the normal atmosphere contains about 21% oxygen, a minimum oxygen index of 28% is required to qualify for a flammability rating of Self-Extinguishing (ASTM D2863). The oxygen index for 40% glass-reinforced Fortron® PPS is 47%, and that for 65% mineral/glass-reinforced Fortron® PPS is 53%, indicating these materials' excellent, inherent flame resistance properties.

Smoke Density

Specimens of 40% glass-reinforced and 65% mineral/glass-reinforced Fortron® PPS were prepared and tested according to procedures established by the National Bureau of Standards (NBS). Flaming and smoldering tests were performed in an NBS smoke density chamber. The results of these tests are presented in Table 2.

The obscuration time is the time for a typical room to reach such a critical smoke density that an occupant's vision would be impaired by smoke and thus hinder his/her escape. This critical level of smoke density or specific optical density (Ds) for obscuring vision is 16.

The test exposes a 3 X 3 in. sample to a circular foil radiometer heat source under flaming or smoldering conditions. Both the heat source and the sample are enclosed in a 3 X 3 X 2 ft cabinet. The smoke density is then measured in terms of light absorption by a photometer.

Table 2 Smoke density data for Fortron® PPS

	Flaming		Smoldering	
Property	40% Glass	65% Mineral/ Glass	40% Glass	65% Mineral/ Glass
Max. Value of Specific Optical Density (Dm)	95	44	12	10
Dm, corrected (Dmc)	91	42	11	9
Specific Optical Density @ 1.5 min	1	[illegible]	0	0
Specific Optical Density @ 4.0 min	18	4	0	1
Obscuration Time (min) (Time to Ds = 16)	4.1	7.1	—	—

Mechanical Properties

Properties that account for the load-bearing capability of a material are especially important to the designer for determining the proper wall thickness of a geometric part.

The following discussion is presented so that the designer will be able to account for the various effects that temperature, loads, molding conditions, etc. will have on the properties related to structural design.

Poisson's Ratio

Poisson's ratio, ν, is the ratio of lateral strain to longitudinal strain. The value of Poisson's ratio is 0.38 for unfilled Fortron® PPS and 0.35 for glass-reinforced and mineral/glass-reinforced Fortron® PPS.

Stress–Strain Properties

Figures 1 and 2 demonstrate the stress–strain behavior of 40% glass-reinforced and 65% mineral/glass-reinforced Fortron® PPS products at various temperatures. At room temperature the behavior approaches that of an elastic (Hookean) response, due to its high degree of crystallinity and high filler content. At temperatures above T_g, the properties show relatively lower values (see Chapter 2, Glass Transition Temperature section, for explanation).

Temperature Dependence of Mechanical Properties

Knowledge of the dependence of a polymer's mechanical properties on temperature is essential in designing

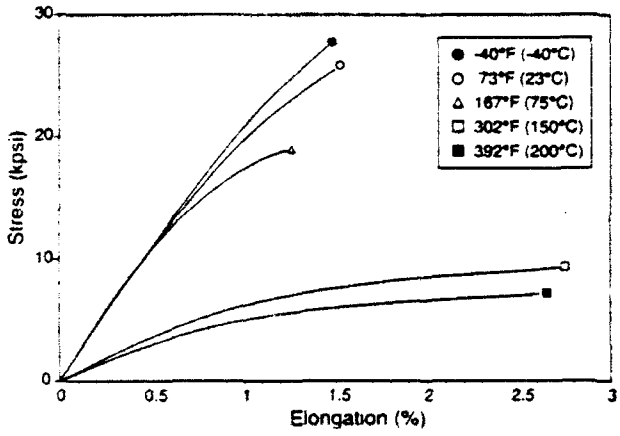


Figure 1 Stress–strain behavior of 40% glass-reinforced Fortron® PPS

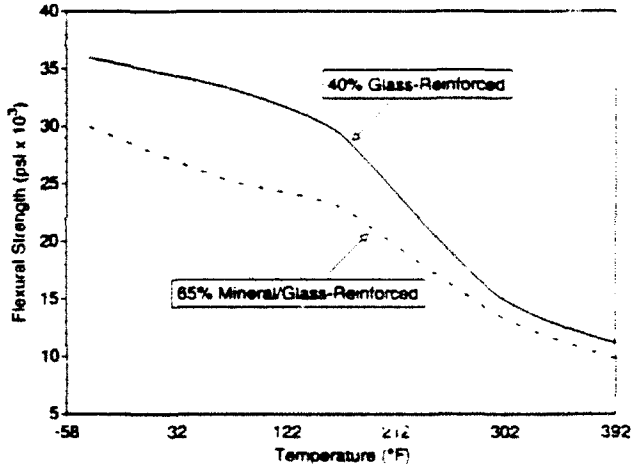


Figure 3 Temperature dependence of flexural strength

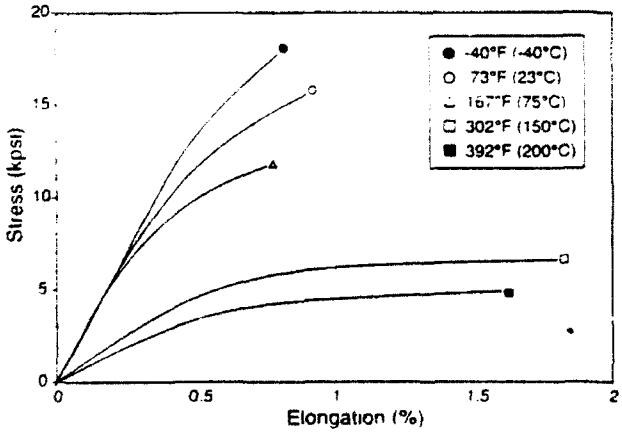


Figure 2 Stress–strain behavior of 65% mineral/glass-reinforced Fortron® PPS

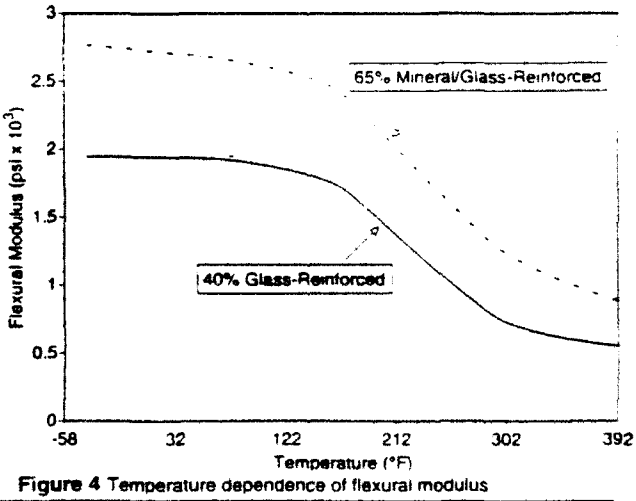


Figure 4 Temperature dependence of flexural modulus

Chapter 3

Mechanical Properties

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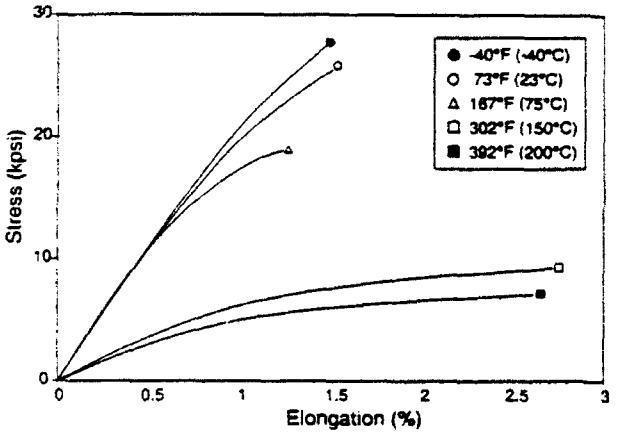


Figure 1 Stress–strain behavior of 40% glass-reinforced Fortron® PPS

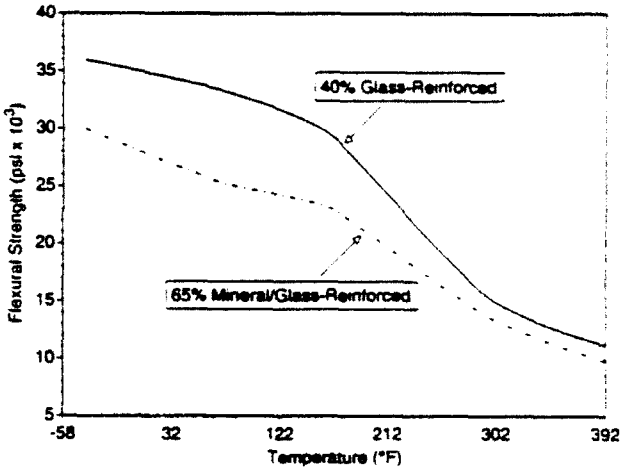


Figure 3 Temperature dependence of flexural strength

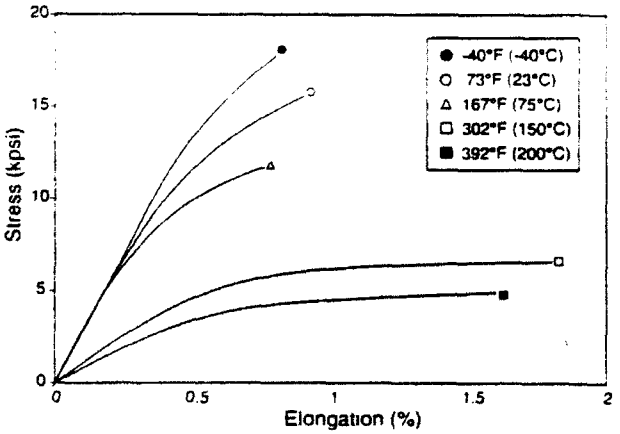


Figure 2 Stress–strain behavior of 65% mineral/glass-reinforced Fortron® PPS

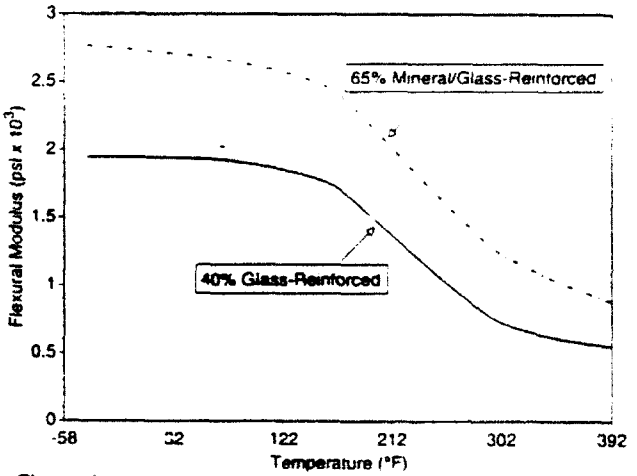
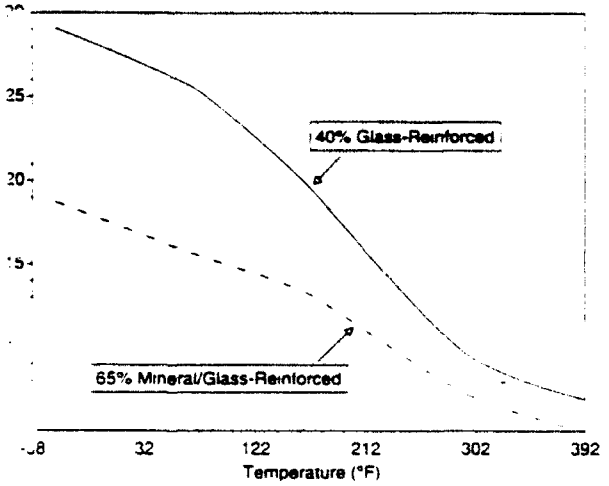


Figure 4 Temperature dependence of flexural modulus



e 5 Temperature dependence of tensile strength at break

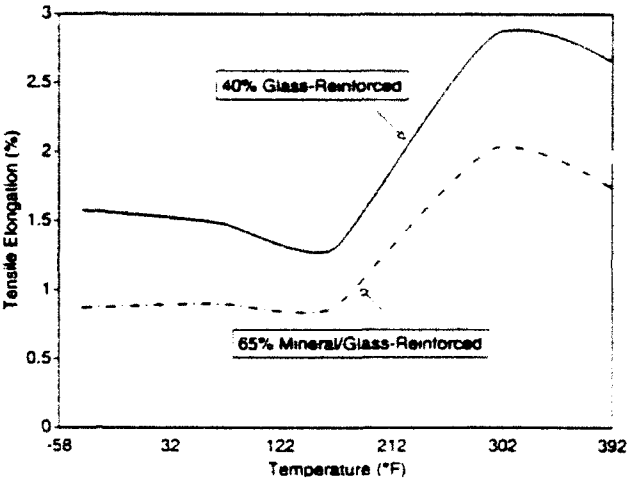


Figure 6 Temperature dependence of tensile elongation at break

n that material. Figures 3–6 show the temperature
ndence of the flexural strength (Fig. 3), flexural
lus (Fig. 4), tensile strength (Fig. 5), and tensile
ngation (Fig. 6) of 40% glass-reinforced and 65%
eral/glass-reinforced Fortron® PPS.

Aging

tron® PPS shows little significant change in mechani-
operties after prolonged exposure to elevated
ratures. Many Fortron® PPS grades have been
nted Relative Thermal Index (RTI) values of 200–
°C (392–446°F) by Underwriters Laboratories. It is
cant that these values are higher than those of
other plastics (thermoplastics and thermosets).

p Modulus

n® PPS polymers demonstrate outstanding creep
perties below T_g (ca. 90°C). Even at elevated tem-
res, the creep modulus of Fortron® PPS is
ent when compared to that of other high-perfor-
ce polymers.

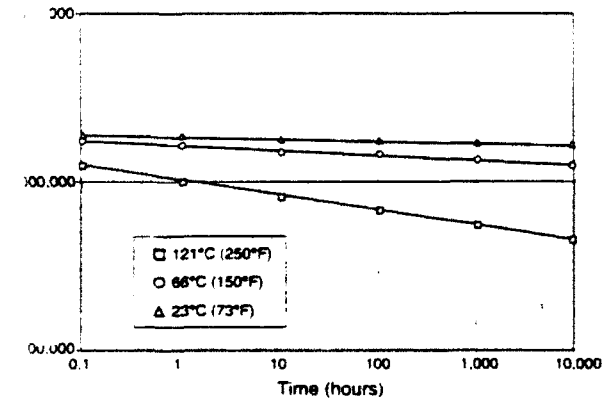
Figures 7 and 8 show the creep modulus in three-point bending of 40% glass-reinforced (Fig. 7) and 65% mineral/glass-reinforced (Fig. 8) Fortron® PPS at temperatures ranging from 23 to 120°C (72 to 250°F) under an applied stress of 5000 psi for 10,000 h.

Compressive Creep

Compressive creep data of 40% glass-reinforced Fortron® PPS are seen in comparison with those of several other thermoplastic and thermoset materials, at 200°F for 16 h (Fig. 9A) and 300°F for 24 h (Fig. 9B) under 10,000 psi applied stress.

Molding Temperature Effects

In order to achieve optimal load-bearing capabilities at elevated temperatures, optimal dimensional stability, and a glossy surface appearance, it is necessary to use a mold temperature of at least 275°F. Such a temperature requires the use of electric or, preferably, oil heating systems to maximize the crystallinity. Table 1 shows the



r 7 Creep modulus in three-point bending of 40% glass-
rced Fortron® PPS; stress = 5000 psi

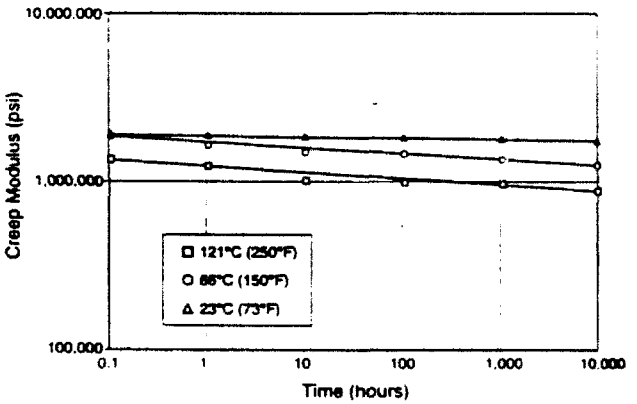


Figure 8 Creep modulus in three-point bending of 65% mineral/glass-reinforced Fortron® PPS; stress = 5000 psi

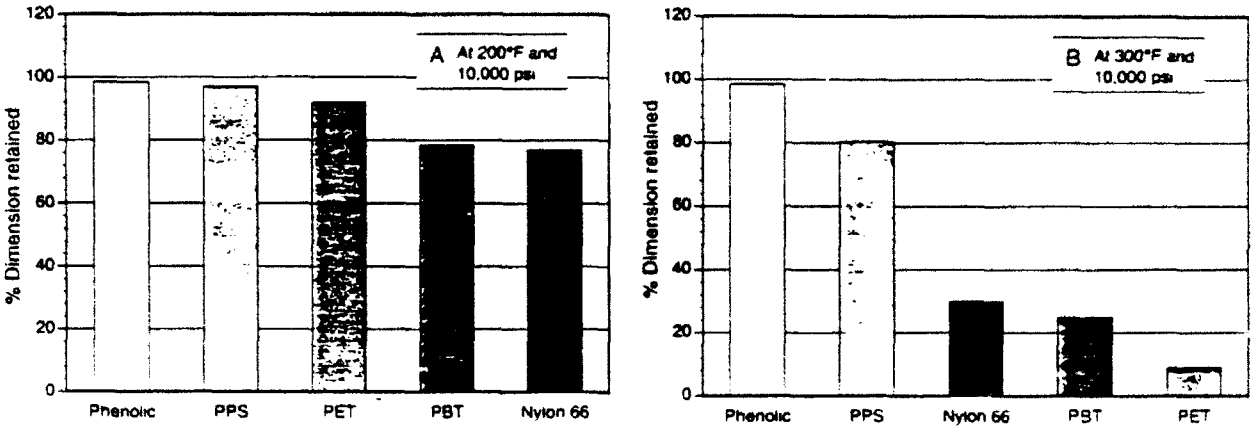


Figure 9 Compressive creep data of thermoset and thermoplastic materials at 200°F for 16 h (A) and at 300°F for 24 h (B)

percent property retention of samples molded at various temperatures, both above and below the optimal mold temperature of 275°F. As shown, the only physical properties to exhibit significant changes are the HDT and the percent crystallinity.

The high surface crystallinity obtained by higher mold temperatures results in a more complete part shrinkage. This is especially important in maintaining dimensional stability at elevated temperatures.

Weld Line Strength

Unlike traditional branched PPS products, Fortron® PPS products exhibit excellent weld line integrity, primarily because of Fortron® PPS's linear structure. Figure 10 compares the tensile strength of both 40% glass-reinforced and 65% mineral/glass-reinforced Fortron® PPS with weld lines with the values of those products without a weld line. Figure 11 compares the weld line strength of reinforced Fortron® PPS products to the

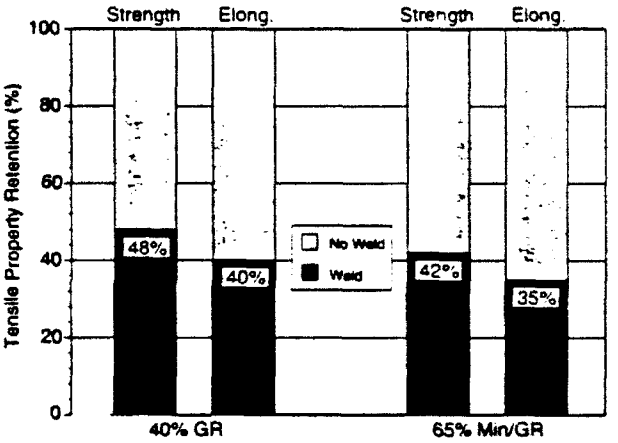


Figure 10 Comparison of tensile strength retention with and without weld lines

Table 1 Percent property retention of samples of 40% glass-reinforced Fortron® PPS molded at various temperatures

	Percent of Optimal Property Value at Given Mold Temperature			
Property	**140 °F**	**194 °F**	**248 °F**	**300 °F**
Crystallinity	10	21	73	100
Heat Distortion Temperature*, °F	185	200	210	500
Tensile Strength	91	96	97	100
Tensile Elongation	109	108	106	100
Flexural Modulus	96	97	97	100
Notched Izod Impact Strength	117	108	104	100

*Because one cannot take a percentage of a temperature, the values given here are absolute.

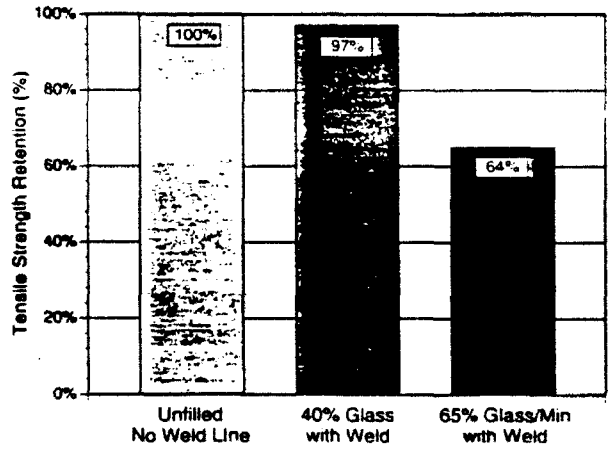


Figure 11 Weld line tensile strength vs. unfilled Fortron® PPS with no weld line

properties exhibited by the base resin without a weld. The significance of this comparison is that it shows the contribution of the weld line strength to the excellent weldability of the base resin.

Fatigue Resistance

Fortron® PPS resins show a high resistance to fatigue from repeated stress, provided that the ultimate elongation of the material is not exceeded. The ultimate elongation of glass- and mineral/glass-reinforced Fortron® PPS products is ca. 1%. Figures 12 and 13 show the fatigue resistance (ASTM D638) of 40% glass-reinforced Fortron® PPS at 23°C and 65% mineral/glass-reinforced Fortron® PPS both at 73°F (23°C) and at 320°F (160°C).

Impact Strength

The toughness of Fortron® PPS products can be best described by the energy required to initiate a crack, as well as by the total impact energy required to break through a sample. Results were obtained by using the multiaxial impact test, outlined by ASTM Method D3763, which requires dropping a dart, in this case at 5 mph, onto a 4-in. disk (1/8 in. thick). Table 2 illustrates the results of this test obtained with Fortron® PPS and a highly branched PPS product.

Anisotropic Effects

The mechanical properties in the flow direction of a part are greater than those in the transverse direction, due to glass fiber orientation. Table 3 gives the ratio of flow direction (D_f) to transverse direction (D_t) for the flexural strength, the flexural modulus, and the tensile strength and elongation at break of Fortron® PPS products.

Use of Regrind

The use of regrind can affect the mechanical properties of a molded part. However, it is worth noting that

Table 2 Results of Drop Dart Impact Test (ASTM D3763, 5 mph)

Material	Crack Initiation Energy (ft-lb)	Total Energy to Break (ft-lb)
40% Glass Fortron® PPS	5.66	7.195
65% Glass Fortron® PPS	2.85	4.77
40% Glass Highly Branched PPS	2.6	4.3
65% Mineral/Glass Highly Branched PPS	2.25	4.22

Fortron® PPS products show very little loss in properties when regrind is used. Table 4 demonstrates the effect of five moldings using 100% regrind on several important mechanical properties. This set of data demonstrates the thermal stability of Fortron® PPS. It is recommended, however, that the maximum use of regrind be limited to 25%.

Abrasion Wear

The amount of wear caused by abrasion against a part can be due to a number of factors, e.g., the velocity of the moving parts, the nature of the abrasive substance, the temperature, and the load applied.

Abrasion wear results for Fortron® PPS are tested by ASTM D1044, using the Taber abrasion apparatus. In this test a specimen is mounted on a turntable so that it is in contact with a 1-kg CS-17 abrasive wheel. After the specified number of revolutions at constant speed, the weight loss of the specimen is determined in milligrams.

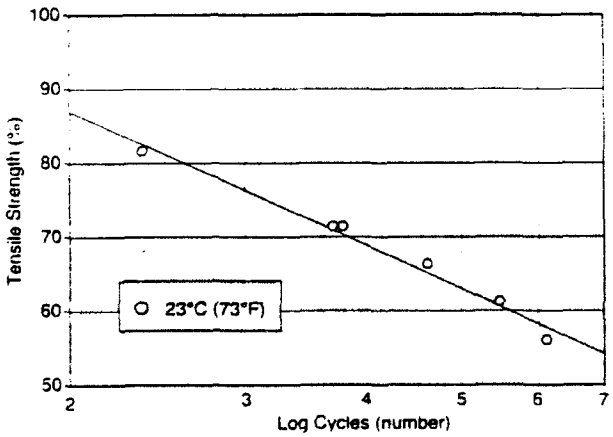


Figure 12 Fatigue resistance of 40% glass-reinforced Fortron® PPS

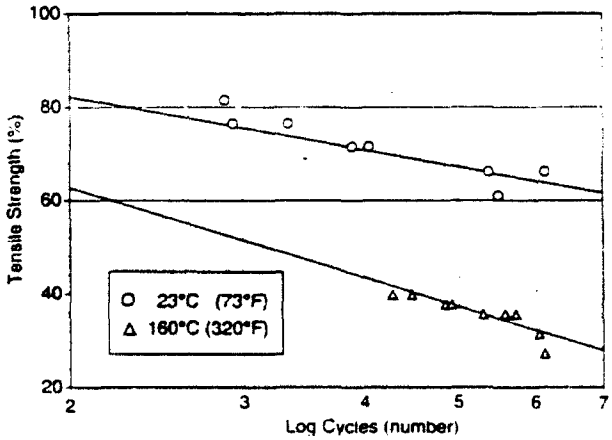


Figure 13 Fatigue resistance of 65% mineral/glass-reinforced Fortron® PPS

Table 3 Anisotropic effects on mechanical properties

Material	Df/Dt (%) Flexural Strength	Flexural Modulus	Tensile Strength	Tensile Elongation
40% Glass-Reinforced Fortron® PPS	50	80	45	38
65% Mineral/Glass-Reinforced Fortron® PPS	90	90	85	100

Table 4 Effect of regrind on mechanical property retention

Property	ASTM Method	Initial Value	40% Glass-Reinforced after 5th Molding	65% Mineral/Glass-Reinforced after 5th Molding
Tensile Strength	D638	100%	81%	79%
Elongation	D638	100%	82%	83%
Flexural Strength	D790	100%	88%	82%
Flexural Modulus	D790	100%	84%	95%

Table 5 Weight loss due to abrasion of Fortron® PPS (ASTM D1044)

Material	Weight Loss (mg)
40% Glass Reinforced	
First 1000 cycles	35
1000–10,000 cycles	11
65% Mineral/Glass Reinforced	
First 1000 cycles	43
1000–10,000 cycles	13

Table 6 Coefficient of friction of Fortron® PPS

Material	Coefficient of Friction Static	Dynamic
Steel	0.23	0.23
Aluminum	0.20	0.22
Brass	0.25	0.25

The weight loss values for 40% glass-reinforced Fortron® PPS (black) and for 65% mineral/glass-reinforced Fortron® PPS (black) due to abrasion are shown in Table 5.

Coefficient of Friction

The static and sliding coefficients of friction of 40% glass-reinforced Fortron® PPS against steel, aluminum, and brass are shown in Table 6. These results represent the average of samples from one molding, and are tested according to ASTM Method 1894-63. Test conditions are as follows:

- Specimens: 2-in. discs
- Contact area: 3 in.^{2}
- Force: 1 lb weight
- Speed: 5 in./min
- Temperature: 72°F

Chapter 4

Dimensional Stability

It is important for the part designer to understand the exceptional dimensional control obtainable with Fortron® PPS. We consider possible tolerances, as well as the dimensional effects caused by shrinkage, annealing, or moisture absorption. Dimensional effects caused by exposure to various chemicals are treated in Chapter 5.

Coefficient of Linear Thermal Expansion

The coefficient of linear thermal expansion is the slope of the curve divided by the specimen length, i.e., Δ dimension/(Δ temperature X length). Figures 1 and 2 show the dimensional change for both the flow and transverse directions of 65% mineral/glass-reinforced and 40% glass-reinforced Fortron® PPS, respectively. The curves are measured by the Perkin-Elmer Thermomechanical Analyzer (TMA 7) from −13 to 392°F (−25 to 200°C), ASTM Test Method E831.

At the glass transition temperature, T_g, the rate of expansion changes. Above the glass transition temperature, the rate of thermal expansion may shift due to an increase in molecular chain motion and its attendant effects, stress relaxation and/or crystallization. Thus, samples molded from different sources and under different conditions will probably yield results significantly influenced by the processing and end-use thermal history. This is especially true of data taken in the transverse direction, where the effects of orientation and processing are most pronounced.

Shrinkage from Injection Molding

Typically, the mold shrinkage of Fortron® PPS products is very low, and therefore, quite suitable for precision molding. Typical shrinkage values for Fortron® PPS products are as follows:

40% Glass-Reinforced:

- Flow Direction: 1–3 mil/in.
- Transverse Direction: 5–7 mil/in.

65% Mineral/Glass-Reinforced:

- Flow Direction: 1–2 mil/in.
- Transverse Direction: 3–5 mil/in.

While the shrinkages given above are typical, these values vary, depending on the variables listed on p. 4-2 under Warpage. It is highly recommended that prototyping be employed prior to cutting a tool to determine the proper shrinkage for a given part. If prototyping is not economical, then for safety it is recommended that oversized cores and undersized cavities be cut, since it is always easier and less expensive to cut steel than to add it.

The effect of part thickness on shrinkage of 40% glass-reinforced and 65% /mineral/glass-reinforced Fortron® PPS is shown in Figure 3. The reason for greater shrinkage in thicker parts is that thicker parts exhibit slower cooling, which results in a greater degree of crystallization, thus causing more shrinkage.
Figure 4 illustrates the effect of filler/reinforcement level on shrinkage of Fortron® PPS. as filler level increases, shrinkage decreases and becomes less sensitive to part thickness.

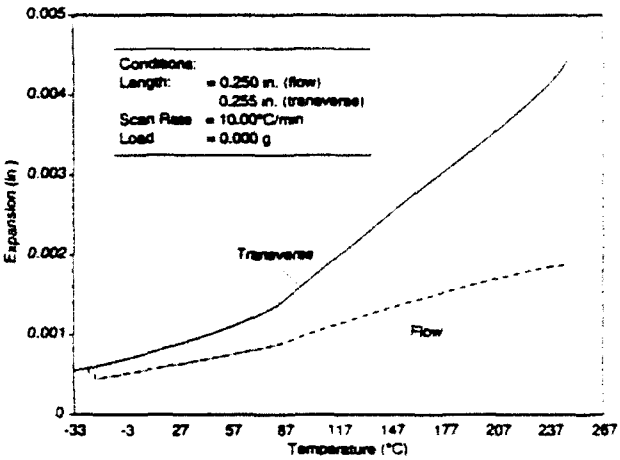


Figure 1 Dimensional change of 65% min/glass-reinforced Fortron® PPS

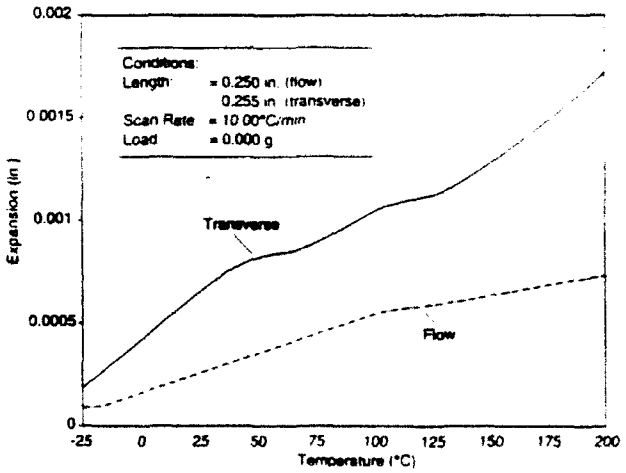


Figure 2 Dimensional change of 40% glass-reinforced Fortron® PPS

Figures 5 and 6 show the effect of injection pressure on the shrinkage of 40% glass-reinforced and 65% mineral/glass-reinforced Fortron® PPS, respectively. As injection pressure is increased, the parts are more densely packed, thus slightly decreasing shrinkage. The test piece was 80 X 80 mm, 2 mm thick, with a rectangular (4 X 2 mm) side gate at one point; the cylinder temperature was 320°C (608°F), and the mold temperature was 150°C (302°F).

Warpage

Anisotropic effects on dimensions (warping) can be caused by a number of factors, including the following:

- Mold temperature
- Nonuniform part thickness
- Nonuniform cooling
- Filler type/level
- Orientation of filler
- Location of dimensions with respect to the gate
- Molded-in stresses
- Gate size

To describe the effects of anisotropy in geometrically complex parts, a sample part containing a variety of shapes was designed. Figure 7 shows the specifications for this warpage sample. Figure 8 shows the measured points used to obtain the data shown in Figures 9–12, which compare the largest dimensional differences of 40% glass-reinforced and 65% mineral/glass-reinforced Fortron® PPS products with respect to flatness (Fig. 9), roundness of a cylinder (Fig. 10), roundness of a hole (Fig. 11), and bowing angle (Fig. 12).

From these figures it can be seen that 65% mineral/glass-reinforced Fortron® PPS has the least warpage.

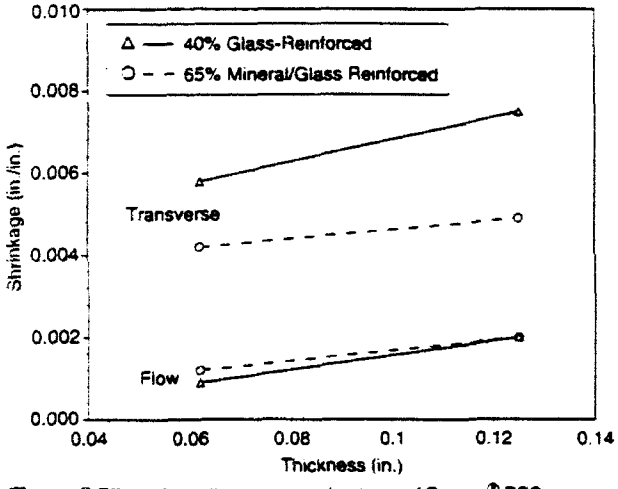


Figure 3 Effect of part thickness on shrinkage of Fortron® PPS

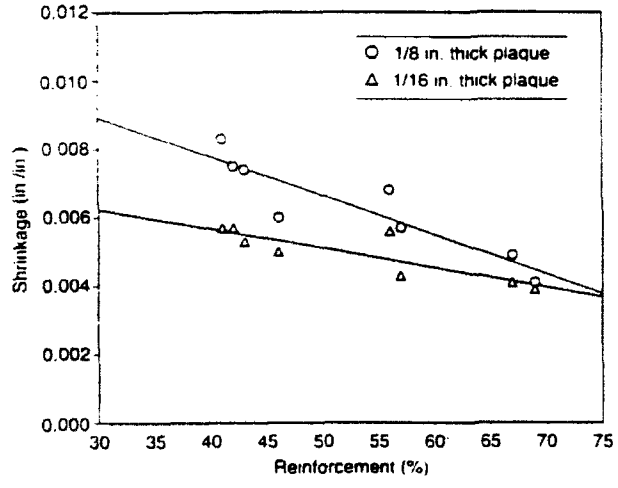


Figure 4 Effect of filler level on shrinkage of Fortron® PPS (Please note that not all reinforcement levels are available as commercial products.)

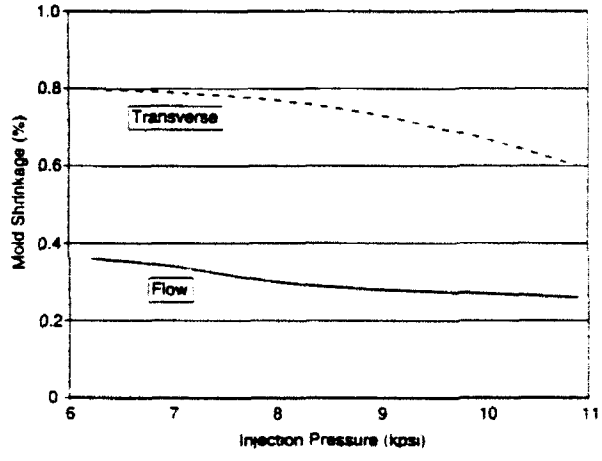


Figure 5 Effect of injection pressure on shrinkage of Fortron® PPS (40% glass)

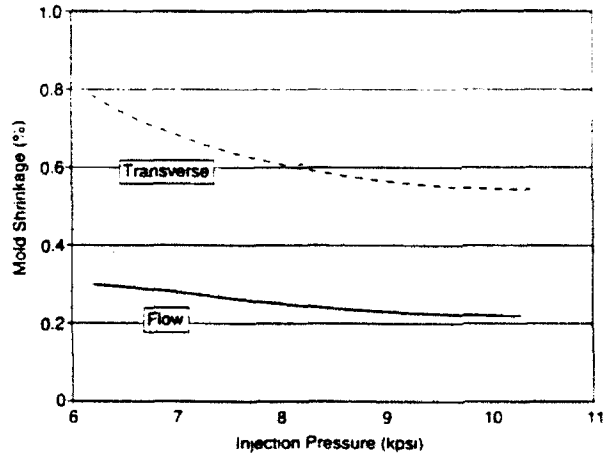


Figure 6 Effect of injection pressure on shrinkage of Fortron® PPS (65% mineral/glass)

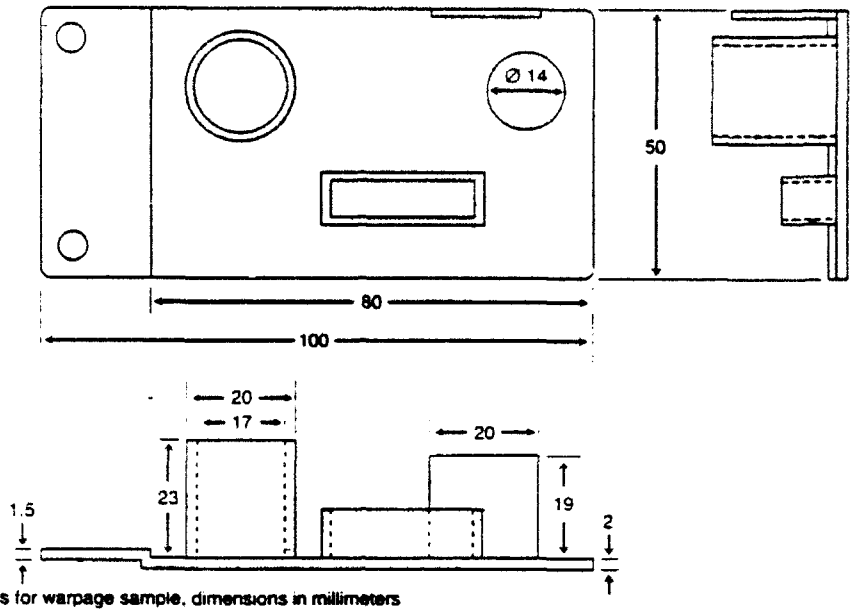


Figure 7 Specifications for warpage sample, dimensions in millimeters

due to the fact that this material uses less glass than the 40% glass-reinforced material, and that mineral filler has a smaller aspect ratio than glass fibers.

Annealing

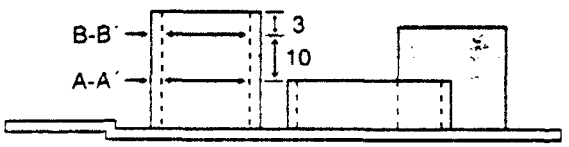
When processed at a mold temperature of 275°F or greater, parts molded of Fortron® PPS are able to fully crystallize, and therefore, show very little continued shrinkage when exposed to temperatures as high as 450°F (232°C) for 24 h. A study of the effects of annealing Fortron® PPS products showed the following additional shrinkage values for the flow direction, using 1/8-in. thick samples:

40% Glass-Reinforced:
- 0.0009 in./in. after 2 h annealing
- 0.001 in./in. after 24 h annealing

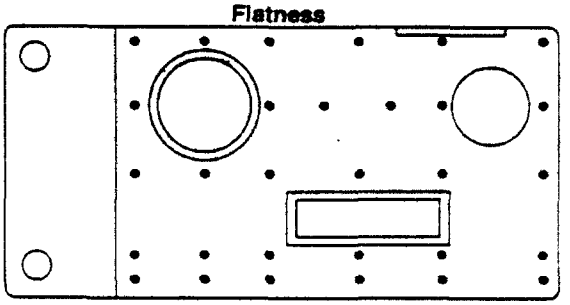
65% Mineral/Glass-Reinforced:
- 0.001 in./in. after 2 h annealing
- 0.0012 in./in. after 24 h annealing

Thus, there is very little advantage in annealing a sample molded at or above 275°F for more than 2 h to obtain further shrinkage.

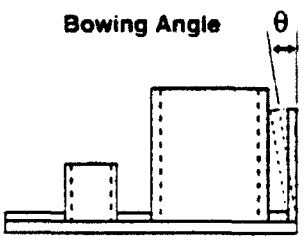
Roundness of a Cylinder



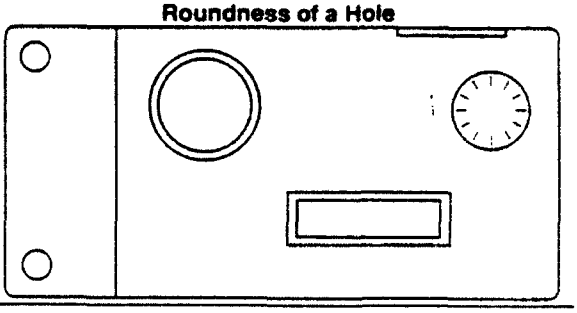
Flatness



Bowing Angle



Roundness of a Hole



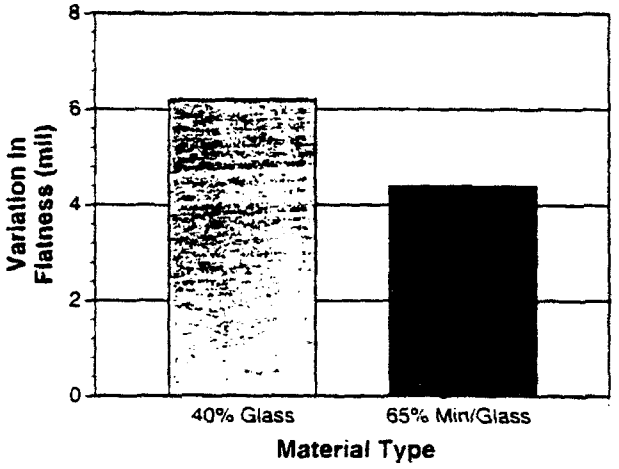


Figure 9 Warpage with respect to flatness

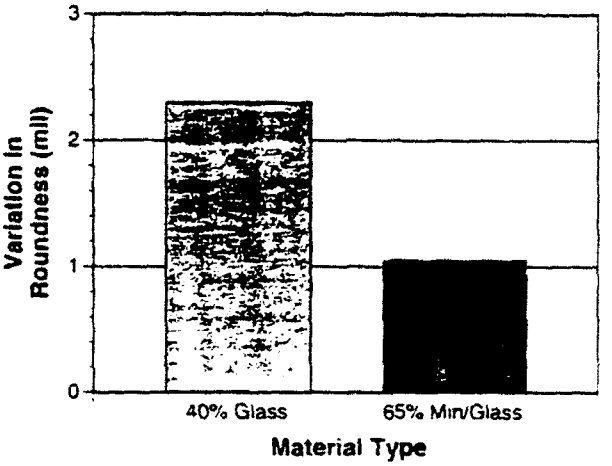


Figure 11 Warpage with respect to roundness of a hole

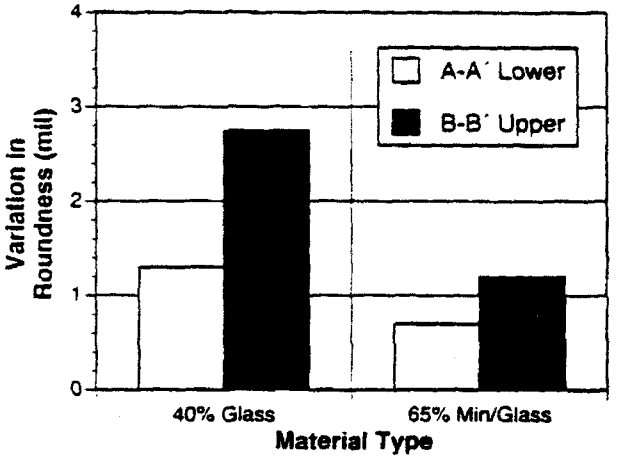


Figure 10 Warpage with respect to roundness of a cylinder

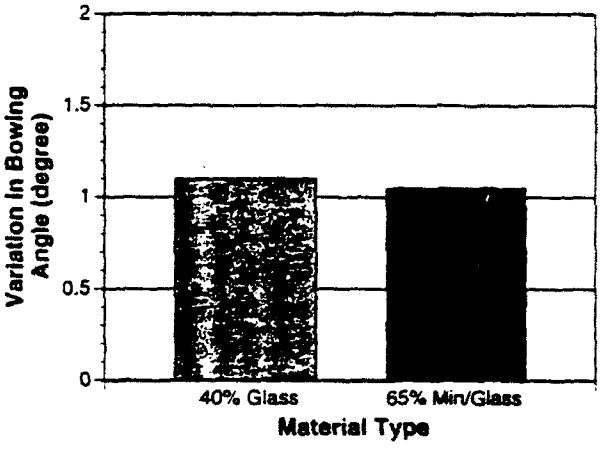


Figure 12 Warpage with respect to bowing angle

Fortron® PPS can be molded at lower mold temperatures at the expense of reduced thermal/load properties, i.e., heat distortion temperature. Annealing parts that have been molded at lower temperatures (<275°F) will increase the load-bearing capabilities of those parts, but such practice may cause warpage; thus, strict care (e.g., fixturing the part) should be taken with parts requiring critical tolerances.

Tolerances with Injection Molding

When Fortron® PPS is injection molded, it is possible to routinely hold tolerances of 2–3 mil/in. To achieve tolerances such as 1 mil/in., the material should be uniformly oriented in the direction of flow, and precision processing machinery, including at least the following parameters, should be used:

- Uniform tool heating (efficient oil flow and proper placement of cooling lines)
- Closed-loop, feedback controllers for temperatures, pressures, injection speeds, and ram distances

Table 1 demonstrates the dimensional reproducibility obtained in molding 65% mineral/glass-reinforced Fortron® PPS for 10 months. At the end of 10 months, the variability over a 1.9593 in. dimension was ± 0.0006 in. (0.03%).

Moisture Absorption

Fortron® PPS products are not hygroscopic, and therefore, do not experience dimensional expansion like polyamides. For both 40% glass-reinforced and 65% mineral/glass-reinforced Fortron® PPS products, a typical moisture absorption value is 0.03%, tested according to ASTM Method D-570 by immersion in water at 73°F (23°C) for 24 h. Figure 13 shows how this value compares with those of other engineering plastics under the same conditions.

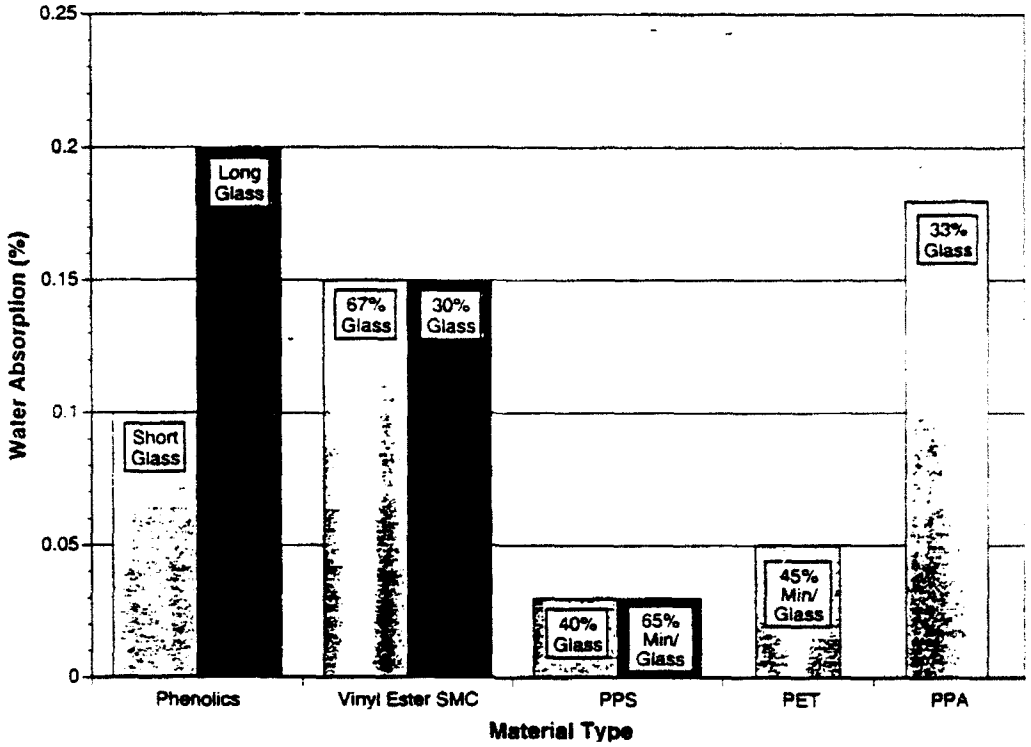


Figure 13 Comparison of the moisture absorption of several plastics by immersion in water at 73°F (23°C) for 24 h

Test Date	$\bar{x}$ (in.)	σ (in.)	$3\bar{\sigma}/\bar{x}$ X 100 (%)	$3\bar{\sigma}/\bar{x}$ X 100 (%) for 3 days	Reproducibility for 10 Months
8/10/88	1.9593	0.00016	0.024	0.022	Dimension = 1.9593 in. ± 0.0006 in. (0.030%)
8/11/88	1.9593	0.00012	0.017		
8/12/88	1.9594	0.00016	0.025		
11/17/88	1.9594	0.00016	0.026	0.025	
11/18/88	1.9593	0.00016	0.025		
11/19/88	1.9592	0.00016	0.025		
2/27/89	1.9592	0.00024	0.036	0.035	
2/28/89	1.9591	0.00028	0.043		
2/29/89	1.9592	0.00016	0.026		
5/29/89	1.9593	0.00020	0.029	0.027	
5/30/89	1.9593	0.00016	0.022		
5/31/89	1.9594	0.00020	0.029		

Table 1 Long-term dimensional reproducibility of injection molding Fortron® PPS

Chapter 5

Chemical Resistance

Fortron® PPS exhibits good resistance to the effects of chemicals on its properties. It is essentially unaffected by a broad class of chemicals at elevated temperatures and for prolonged periods of time. In general, the few classes of compounds that may cause some loss of mechanical properties include strong acids, oxidizing agents, and some amines.

Effects of Hot Water

Fortron® PPS resists hydrolysis very well. Unfilled Fortron® PPS shows no significant change in properties after long-term exposure to water at high temperatures, showing the polymer's resistance to hydrolytic attack. Figure 1 shows the tensile strength retention of unfilled, 40% glass-reinforced, and 65% mineral/glass-reinforced Fortron® PPS products after exposure to hot water at 203°F (95°C) under 15 psi.

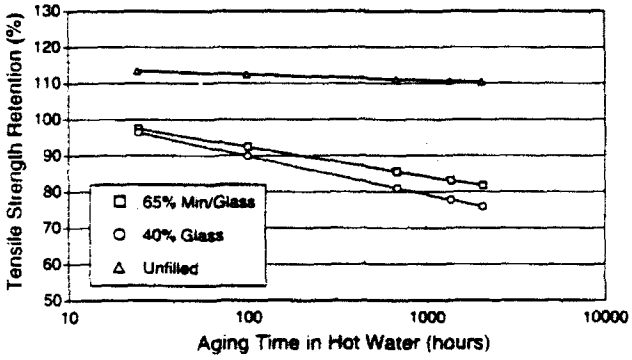


Figure 1 Tensile strength retention at break in hot water under pressure

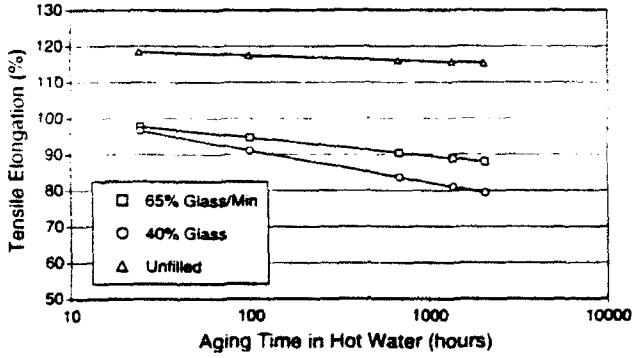


Figure 2 Tensile elongation in hot water under pressure

There is some loss of strength attributed to a reduced adhesion at the glass reinforcement/polymer interface. This phenomenon, known as the "wicking effect," is normal for glass-reinforced plastics. The designer should compensate for this loss of strength.

Chemical Resistance

Table 1 lists the property retention ratings of a large number of chemical compounds on test specimens, ASTM Type I tensile or flexural bars, molded at a mold temperature of 275°F, using 40% glass-reinforced Fortron® PPS. The rating method is adapted from that used in *Modern Plastics Encyclopedia*; however, please note that surface effects were not evaluated.[1] Numerical data are available from Hoechst Celanese Engineering Plastics Division marketing representatives or in material monographs.

It is important for the designer to note that the standard chemical resistance test methods (*i.e., those used* to prepare Table 1) are only intended to serve as a general guideline. Because the samples are not tested in the chemical environment under load, the results can be misleading for design purposes concerning the performance properties of a plastic part in a particular chemical environment under load. Therefore, the designer is strongly recommended to pursue creep rupture testing in the actual end-use environment on test bars or, preferably, prototype parts to determine the suitability of a particular plastic in such an environment.

[1] Key to chemical resistance table, as suggested in *Modern Plastics Encyclopedia*, McGraw-Hill Pub. Co., 1986–1987, p. 442:

A = No significant effect: <0.5%, <0.2%, and <10% change in weight, dimension, and strength, respectively; slight discoloration.

B = Significant, but usually not conclusive: 0.5–1.0%, 0.2–0.5%, and 10-20% change in weight, dimension, and strength, respectively; discolored

C = Usually significant: >1.0%, >0.5%, and >20% change in weight, dimension, and strength, respectively; distorted, warped, softened, or crazed.

Table 1 Chemical resistance of 40% glass-reinforced Fortron® PPS

Reagent (Conc.*)	Temp. (°C)	Time (days)	Tens. Elong.	Tens. Str.	Weight	Length	Thick-ness
Acids:							
Hydrochloric Acid (10%)	23	40	A	A	A		
Hydrochloric Acid (10%)	80	42	—	C	C	A	—
Nitric Acid (10%)	23	40	A	A	A	—	—
Sulfuric Acid (10%)	23	40	A	A	A	—	—
Sulfuric Acid (30%)	80	90	A	A	—	—	—
Alcohols:							
1-Butanol	80	180	A	A	—	—	—
Ethanol (5%)	80	180	A	A	C	A	C
Methanol	60	180	B	A	A	A	B
Methanol (60%)	55	180	A	A	A	A	A
Methanol (15%)	65	180	A	A	A	A	A
Ethylene Glycol (Antifreeze)	120	180	B	A	A	A	A
Bases:							
Sodium Hydroxide (10%)	23	40	A	A	A	A	B
Sodium Hydroxide (30%)	80	180	A	A	—	—	—
Hydrocarbons:							
Brake Fluid	80	42	—	A	A	A	A
Diesel Fuel	80	180	A	A	A	A	A
95% Fuel A/5% Ethanol	80	180	A	A	C	A	C
85% Fuel B/15% Methanol	65	180	A	A	A	A	A
40% Fuel C/60% Methanol	55	180	A	A	A	A	A
Gasoline (Regular)	80	125	A	A	—	—	—
Gear Oil (75W-90)	150	142	A	A	A	A	—
Kerosene	60	40	A	A	A	—	—
Lubricating Oil	60	40	A	A	A	—	—
Mineral Oil (Sat.)	120	30	A	A	A	—	—
Motor Oil	80	42	—	A	A	A	A
Refrigeration Oil	100	60	—	—	A	—	—
Toluene	80	30	—	B	—	—	—
Transmission Fluid	150	42	A	A	A	—	—
Xylene	80	180	B	A	B	A	C
Inorganics:							
Calcium Chloride (Sat.)	80	42	—	A	A	A	A
Potassium Chromate (30%)	80	42	A	A	—	—	—
Zinc Chloride (Sat.)	80	42	—	A	A	A	A
Sodium Hypochlorite (5%)	80	30	B	B	—	—	—
Deionized Water	23	180	A	A	—	—	—
Deionized Water	100	180	C	C	A	A	A

Table 1 Chemical resistance of Fortron® PPS

Reagent (Conc.*)	Temp. (°C)	Time (days)	Tens. Elong.	Tens. Str.	Weight	Length	Thick-ness
Ketones:							
Acetone	55	180	A	A	A	A	B
2-Butanone	58	180	B	A	A	A	A
Others:							
Butyl Acetate	80	180	A	A	—	—	—
Diethyl Ether	23	40	A	A	A	—	—
Dichlorodifluoromethane	100	60	—	A	A	B	—
Freon®	93	—	B	A	—	—	—
Freon® 113	23	40	A	A	A		—
Tetrafluoroethane	100	60	A	A	A	A	—
1,1,1-Trichloroethane	75	180	A	A	A	A	B

Freon® is a registered trademark of E. I. Dupont de Nemours & Co., Inc.

*Concentrations are assumed to be 100% unless stated otherwise.

Chapter 6

Electrical Properties

Fortron® PPS has been demonstrated to be a key high-performance polymer in the electrical/electronic industry. Because of its outstanding electrical properties, as seen in Table 1, the 40% glass-reinforced grades are used most frequently. In certain applications, glass/mineral-reinforced grades exhibiting high arc resistance and low warpage have received increased interest from this industry. Material monographs provide more specific data for individual grades of materials.

Table 1 Electrical properties of 40% glass-reinforced Fortron® PPS

Property & Conditions	Test Method	Units	Property Value
Dielectric Strength (Short Term) @ 50% RH, 73°F	ASTM D149		
0.125 in.		V/mil	450
0.0625 in.		V/mil	680
0.03125 in.		V/mil	960
Hot Wire Ignition (HWI)	UL 746		
@ 1/8 in. (3.18 mm)		sec	68
@ 1/32 in. (0.81 mm)		sec	16
High Voltage Arc Tracking	UL 746	in./ min	4.6
Comparative Tracking Index	ASTM D3638	V	125

A sampling of electrical/electronics applications that frequently benefit from the combination of properties offered by Fortron® PPS are connectors, molded interconnects, bobbins, etc. The E/E Industry Group of Hoechst Celanese, Engineering Plastics Division, in conjunction with the Fortron® Product Group, is continuously developing specialty grades to meet the changing needs of the electrical/electronics industry.

Effect of Frequency, Humidity, and Temperature

As shown in Tables 2 and 3, the dielectric constant and dissipation factor (ASTM D-150) of 40% glass-reinforced Fortron® PPS are only minimally affected by changes in temperature, frequency, or humidity.

Figure 1 illustrates the stability of the volume resistivity of 40% glass-reinforced Fortron® PPS when aged at an elevated temperature (158°F, 70°C) and a 99% relative humidity. Figure 2 shows the minimal effect of high temperatures alone on the volume resistivity (ASTM D-257) of Fortron® PPS.

Table 2 Dielectric constant of 40% glass-reinforced Fortron® PPS (ASTM D150)

Conditions	Dielectric Constant
@ 1 MHz, 50°C, 48 h	3.90
@ 100 MHz, 50°C, 48 h	4.00
Immersion in water, 24 h	
@ 1 MHz, 23°C	3.80
@ 100 MHz, 23°C	3.80
Frequency: 1 MHz	
30°C	3.90
100°C	3.95
130°C	3.97
150°C	3.95
180°C	4.90

Table 3 Dissipation factor of 40% glass-reinforced Fortron® PPS (ASTM D150)

Conditions*	Dissipation Factor
@ 73°F, 1 kHz	0.001
@ 73°F, 100 Hz, Dry	0.001
@ 73°F, 100 Hz, Wet	0.001
@ 73°F, 1 MHz, Dry	0.003
@ 73°F, 1 MHz, Wet	0.003
All at 1 MHz:	
@ 30°C	0.0015
@ 100°C	0.0015
@ 120°C	0.0018
@ 150°C	0.0022
@ 180°C	0.003

*Dry: Dried in desicant at 23°C for 16 h.
Wet: Immersed in water at 23°C for 24 h.

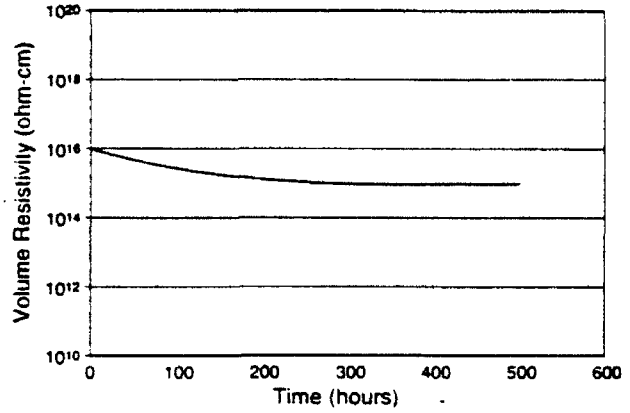


Figure 1 Stable volume resistivity of Fortron® PPS at 70°C (158°F) and 99% relative humidity

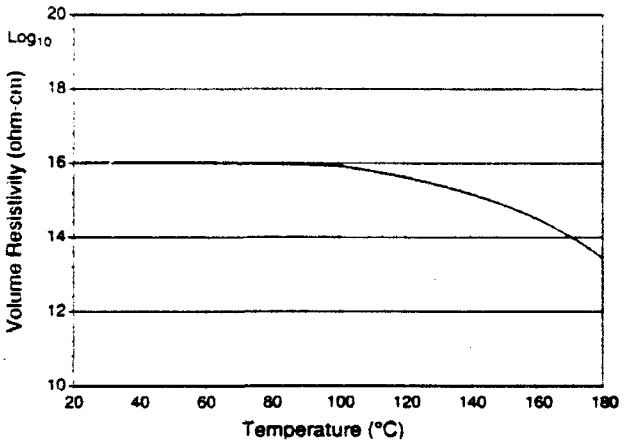


Figure 2 Effect of different temperatures on volume resistivity

Soldering Heat Resistance

Fortron® PPS shows excellent resistance to solder temperatures and dipping times, as shown in Table 4. The test piece (5 X 15 X 0.3 mm) was placed in an aluminum frame and dipped for the times and at the temperatures indicated.

Table 4 Soldering heat resistance of Fortron® PPS

Solder Temp. (°C)	Dipping Time (sec)			
	5	10	30	60
250	A	A	A	A
260	A	A	B	B
270	A	A	B	B
280	C	D	D	D

Key: A = No change; B = Discolored; C = Surface affected; D = Partially melted or deformed.

Ionic Impurities

Fortron® PPS contains few ionic impurities, e.g., Na^+, K^+, Li^+, F^-, Cl^-, Br^-, and SO_4^{2-}. If such ions are abundant, they can adversely affect the performance of some sockets and connector housings. Electrical engineers know that excessive levels of ionic impurity can lead to the corrosion of contacts or shorts/opens in applications that are in contact with a current.[1]

Furthermore, the increasing requirements due to miniaturization have led to shorter center-to-center distances for many electrical housings. Thus, the distances through which ionic impurities must migrate to cause failure is decreased. Compounding this effect are such conditions as higher temperatures and humidity levels, which accelerate the mobility (leaching) of the ionic impurities to the surface.

[1] Corbett, Tim, "Ionic Contamination in Socket Housing Materials," *Connection Technology*, Oct. 1987, p. 19.

Chapter 7

Fundamental Design Criteria

Part Design

For a broader discussion of the fundamental principles involved in plastic part design, it is recommended that the reader refer to Chapter 8, "Design Considerations for Injection-Molded Parts," of *Designing with Plastic: The Fundamentals*, published by Hoechst Celanese, Engineering Plastics Division.

Wall Thickness

The wall thickness of parts made of Fortron® PPS should be uniform throughout. To achieve uniform cooling, and thus uniform crystallization and stress relaxation, a variation of 25% of the nominal wall thickness should not be exceeded. This variation should proceed in as gradual a manner as possible, as illustrated in Figure 1, and the part should be gated so that the material flows from the thicker section to the thinner section.

A typical range of wall thicknesses with Fortron® PPS depends greatly on the flow length, injection pressure, cylinder temperature, etc. Wall thicknesses between 0.020 and 0.200 in. are common.

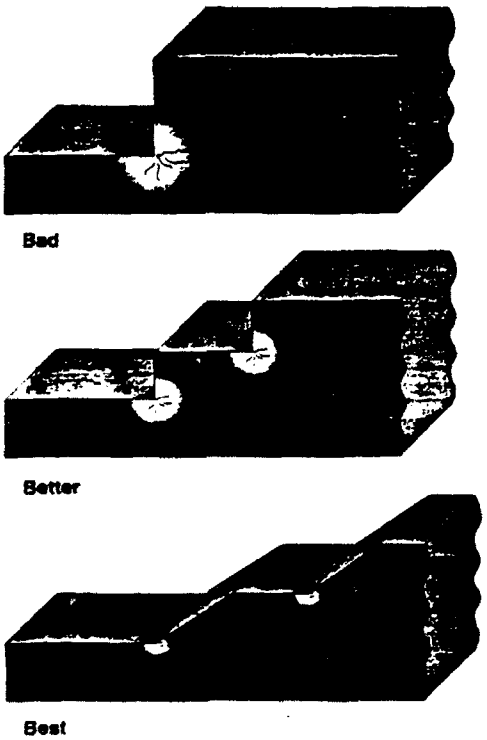


Figure 1 Design of nominal wall from thick to thin sections

Fillets/Radii

Because all PPS materials exhibit a sensitivity to notches, it is recommended that radii be incorporated for all sharp internal corners, particularly those bearing loads. A minimum radius of 25% of the nominal wall thickness is suggested; however, a larger radius allows for a stronger part. Figure 2 shows the significant effect that a notch can have on the energy required to break a sample of either 40% glass-reinforced or 65% mineral/glass-reinforced Fortron® PPS.

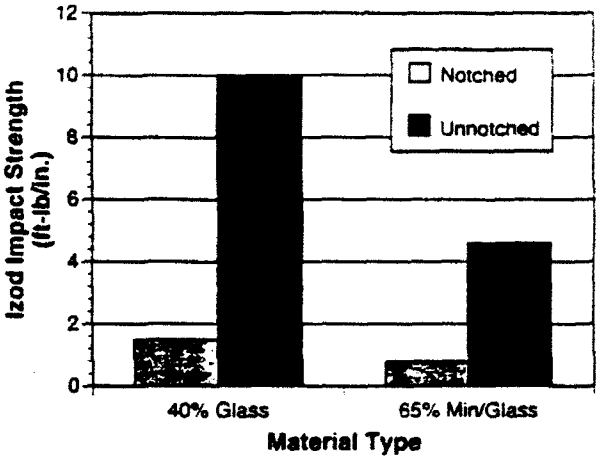


Figure 2 Effect of notches on Izod impact strength

Ribs

The use of ribs in a plastic part design allows the designer to accomplish the following objectives:

- Reduce the wall thickness
- Reduce cooling time
- Improve the flow paths
- Increase the part's strength and stiffness
- Reduce part weight
- Reduce cost

Rib height up to 3 times the wall thickness and the rib thickness half the wall thickness are recommended.

Bosses

Bosses frequently serve as fastening points for other parts, and thus, are subject to many different kinds of stresses, e.g., hoop stresses, molded-in stresses, etc. Figure 8.10 in *Designing with Plastic: The Fundamentals* may be reviewed for general principles regarding the design of bosses. Figure 3 shows the recommendations for design of a thread-cutting, self-tapping screw boss when Fortron® PPS products are used.

In applications requiring particularly high strength, metal rings for bosses can lower hoop stresses and allow for thinner walls. If thread fittings are necessary and a choice is available, mold the pipe threads onto the male part rather than on the female part.

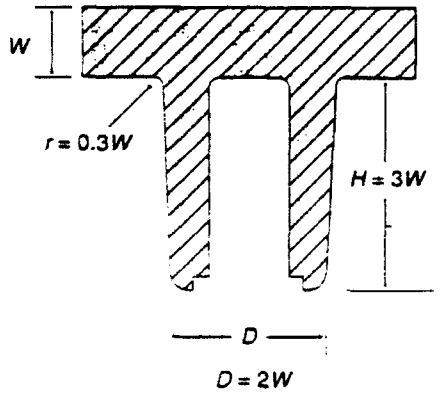


Figure 3 Design of a self-tapping screw boss

Tool Design

Tool, Screw, and Barrel Construction Materials
As is true of all filled plastic products, proper materials must be used in the construction of molds, screws, and barrel liners because glass and mineral filler materials are abrasive compounds. This is also true of PPS products.

For high-volume production parts, the recommended steels for cores and cavities are D-2, D-7, and A-2 steels, which have good wear resistance properties. For lower volume production parts, tool steels such as S-7, P-20, and H-13 are acceptable. An SPI A2 class finish is recommended. For tools that are especially difficult to vent adequately, corrosion-resistar steels D-2, D-7, and stainless steel are suitable.

The abrasive nature of glass and minerals also affects the screws and barrels. The proper materials for construction are important to ensure long life. Stellite is recommended for screws, and Xaloy 800 is recommended for barrel liners for long barrel life.

Gate Location
Gates should be located to provide a flow that is uniform and uninterrupted. Generally, the number of gates should be kept to a minimum. It is common practice to use multiple gates when dealing with a long flow length and/or thin-wall parts to reduce the pressure, and therefore, minimize flash. When multiple gates are necessary, they should be placed so that the weld lines in the product are formed in areas with minimal load-bearing requirements. Where possible, adjacent flow fronts should be forced to meet at an acute angle so that a meld line is formed. Venting at the weld line also promotes stronger welds.

Gate Size
The size of the gate is related to the nominal wall thickness. Gates should always be at least as wide as they are deep.

The high flow of Fortron® PPS materials permits the use of very small gates (as low as 0.04 in. diameter). For example, submarine or pinpoint gates typically have a 0.040–0.070 in. diameter. This smaller gate area minimizes gate vestige and provides satisfactory part separation from the runner. For edge gates, a typical starting point is 50% of the nominal wall thickness. A typical land length is 0.020 in.

Gate Types
Any kind of gate may be used for molding Fortron® PPS. For a review of the various types of gates, see Figure 2 in *Designing with Plastic: The Fundamentals*. It should be noted that if a submarine gate is selected, it should conform approximately to the geometry recommended in Figure 4.

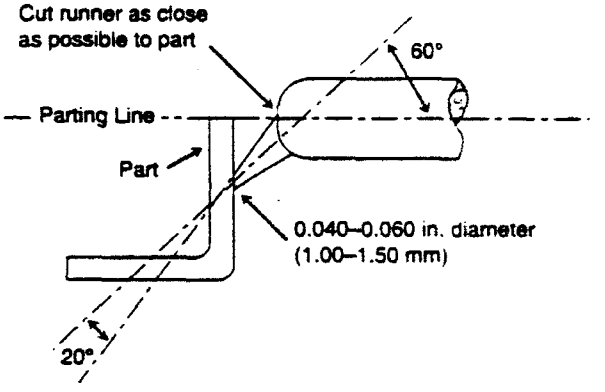


Figure 4 Specifications for submarine gates

Runner Systems
Full-round runners with a diameter as small as 0.125 in. (6 mm) are used for molding Fortron® PPS. Equivalent trapezoidal runners may also be used. When a multicavity mold is being used, it is imperative that the runner system be balanced to ensure that all cavities finish filling simultaneously, thus preventing any one cavity from being overpacked.

Vents
Vents should be located in all sections of the mold cavity where air may become trapped by the molten Fortron® PPS, particularly in the last areas to fill. The tendency of PPS to flash dictates that shallow vents, ca. 0.0003–0.0005 in. (0.007–0.012 mm), be used. Inadequate venting entraps gas, causing incomplete filling of the part, burn marks, and/or poor weld line strength. The vent land length should be about 1/8 in. and then widened to the edge of the tool.

Chapter 8

Assembly Methods

In this chapter, as with all others, the reader is encouraged to refer to *Designing with Plastic: The Fundamentals* for the fundamental principles and equations of the items discussed here, which focus on the specifics of assembly with Fortron® PPS products.

Snap-Fits

Snap-fits are commonly evaluated by calculating dynamic strain rather than stress. The maximum dynamic strain, ε_{max}, at ambient temperature for 40% glass-reinforced Fortron® PPS is 0.014, and that for 65% mineral/glass-reinforced Fortron® PPS is 0.010.

In designing the finger of a snap-fit, it is extremely important to avoid any sharp internal corners or structural discontinuities, which can cause stress risers. Because a tapered finger (a 2:1 taper is usually considered typical) provides a more uniform stress distribution, it is the preferred design where possible.

Chemical Bonding/Adhesives

When adhesives are being used with Fortron® PPS products, the surface should be pretreated by wiping the surface with a solvent cleaner (methyl ethyl ketone). Successful bonds have been obtained with epoxies, urethanes, and acrylic-type adhesives. For further details, please contact your local Hoechst Celanese Engineering Plastics Division representative.

Ultrasonic Welding

Parts made of Fortron® PPS can be ultrasonically welded. However, the joint design is critical for the strength of the finished part. A shear joint is the best design overall with Fortron® PPS parts. Table 1 gives the interference guidelines for shear joints with Fortron® PPS, while Figure 1 shows recommended dimensions for a shear joint. Tables 2 and 3 show a comparison of the ultrasonic strength of Fortron® PPS vs. highly branched PPS materials, including neat, 40% glass-reinforced, and 65% mineral/glass-filled systems. The parts tested were two caps with a wall thickness of 3 mm (1.2 in.) and a radius of 47 mm (18.5 in.). A lead-in angle of 30–45° further reduces the area of contact, pinpointing energy and maximizing shear to allow for a strong structural and hermetic seal. Due to low strength, energy directors are not recommended.

When shear joints are to be welded, use high power with a high-amplitude booster, low pressure, and a slow horn speed. Caution should be used during welding of parts, since an excessively high amplitude and/or an excessively long application time could destroy the part. Care

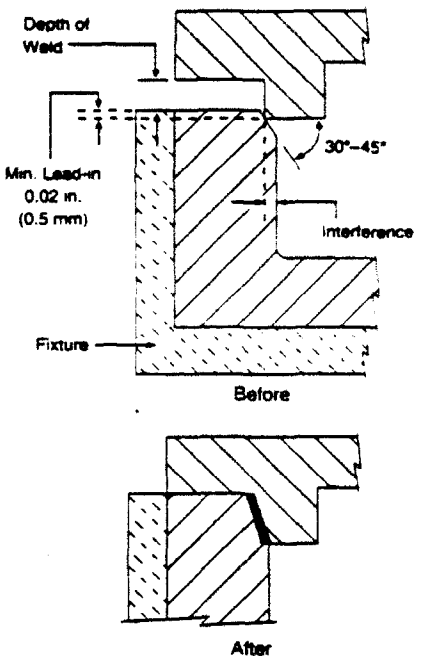


Figure 1 Recommended dimensions for shear joints

Table 1 Interference guidelines for shear joints with Fortron® PPS

Maximum Part Dimension	Interference per Side	Part Dimension Tolerance
<0.75 in. (18 mm)	0.008-0.012 in. (0.2-0.3 mm)	±0.001 in. (±0.025 mm)
0.75-1.5 in. (18-35 mm)	0.012-0.016 in. (0.3-0.4 mm)	±0.002 in. (±0.050 mm)
>1.5 in. (>35 mm)	0.016-0.020 in. (0.4-0.5 mm)	±0.003 in. (±0.075 mm)

Table 2 Comparison of the ultrasonic strength of neat Fortron® PPS vs. highly branched PPS materials

Type of Polymer	Observed Welding Results*	Weld Strength (lb)
Linear PPS		
Medium Flow	Free of cracks	990
High Flow	Cracked 1/5 times	730
Crosslinked PPS		
Medium Flow	Cracked 3/5 times	—
High Flow	Cracked 5/5 times (all)	—

*Observed welding results refer to the number of cracked parts out of all samples (5).

Table 2 Comparison of the ultrasonic strength of filled Fortron® PPS vs. highly branched PPS materials

Type of Material	Observed Welding Results*	Avg. Weld Strength (lb)
40% Glass-Reinforced Systems		
Fortron® PPS	Free from cracks	2690
Fortron® PPS	Free from cracks	2310
Highly Branched PPS	Cracked 1/5	1650 (n = 4)
Highly Branched PPS	Cracked 5/5 (all)	—
Mineral/Glass-Reinforced Systems		
Fortron® PPS	Free from cracks	1980
Fortron® PPS	Free from cracks	1850
Highly Branched PPS	Cracked 4/5	—
Highly Branched PPS	Cracked 5/5 (all)	—

*Results refer to the number of cracked parts out of all samples (5). All welding was performed at an amplitude of 0.004 in. under a pressure of 70 psi for 0.5 sec.

should also be exercised when highly filled mineral/glass-reinforced grades are being welded because of the lower toughness of these grades.

The following practices in joint design should be avoided if at all possible for the reasons given:

- Joints that are either too tight or too close together may prevent adequate ventilation.
- Thin sections transmitting the ultrasonic energy may crack under high amplitude.
- Large steps requiring high power may destroy the part.
- Energy director designs will prevent a homogeneous weld.

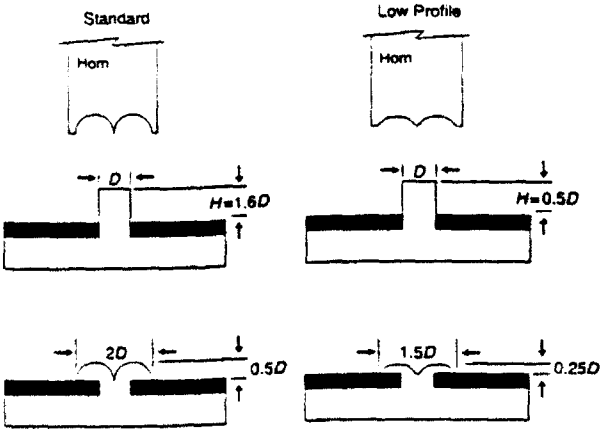


Figure 2 Dimensions for head forms for ultrasonic staking

Typical conditions for ultrasonic welding of Fortron® PPS are as follows:

- High energy
- Low pressure
- Amplitude
  - At 20 kHz, 0.0032–0.0050 in. (80–125 µm): for large parts >2 in. diameter, both near and far field
  - At 40 kHz, 0.0019–0.0030 in. (50–76 µm): for small parts, near field only
- *Vibration time:* typically <1 s
- Minimum wall thickness: 0.050 in.
- Shear joint designs preferred

Heat Staking

Heat staking is a useful assembly technique for forming permanent joints between parts. Heat staking is accomplished by compressively loading the end of a rivet while the body is fixtured. The tip that performs the melting and compressing should have a Rockwell hardness of at least 60C due to the abrasive nature of the glass- and mineral-filled grades of Fortron® PPS. Fortron® PPS parts require a horn or tip temperature of about 615°F. The temperature should be sufficiently high to prevent cracking of the part, while the pressure should be sufficiently low to avoid cracking the part.

Ultrasonic Staking

Ultrasonic staking is a method of melting and reforming a plastic stud or boss to mechanically encapsulate another component. The joining component, which contains a hole, receives the Fortron® PPS stud, which is then progressively melted by the high-frequency vibrations of an ultrasonic horn, under which the stud is placed. The vibrations also cause a light, continuous pressure on the plastic stud, which is then reformed in the shape of the horn tip.

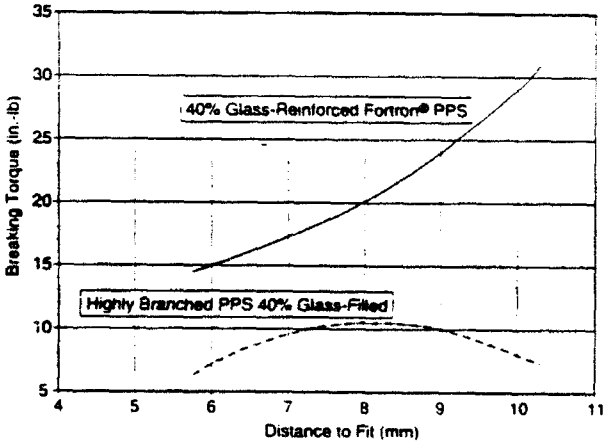


Figure 3 Breaking torque of a self-tapping screw

The requirements of most geometries are satisfied by either the standard or low-profile head-forms. The standard head form produces a head twice the diameter of the original stud, while the low-profile head form produces a head diameter 1.5 times the stud diameter. Figure 2 illustrates these two head forms, as well as the dimensions for each.

Threading

Molding threads into the part is the preferred approach due to the excellent strength, toughness, and surface hardness of Fortron® PPS. It is important to ensure that adequate radii are incorporated to all thread roots. If this practice is not possible, use threaded inserts. The next alternative is to use self-tapping, thread-cutting screws.

The thread characteristics of Fortron® PPS can be seen by the torque required to break a part by tightening a self-tapping screw. The behavior of 40% glass-reinforced Fortron® PPS and that of a 40% glass-reinforced, highly branched PPS product are compared in Figure 3. It is significant that the highly branched PPS product was cracked as soon as it was tightened, and that little or no increase in breaking torque was seen even though the fitting was lengthened extensively.

Since Fortron® PPS is a high-modulus material, it is recommended that only thread-cutting (type BF or BT), not thread-forming, screws be used.

Metal Inserts

Metal inserts have been successfully used. When molded parts with metal inserts are subjected to repeated heat cycling, property fatigue is expected. Table 4 shows how well both 40% glass-reinforced and 65% mineral/glass-reinforced Fortron® PPS products compare in breakage with a highly branched 40% glass-reinforced PPS resin.

Table 4 Fractured pieces per 10 test pieces subjected to heat cycling

	Fortron® PPS		Highly Branched
W/R	40% Glass	65% Mineral /Glass	40% Glass PPS
0.4	0	0	0
0.3	0	0	1
0.2	0	0	2
0.1	0	2	2

Conditions: [1 h at -40°C (0°F) + 1 h at 150°C (302°F) X 60 cycles.

W = Wall thickness of test piece.

R = Radius of metal insert.

Chapter 9

Secondary Operations

Machining

Because of its exceptional mechanical properties, Fortron® PPS can be machined with conventional metal-working tools. The use of tungsten carbide tipped tools is recommended when reinforced Fortron® PPS products are being machined.

A high degree of precision can be obtained in cutting operations when moderate cutting speeds, i.e., 25–40 m/min, 0.4–0.7 m/s, 80–130 ft/min), are used with fast feed rates. Slow feed results in excessive tool wear and tends to give the part a poor surface appearance. The preferred coolant is ethylene glycol (antifreeze). The tool angle should be about 10°.

Cuts (up to 1/8 in., 3.17 mm) can be made; finish cuts should remove no more than 0.005 in. (0.13 mm) of the material.

Surface Decoration

Many applications that require Fortron® PPS's high-temperature stability, chemical resistance, and desirable mechanical properties are not highly visible parts, and therefore, do not require surface decoration. However, in applications that require surface decoration, several methods, such as painting, printing, and laser beam marking, are possible with Fortron® PPS products.

Because many one-coat painting systems do not give sufficient peel strength, pretreatment with a primer is recommended. Melamine- or alkyd-type paints are recommended for the best results. A urethane-based paint has been identified as a useful primerless paint system.

Printing is also possible, but a pretreatment is again recommended. Two-component urethane-based printing inks generally have been found to give good results.

Laser beam marking has also been accomplished successfully with Fortron® PPS products.

Colorability

Because the base polymer for Fortron® PPS is a light beige, products can be compounded in a variety of colors. However, it is suggested that colored Fortron® PPS be used only for purposes of color coding, since Fortron® PPS colors tend to turn to a darker shade when exposed to heat or UV light for prolonged periods of time, or for short periods at very high temperatures. This phenomenon makes Fortron® PPS an unlikely candidate for applications requiring color matching; however, Fortron® PPS resin is well suited for color coding purposes.

As already stated, Fortron® PPS does undergo a color change at elevated temperatures. However, this color shift is not a sign of degradation and does not significantly affect the bulk properties, such as tensile strength, flexural modulus, and other mechanical and electrical properties.

Engineering Plastics Division

Vectra

Liquid Crystal Polymer

Design Manual (VC-10)

Hoechst Celanese

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Chapter 1

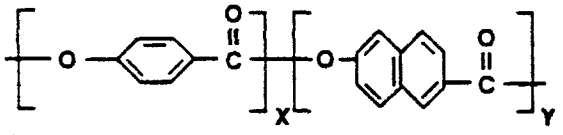
Introduction and Overview

Vectra® resins are members of a relatively new family of high-performance plastic materials that have been given the generic name "liquid crystal polymer" or "LCP".

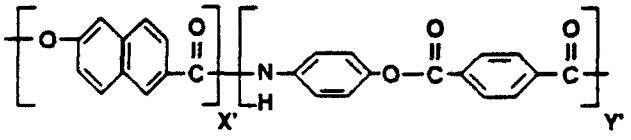
Vectra® products, members of the LCP family, are thermotropic (melt orienting) and fully thermoplastic. They can be processed with all of the techniques common to thermoplastics except for rotational molding. Vectra polymers have extremely rigid, rodlike molecules and are highly ordered, both in the melt state and solid state. Though highly ordered, the molecules flow readily in the melt state, providing good molding characteristics, and can be compounded with reinforcements and fillers, forming unique compounds. Molded parts exhibit very low warpage and shrinkage, along with a high dimensional stability, even when heated up to 200 – 250°C (390 – 480°F).

Chemistry

Vectra A and C Series resins are based on poly (benzoate-naphthoate), a wholly aromatic copolyester:



Vectra B Series is based on poly (naphthoate-aminophenoterephthalate), a wholly aromatic copolyester-amide:



These resins are made in a melt condensation polymerization reaction

LCPs can be viewed in much the same context as other resin families, such as the nylons. That is, while belonging to a common family, individual LCPs may have widely disparate processing characteristics, performance, and applications. As a group, however, Vectra LCPs have in common an excellent processability, which means short cycle times, high flowability in thin sections, and exceptional repeatability of dimensions.

Morphology

The rigid-rod nature of Vectra LCP molecules results in a profile of molecular orientation that resembles the physical orientation of the fibers in a reinforced thermoplastic. The "fountain flow" effect occurring during injection mold filling causes the molecules on the surface of the flow front to be stretched in an elongational flow. Ultimately, these molecules are located on the part surface, which results in a skin that is oriented in the flow direction. The skin may be 15 – 30% of the part's total thickness. Generally, as the part becomes thinner, the skin percentage increases.

During mold filling, the core of the part is subject to shear forces, causing a "tumbling" effect; the core molecules eventually are oriented more or less perpendicular to the flow direction. This behavior mirrors the orientation of glass fibers in the core of a part reinforced with short fibers.

Self-Reinforcement

The flow behavior discussed in the preceding section causes a self-reinforcing effect, i.e., the skin or outer portion of a molded part is highly oriented, giving exceptional flexural strength and modulus, as well as good tensile performance. For example, parts molded from neat (unfilled) Vectra A950 typically have the strength and stiffness associated with 30% glass-reinforced engineering resins (e.g., PBT,PET). When reinforced with 30% glass fibers, Vectra A130 has strength 5 – 10 kpsi higher and stiffness about 1 Mpsi higher than that of typical glass-reinforced engineering resins.

Anisotropy

Injection-molded filled and reinforced Vectra resins have a degree of anisotropy (physical properties in the flow direction differ from those in transverse to flow) slightly greater than that of conventional 30% glass-reinforced resins. Thus, anisotropy is not a major impediment when designing for mechanical properties. Vectra LCPs differ in degree of anisotropy rather than in kind. Plastics part designers have learned to deal with anisotropy by working with glass fiber reinforced engineering resins.

Creep

Vectra resins are quite resistant to creep at ambient temperatures. A glass transition results in a diminishing level of creep resistance in the 100 – 180°C (212° – 356°F) temperature range.

Fibrillation

Because of LCPs exceptionally high level of self - reinforcement through orientation, the surface molecules on a molded part tend to align parallel to the flow direction. Fibrillation, which is manifested by the peeling or pulling off of small fibrils of an oriented surface, occurs with abrasion. This effect is eliminated in filled or reinforced Vectra resins. Fibrillation is a problem with neat (unfilled) LCPs such as A950, B950, and C950 which are not recommended for injection molding applications.

Thermal Resistance

The dimensional stability of parts molded from Vectra resins is sufficient to make them suitable for vapor phase soldering (VPS) at 215°C (419°F), and for infrared (IR) soldering used in surface mount technology (SMT). There is very little shrinkage or warpage during exposure to SMT soldering, making Vectra LCPs a preferred choice for SMT parts. The low coefficient of thermal expansion minimizes any tendency to warp or bow. In addition, Vectra resins are extremely resistant to thermal degradation, both as solids and in the melt phase, because of their highly aromatic structure. The rigid-rod molecular structure gives high melting and use temperatures. Fiber reinforced resins have HDTs (264 psi) of 220 – 240°C (428 – 465°F), and 250 –270°C (480 – 518°F) at lower stress (66 psi). Underwriters Laboratories has granted continuous service temperatures (RTI) over 200°C (392°F).

Flammability

In reinforced grades, Vectra compounds are rated UL94 V-0 in thicknesses as low as 1/32 in. (0.031 in. or 0.8 mm). The Limiting Oxygen Index of Vectra resin is in the 35 – 40% range, depending on the base resin and level of filler or reinforcing fiber. Being wholly aromatic, Vectra resins form a char on exposure to open flame. This layer of char acts to slow the formation of combustible gases.

Electrical Properties

Vectra resins are excellent electrical insulators with exceptional dielectric strength even at elevated temperatures. Vectra materials are relatively transparent to household and radar microwaves, and are quite suitable for a wide variety of electronic connectors and devices.

Environmental Resistance

Chemicals: Vectra LCPs are highly resistant to most solvents at moderate to elevated temperatures (about 150 – 200°C). They are stable when exposed to steam and hot water for extended periods of time, and to strong acids and mild bases at temperatures ranging from 50 –100°C (120 – 210°F).

Weathering: Vectra resins have generally good resistance to weathering but do show some chalking on extended exposure to sunlight (>365 days)

Radiation: Vectra materials, show excellent resistance when exposed to gamma radiation, there are virtually no changes in properties.

Approvals

Extensive UL short and long-term property listings for Vectra LCPs are available on UL "Yellow Cards." Available data include Vectra A115, A130, A150, A230, A410, A420, A422, A430, A515, A530, A540, A550, A950, B130, B950, C115, C130, C150, and C950. In addition, Mil Spec 24519 has been granted for Vectra A130, (GLCP-30F), Vectra A150,(GLCP-50F), and Vectra C130,(GLCP-30F)

Processing

Vectra resins are well suited for injection molding applications. They exhibit low shrinkage and are noted for their low coefficient of thermal expansion (CTE). They can be injection molded with unusually fast cycle times and high levels of regrind; they can be molded into long thin sections without flash. For these reasons, Vectra LCPs are actually much more economical for injection molding applications than their price per pound or per cubic inch would initially indicate. Furthermore, with proper design of parts and molds, they are among the easiest materials to process.

Low Mold Shrinkage: Vectra resins have uniquely low mold shrinkage because there is virtually no conventional crystallinity developed during the transition from melt phase to solid phase. Therefore, essentially all of the shrinkage occurs as a result of thermal expansion or contraction as the part changes temperature. Typically, fiber-reinforced Vectra resins have 0.1 – 0.2% shrinkage in the flow direction and 0.3 – 0.5% in the transverse direction. This is about one-third to one-half that of a crystalline resin of comparable filler content.

Coefficient of Linear Thermal Expansion (CTE): Vectra resins have a very low CTE; for fiber-reinforced grades, the CTE is about 5 ppm/°C (9 ppm/°F) in the flow direction and 30 – 50 ppm/°C (55 – 90 pm/°F) in the transverse direction. [ppm = cm/cm x 10^{-6} or in./in.x 10^{-6}].

The CTE is low enough so that the expansion of connectors, bobbins, and other items can nearly match that of FR-4 (glass-reinforced epoxy) printed wiring board materials. Matched CTE's result in lower contact stress and less tendency to bow the board when surface mount technology processing is used.

Injection Molding: The very fast cycle times possible with Vectra materials result from the near zero heat of transformation (fusion) at the melt transition temperature. The heat of fusion is only 5 – 10% that of polybutylene terephthalate or polyethylene terephthalate. In addition, use of a cool mold 90 – 100°C (195 – 212°F) accelerates the cooling process and further trims cycle times. Molded-in stress is virtually nonexistent at all mold temperatures,ambient to 150°C (300°F).

The use of runners and reground parts requires care and some special techniques which are described later. However, once a well-ground product is obtained, regrind levels of 25% are recommended. With care and proper testing, regrind levels to 50 - 75% may be possible. Careful drying is crucial to maintaining molecular weight and thus ensures a consistent process and product.

The exceptionally low melt viscosity of Vectra resin allows easy flow at low pressure. Parts are usually gated at one end; multiple gates are generally discouraged because of knit lines. Careful design, however, minimizes the effect of weak knit lines in all but the most critical cases. For example, parts that have the shape of a "picture frame" and have thin or narrow sections at the knit lines may require overflows in the mold design.

Vectra LCPs have been injection molded on nearly all types of commercial machines. The preferred machine is a reciprocating screw injection molding type. The shot size should be 50 - 75% of the machines rating. There should be a provision for zero back pressure during plastication, a functional check ring, thermocouple-controlled heating zones, and a reverse taper (nylon-type) nozzle.

Extrusion: Please consult your Vectra LCP technical service engineer for information on extrusion of Vectra resins.

Chapter 2

The Family of Vectra Resins

Individual members of the Vectra resin family are tailored with functional fillers, fibers, and pigments to accommodate the requirements of many different applications. LCPs retain their excellent flow properties and reliable processing performance at filler levels up to 55%.

Base Resins

Vectra base resins are divided into two wholly aromatic groups: copolyesters and copolyester–amides. The copolyesters can be further arranged according to their melt point and processing temperature ranges. The designations for all standard Vectra resins consist of a letter indicating the polymer type and three digits indicating the filler/fiber type and level.

Vectra Family Groups

Grade	Chemistry	Melt Point °C (°F)	Characteristics
A950	Copolyester	280 (535)	General purpose.
C950	Copolyester	325 (615)	Easier flow. Higher stiffness and creep resistance above 200°C.
B950	Copolyester-amide	280 (535)	Highest strength and stiffness.

Glass Fiber Reinforced Resins

Reinforcement with glass fibers adds stiffness, strength and heat resistance, and reduces the degree of anisotropy. As the amount of glass fiber is increased, warpage is found to decrease. Some of the glass-reinforced Vectra LCPs are offered in three glass levels: 15, 30, and 50%. These are general purpose resins suitable for a wide variety of precision industrial, automotive, medical and aerospace applications. They are also rated UL V-0 to 1/64 of an in., and are specified for electrical and electronic devices such as connectors, passive components, bobbins, potting shells, and relay components. In surface-mounted applications, Vectra LCPs are dimensionally stable and vapor-phase and IR solderable. The designations are:

A115, A130, A150: 15, 30 and 50% glass fiber in A950

B130: 30% glass fiber in B950

C115, C130, C150: 15, 30 and 50% glass fiber in C950

Carbon Fiber Reinforced Resins

Reinforcement with carbon fibers gives higher stiffness and strength than that obtained with glass fibers. Otherwise the physical properties are similar to Vectra resins modified with glass. Carbon fiber modified resins are electrically conductive and generally applied where the highest possible modulus is required. Carbon fiber reinforced Vectra resins are offered with 30% reinforcement and are designated as follows:

A230: 30% carbon fiber in A950

B230: 30% carbon fiber in B950

Other Filler/Fiber Combinations

Miscellaneous combinations of fillers and fibers generally suitable for bearing and wear applications are grouped in the 400 Series of Vectra LCPs as listed below:

A410: highly filled glass-fiber/mineral variant; easy flow and excellent dimensional stability.

A420: highly filled glass-fiber/mineral/graphite flake variant; good wear characteristics.

A422: moderately higher glass content and higher graphite flake content; better bearing properties, good wear and chemical resistance.

A430: moderately filled with polytetrafluoroethylene (PTFE) powder

A435: a glass-reinforced, polytetrafluoroethylene modified bearing and wear variant with high strength and stiffness.

B420: similar to A420, but using B950 resin as a base; hardest Vectra resin variant; good wear resistance for light-duty bushings and bearings.

Mineral-Filled Resins

The mineral filled variations listed below have easy flow and good to excellent impact resistance. They are usually specified in applications where flatness is important.

A515, A540: 15 and 40% mineral filled A950

A530: moderately mineral filled, with softer filler; easy flow, good toughness and excellent dimensional stability; used in wear applications where low wear of counter surface is critical.

C550: mineral-filled C950; excellent dimensional stability, high temperature resistance.

Graphite Flake Filled Resins

Vectra LCP filled with graphite flake has exceptional hydrolytic stability and resistance to chemical attack. Useful in vessels, tubing and fittings where chemical resistance is needed; also for thin-wall encapsulation (0.015 in).

A625: graphite flake filled A950.

Electrostatic Dissipative Grades

Resins in the 700 Series are modified with a conductive carbon black to provide electrostatic dissipation. They are suitable for PWB carriers, static draining guides, and metal replacement.

A230: 30% carbon fiber in A950.

B230: 30% carbon fiber in B950.

A700: 30% glass reinforcement with conductive carbon black in A950. Good static dissipation, stiffness and strength; requires higher pressures to mold.

Color Concentrates

Color concentrates are available in letdown ratios of 10, 15 or 20 to 1. These concentrates are intended for color identification purposes rather than color matching. Cadmium pigments have been eliminated in these color concentrates. The color concentrates are available in these colors: red, yellow, white, back, blue, brown and green.

Precompounded colors may be available; please check with your Vectra resin marketing representative

Developmental Resins

The developmental Vectra resin described below is being introduced to the market to meet specific needs.

Platable Grades: for printed circuitry applied directly to a molded part.

C810: highly filled; conventional cycle times, special etch step, smooth surface.

C130M: 30% filled, conventional cycle time, used as the non-platable plastic in the two shot molding process.

Other platable grades can be developed to suit the particular needs of the application. For further information, contact your local Vectra resin marketing representative.

Chapter 3

Design Considerations

Key properties of Vectra LCPs of interest to those who design and specify materials are covered in this section. These include mechanical, physical, thermal, flammability, electrical and environmental characteristics.

Mechanical Considerations

Mechanical Properties: The data presented here were all measured on ⅛ in. (3.2 mm) thick injection molded bars, unless otherwise noted. When considering these property data, it is important to keep in mind that the thick, highly oriented skin, which is characteristic of parts molded from Vectra resins, may comprise about 40% of a ⅛ in. thick piece. This unusual flow-induced orientation of both polymer and fibrous fillers results in an unusual relationship between part thickness and mechanically related properties—strength, stiffness, coefficient of thermal expansion, heat deflection temperature, and others. When designing parts, it is necessary to consider the thickness of a molded section as well as the flow-induced orientation. For example, a cantilever beam in a snap fit must be scaled for modulus as well as the strain level. Contrary to what might be expected, very thick sections are noticeably lower in modulus and strength than thinner ones.

Fibrous Nature: The layered, fibrous nature of a section molded from Vectra resins compared with that of a glass-reinforced engineering plastic is shown in Figures 3.1 and 3.2. The skin can be seen to contain glass fibers that are highly oriented in the flow direction, while fibers in the part's core are much less oriented. The conventional resin appears to break quite cleanly and does not have the woodlike fibrous surface.

Figure 3.1 Fractured Vectra—A130 (30% glass reinforced A950) injection molded bar.

Figure 3.2 Fractured Celanex 3300 (33% glass fiber reinforced PBT) injection molded bar.

Anisotropy: The anisotropy of Vectra LCPs vary sharply as a function of filler type and amount. Contrary to experience with conventional resins that are nearly isotropic when unfilled, LCPs are highly anisotropic when unfilled. One result of this situation is that neat Vectra resins fibrillate easily when lightly abraded. Unlike other resins, LCPs become more isotropic as the level of fiberous reinforcement increases. For example, while the transverse stiffness or strength of Vectra A950 is about 10% of that in the flow direction (MD), it is 40 – 60% of the flow direction measurement in the reinforced resins A130 or A150. In contrast, PBT with 30% glass reinforcement is about the same ratios of transverse-to-flow direction (TD/MD) mechanical properties as Vectra A130 or C130. Figures 3.3 – 3.6 illustrate this effect for some of the most frequently used Vectra variants and a typical 30% glass-reinforced PBT, Celanex® 3310 (see Fig. 3.5 and Fig. 3.6).

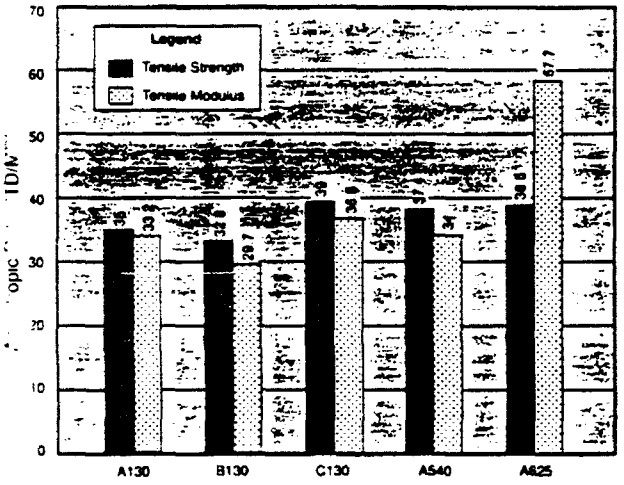


Figure 3.3 Vectra® Anisotropy - Tensile Properties 1/16 in. Thickness

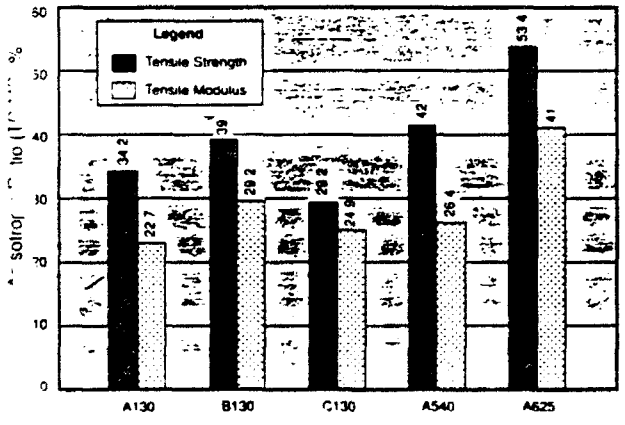


Figure 3.4 Vectra® Anisotropy - Flexural Properties 1/16 in. Thickness

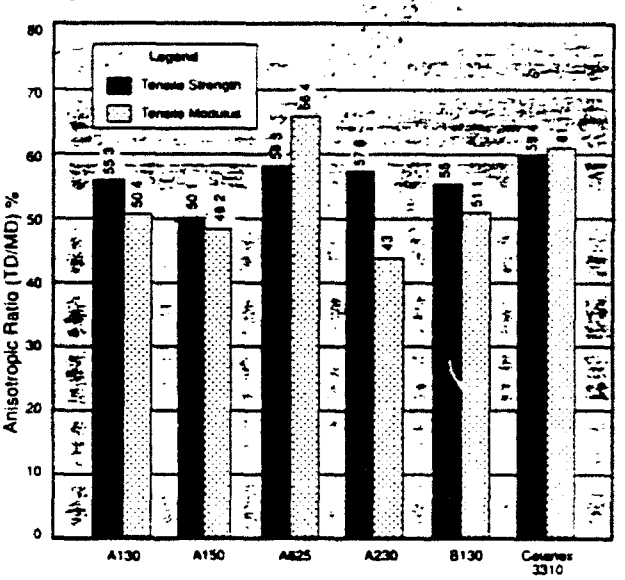


Figure 3.5 Vectra®, Celanex® Anisotropy - Tensile Properties 1/8 in. Thickness

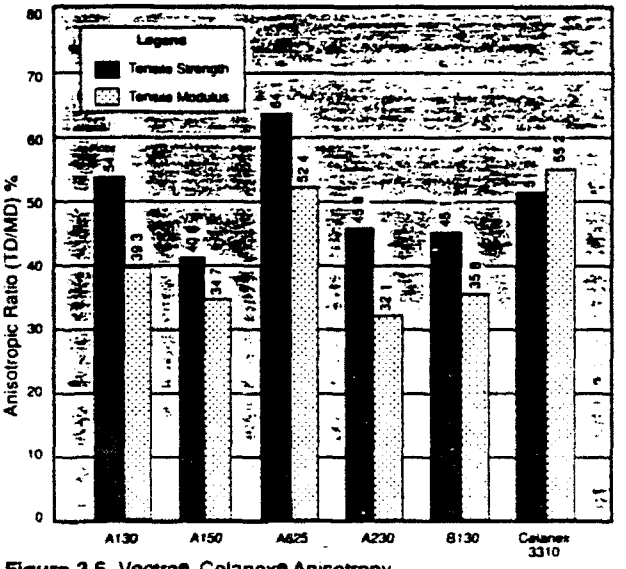


Figure 3.6 Vectra®, Celanex® Anisotropy - Flexural Properties 1/8 in. Thickness

Thickness: The effect of thickness on the mechanical properties is shown in Figure 3.7 and Figure 3.8, where stiffness and strength are compared as a function of thickness for several commonly selected compounds.

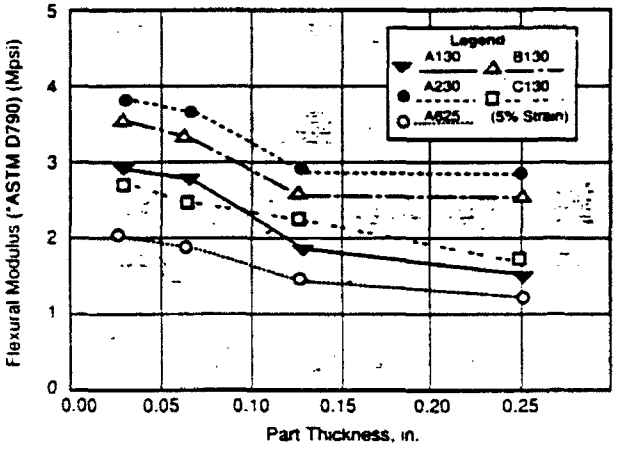


Figure 3.7 Flexural Modulus* vs. Part Thickness

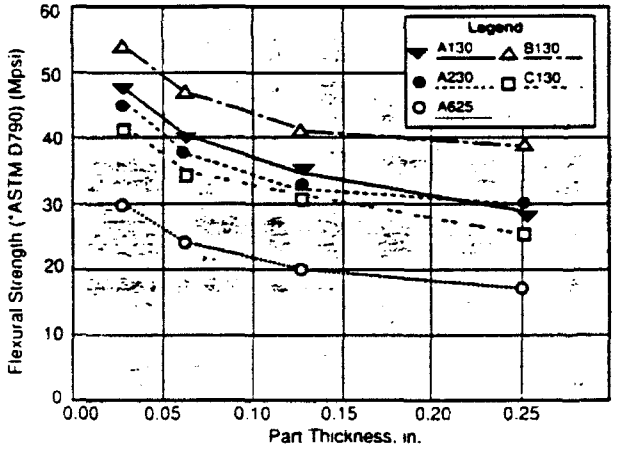


Figure 3.8 Flexural Strength* vs. Part Thickness

Temperature: The effect of temperature on Vectra resins is similar to that of other semicrystalline plastics. That is, as temperature increases, stiffness and strength are reduced. However, toughness of molded parts is maintained without noticeable embrittlement down to cryogenic temperatures as low as that of liquid nitrogen; see Table 3.1 (A950). Figures 3.9 – 3.14 illustrate the effects of temperature on strength and stiffness of several Vectra compounds.

Table 3.1 Low Temperature Properties Vectra A950

Temperature (°F)	Tensile Strength (psi)	Tensile Modulus (psi)	Impact, Notched Izod (ft-lb/in.)
73	23,000	1.5 x 10⁶	13.0
-32	26,000	1.6 x 10⁶	12.0
-220	24,000	2.1 x 10⁶	10.5
-320(LN₂)*	24,000		9.5

*Tests conducted following immersion of samples in liquid nitrogen.

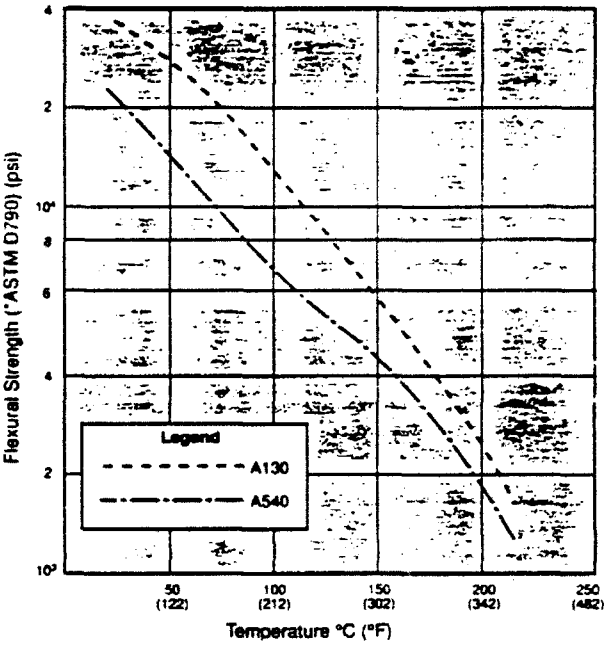


Figure 3.9 Flexural Strength* vs. Temperature

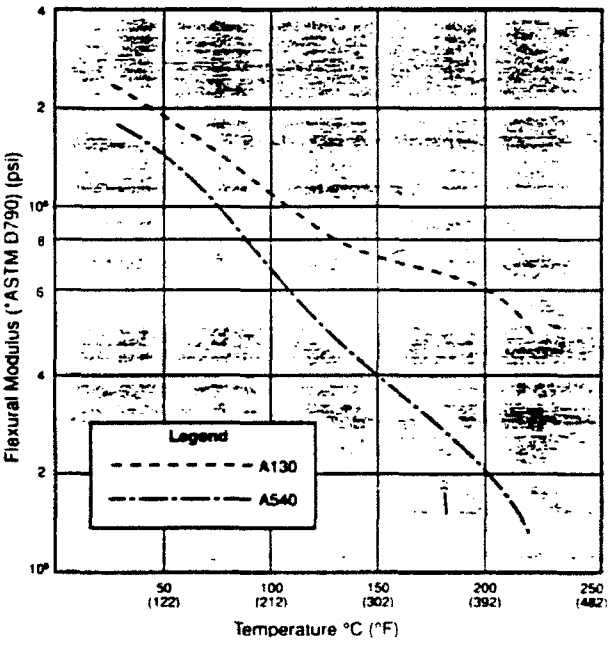


Figure 3.10 Flexural Modulus* vs. Temperature

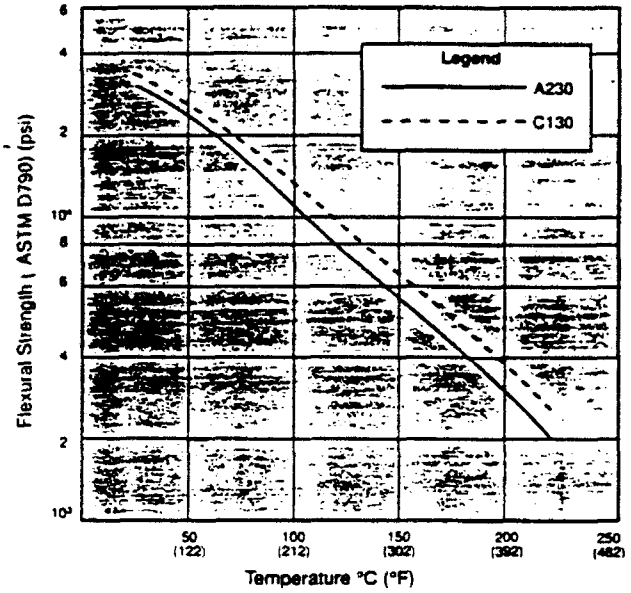


Figure 3.11 Flexural Strength* vs. Temperature

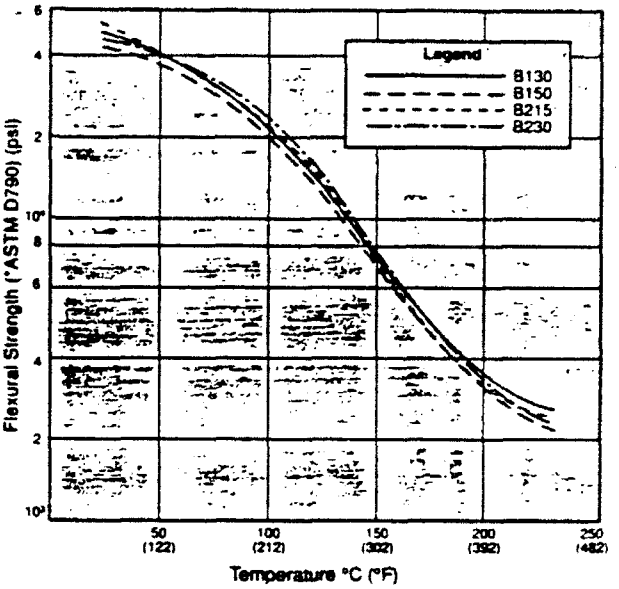


Figure 3.13 Flexural Strength* vs. Temperature

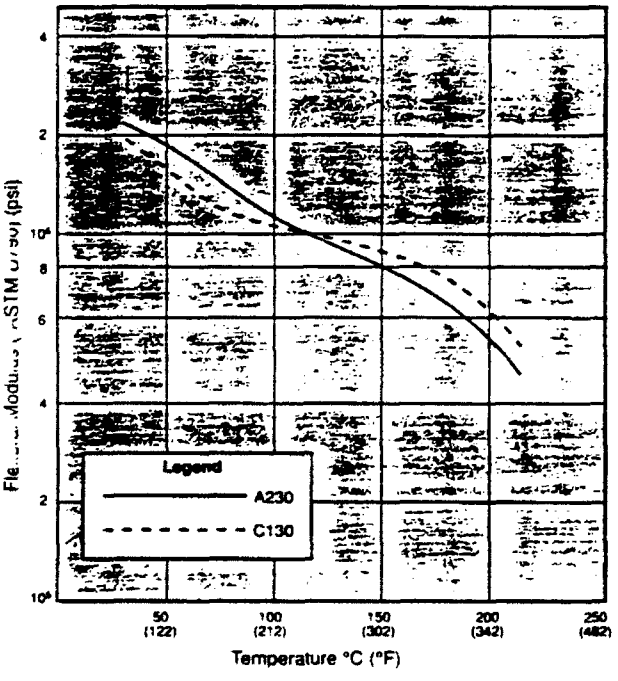


Figure 3.12 Flexural Modulus* vs. Temperature

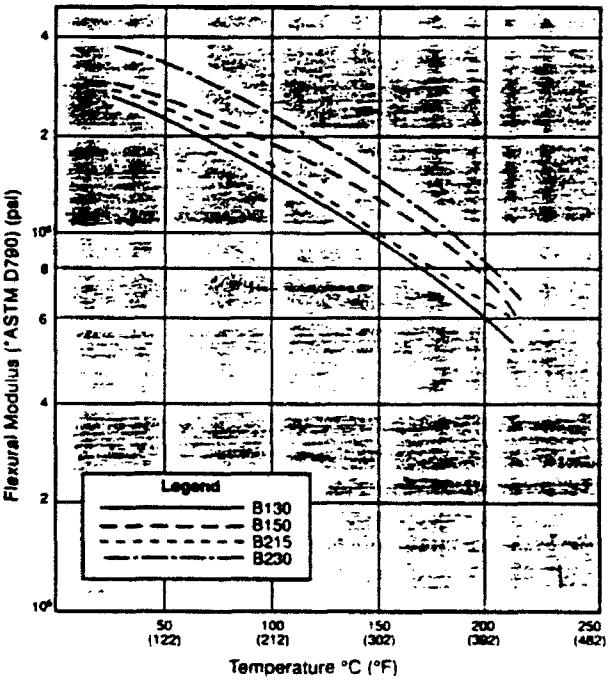


Figure 3.14 Flexural Modulus* vs. Temperature

Creep Resistance: Vectra LCPs have good resistance to creep. The creep moduli for several grades at temperatures from ambient to 250°C (480°F) and appropriate stress levels are shown in Figures 3.15 – 3.17. The test stresses were chosen to be 30% of the short-term failure stress, and none of the samples failed in testing, which extended beyond 10,000 hours. No sign of creep rupture—a common form of failure—was observed at stress levels below 30%.

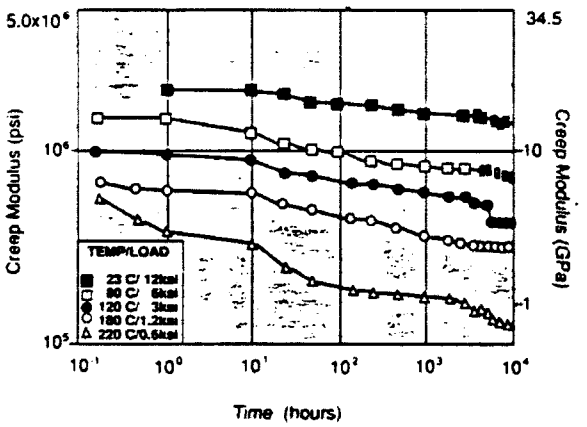


Figure 3.15 Vectra A130 Creep Modulus

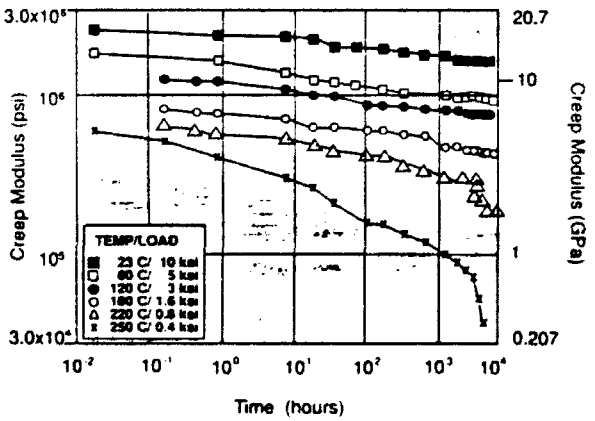


Figure 3.16 Vectra C130 Creep Modulus (Annealed)

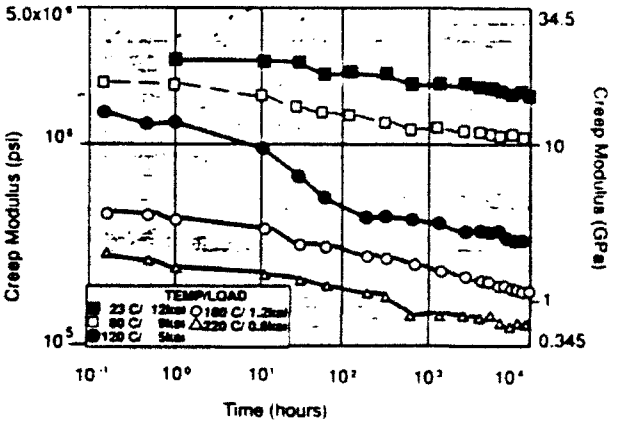


Figure 3.17 Vectra B130 Creep Modulus

Fatigue: The fatigue resistance of Vectra materials is also good, according to somewhat limited testing performed thus far. Figure 3.18 is an example of tensile fatigue data for Vectra A230.

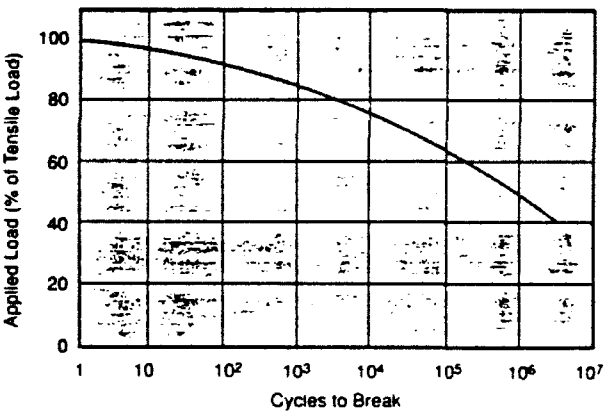


Figure 3.18 Vectra A230 Tensile Fatigue

Table 3.4 Heat Deflection Temperature (HDT) Ranges

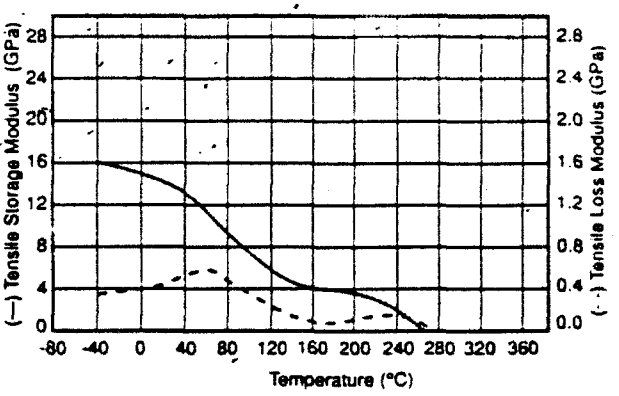
Grade	Heat Deflection Temperature °F (°C) at 264 psi (ASTM D648)
100 Series (glass filled)	430-485 (220-250*)
200 Series (carbon fiber filled)	430-445 (220-230)
400 Series (glass/graphite/mineral)	430-445 (220-230)
500 Series (mineral filled)	355-375 (180-190)
600 Series (graphite filled)	355 (180)
900 Series (unfilled)	355-375 (180-190)

Table 3.5 Coefficient of Linear Thermal Expansion (CTE)

Grade	CTE ppm/ °F (°C)	
	Flow Direction	Transverse Direction
Vectra 30% glass reinforced	1 - 3 (2 - 6)	30 - 40 (50 - 70)
Vectra 40% mineral reinforced	5 (9)	35 (65)
Vectra 30% carbon fiber reinforced	-1 to -2 (-2 to -3)	25 - 35 (45 - 65)
PPS 40% glass reinforced	10 - 15 (20 - 25)	n.a.
PBT 30% glass reinforced	25 - 30 (45 - 50)	n.a.

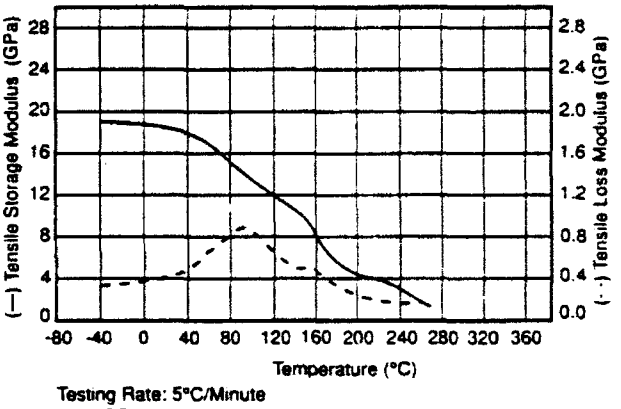
Dynamic Mechanical Spectra: Dynamic Mechanical Analysis (DMA) is a powerful technique for indicating the stiffness of a molded part as a function of temperature. Thus, it is a useful method to compare semiquantitatively the thermomechanical performance of different resins. For instance, DMA curves for Vectra A130, B130 and C130 are shown in Figures 3.19 - 3.21. Stiffness of Vectra B130 at room temperature is seen to be much higher than that of general purpose Vectra A130, while in the vapor phase and IR soldering range of 215 – 230°C (419 – 445°F), the stiffness of C130 exceeds that of A130.

An additional property that should be noted is the damping or energy-absorbing characteristics of the resins. The curves indicate strong damping peaks at about 50 – 80°C (120 – 175°F); therefore, at these temperatures plastic parts of Vectra resin are especially efficient at absorbing mechanical energy or acting as sound dampers. At other temperatures, Vectra parts are already very good for absorbing energy, as evidenced by the lack of "ringing" when they are dropped on a hard surface or subjected to vibration in service.



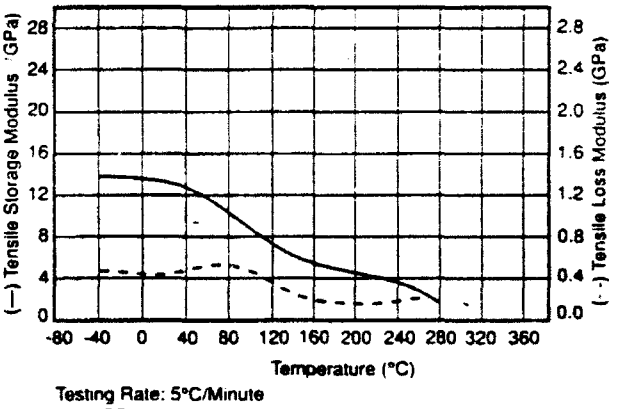
Testing Rate: 5°C/Minute
psi = GPa x 145,000

Figure 3.19 Dynamic Mechanical Analysis (DMA) Vectra® A130



Testing Rate: 5°C/Minute
psi = GPa x 145,000

Figure 3.20 Dynamic Mechanical Analysis (DMA) Vectra® B130



Testing Rate: 5°C/Minute
psi = GPa x 145,000

Figure 3.21 Dynamic Mechanical Analysis (DMA) Vectra® C130

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Soldering Stability: Vectra glass-filled variants are commercially successful in applications requiring wave, vapor-phase, and IR soldering. Table 3.6 shows the reflow soldering stability of LCPs versus some other thermoplastics.

Table 3.6 Vapor-Phase Solder Stability

Thermoplastic	Percent Dimensional Change after 419°F (215°C) Exposure*
LCP (30% G.R.)	L < 0.05 W < 0.05 D < 0.05
PBT (30% G.R.)	L 0.2 W 0.3 D 0.2
PPS (40% G.R.)	L −0.15 W 0.53 D 0.55
PEI (30% G.R.)	L 0.25 W 0.06 D 0.55

L = flow direction dimension change (in percent)
W = transverse direction dimension change (in percent)
D = thickness direction dimension change (in percent)
* Exposure to Fluorinert® FC-70
® Registered trademark of 3M Co.

Blistering: When exposed to temperatures near the melt point, Vectra LCP parts can blister. Blisters are caused by insufficient drying before molding or thermal abuse during molding. Molders should avoid excessive melt temperature and residence time in the barrel. Increasing thermal abuse decreases the temperature at which blistering is first evident. This effect can be used to gauge manufacturing quality, since excessive thermal abuse results in blistering when the piece is exposed to a threshold temperature. With proper processing, parts do not blister at temperatures up to 240 – 260°C (465 – 500°F).

Continuous Service: Underwriters Laboratories' UL746B test sequence is used to establish Relative Thermal Indices (RTI), sometimes called continuous use temperatures. Based on thermal aging measurements, RTI's give a guideline temperature for long term retention of properties such as dielectric strength, tensile strength (mechanical strength without impact), and tensile impact (strength. The final RTI's for the glass-reinforced Vectra Series A130, A150, and C130 are listed in Table 3.7. Please consult your Vectra LCP marketing representative for further UL information on other compounds.

Table 3.7 UL 746B Long-Term Properties

	Relative Thermal Index, °F (°C)		
Material	Electrical	Mechanical	
		without impact	with impact
A 130	465 (240)	430 (220)	430 (220)
A 150	430 (220)	430 (220)	430 (220)
C 130	465 (240)	392 (200)	392 (200)

Flammability

Vectra LCPs are inherently flame resistant. They are rated UL94V-0 by UL test procedure without any additive package for flame resistance. The limiting oxygen indices range from 35 – 50%. Vectra resins meet the current Federal Aviation Administration standards for aircraft interiors. They have a low NBS smoke density rating (Table 3.8) and the products of combustion contain nondetectable levels of halogens and cyanides (Table 3.9). In addition, Vectra LCPs performed very well in The Ohio State University Heat Release Test (Table 3.10) per FAR 25.853 (A-1), part IV of Appendix F.

Table 3.8 Smoke Density* Vectra A950

	1/16 in. (1.6 mm)		1/8 in. (3.2 mm)	
	Flaming	Smoldering	Flaming	Smoldering
D_s @ 1.5 min	0	0	0	0
D_s @ 4.0 min	3	2	3	0
Time to 90% D_m (min)	16.5	20.0	17.0	18.7
D_s	95	2	94	1
D_m	94	2	92	0
Vectra B950				
	1/16 in. (1.6 mm)		1/8 in. (3.2 mm)	
	Flaming	Smoldering	Flaming	Smoldering
D_s @ 1.5 min	0	0	0	0
D_s @ 4.0 min	5	2	2	0
Time to 90% D_m (min)	14.5	20.0	17.5	19.0
D_s	70	2	80	1
D_m	69	2	70	0

*NBS Smoke Density Chamber ASTM E-622, NFP 258
Above are typical values, not to be used for specification purposes.

Table 3.9 Vectra Products of Combustion (ppm)

Gas	A950 Smoldering	A950 Flaming	B950 Smoldering	B950 Flaming
Chlorine	0	0	0	0
Phosgene	0	0	0	0
Hydrogen Chloride	0	0	0	0
Hydrogen Fluoride	0	0	0	0
Formaldehyde	0	<2	0	<2
Ammonia	0	0	0	0
Carbon Monoxide	<10	320	<10	300
Carbon Dioxide	600	8000	6000	7000
Nitrogen Oxides	<2	5	<2	12
Hydrogen Cyanide	0	<2	0	<2
Sulfur Dioxide	0	0	0	0
Hydrocarbons, as n-Octane	0	250	0	300

The above data were generated on 3 inch x 3 inch x 1/8 inch (76.2 mm x 76.2 mm x 3.2 mm) thick plaques. The gases were measured using Drager tubes attached to a sampling post and circulating system added to the NBS smoke density chamber.

NBS Smoke Density Chamber
ASTM E-662, NFP 258

Above are typical values, not to be used for specification purposes.

Table 3.10 The Ohio State University Heat Release Test: Vectra A950

Test Panel Thickness, Inches, (mm)	Accumulative Heat Release @ 2 Minutes (kW/cm²)	Maximum Rate of Heat Release (kW/cm²)
0.062 (1.6)	16.8	57.8 @ 177 seconds
0.125 (3.2)	2.4	59.2 @ 293 seconds
Standard	<65.0	<65.0

• Tested per FAR 25.853 (A-1), Part IV of Appendix F
• Above are actual data from one tested lot believed to be typical.

Electrical Properties

Vectra resins exhibit good electrical properties. These characteristics combined with easy processing, dimensional stability, heat resistance, and mechanical integrity make Vectra LCPs widely chosen for electronic components, especially for applications involving surface mount technology. With outstanding dielectric strength—typically 30 – 50% higher than that of other engineering thermoplastics—Vectra resins are also available with low to moderate conductivity (Table 3.11). These variants can be used for static dissipating applications (ESD) and limited electromagnetic interference (EMI) applications.

Table 3.11 Conductive Vectra Variants

Vectra Variants	Carbon Fiber	Conductive Carbon Black
Grade	A230	A700
Volume Resistivity, ohm-cm	$10 - 10^2$	$10^2 - 10^7$

* Measured on molded bars, silver-painted ends.

In addition, Underwriters Laboratories has tested a number of Vectra variants (Table 3.12); they report measurements of flammability, arc resistance, hot wire ignition, high current arc ignition, high voltage arcing rates, and comparative tracking index. These data are all reported on the standard U.L. "Yellow Cards."

Table 3.12 Electrical Properties of Vectra variants

Property	ASTM Test	Unit	Variants									
			A130	A150	A230	A410	A420	A540	A625	B130	C130	C150
Volume Resistivity	D257	ohm-cm	9.7×10^{15}	2.7×10^{15}	4.3×10^{3}	6.8×10^{15}	1×10^{16}	2.9×10^{16}	1×10^{16}	1.7×10^{16}	2.5×10^{16}	2.5×10^{16}
Surface Resistivity	D257	ohm	7.9×10^{15}	3.0×10^{15}	5.9×10^{2}	8.6×10^{15}	1.6×10^{16}	5.3×10^{16}	9.4×10^{15}	1.6×10^{17}	5.2×10^{16}	2.1×10^{16}
Arc Resistance	D495	sec	128	180	—	181	175	139	124	131	181	
Comparative Tracking Resistance	D3636	volt	175	200	—	200	225	200	225	150	175	200
Dielectric Strength Short Time	D149	kV/mm	24	22	—	22	17	22		23	23	22
Dielectric Constant* 1 kHz	D150		4.1	4.5	—	4.2	6.6	4.5	11	3.9	4.0	4.6
1 MHz			3.7	4.2	—	3.8	6.0	4.1	9	3.7	3.6	4.2
Dissipation Factor* 1 kHz	D150		0.020	0.016	—	0.019	0.019	0.017	0.041	0.011	0.020	0.015
1 MHz			0.017	0.015	—	0.016	0.020	0.014	0.060	0.012	0.018	0.014

*Specimen thickness: 3 mm
Condition: 20° C @ 60% RH

Environmental Considerations

Water Resistance: Figures 3.22 and 3.23 illustrate the effect of steam exposure and water immersion on Vectra A950, A130, and A625. In general, water immersion is more severe than steam exposure. Vectra A625 exhibits excellent retention of tensile strength and modulus. Most grades retain 60 – 80% of tensile properties after 1000 hour exposures.

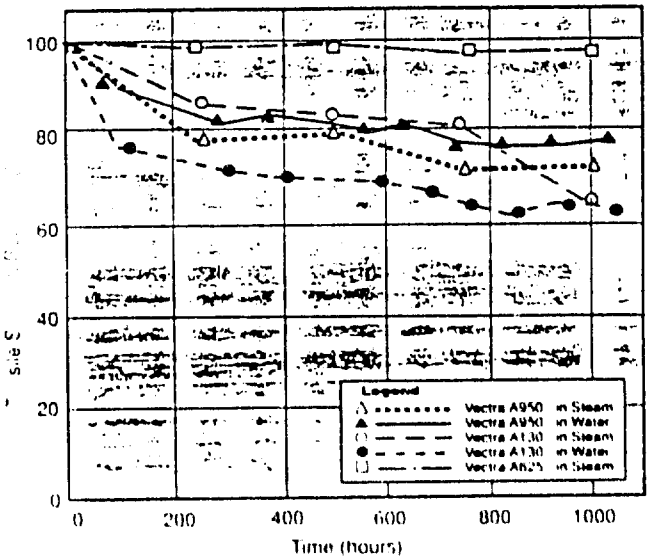


Figure 3.22 Hydrolytic Stability in Water and Steam @ 121°C and 15 psig

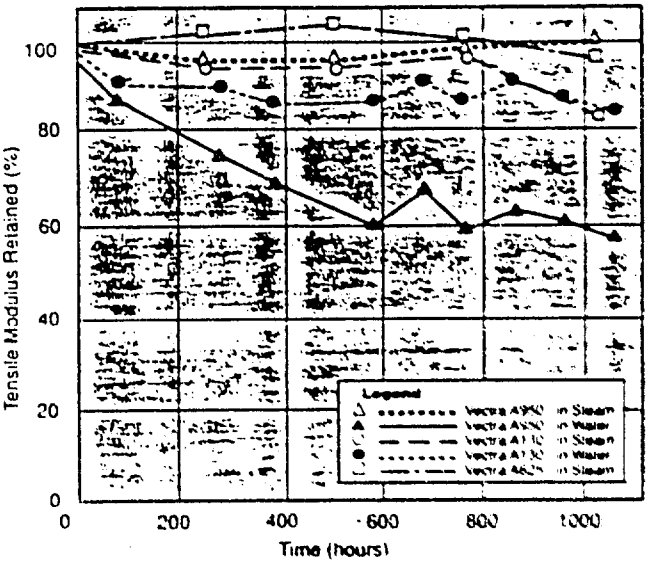
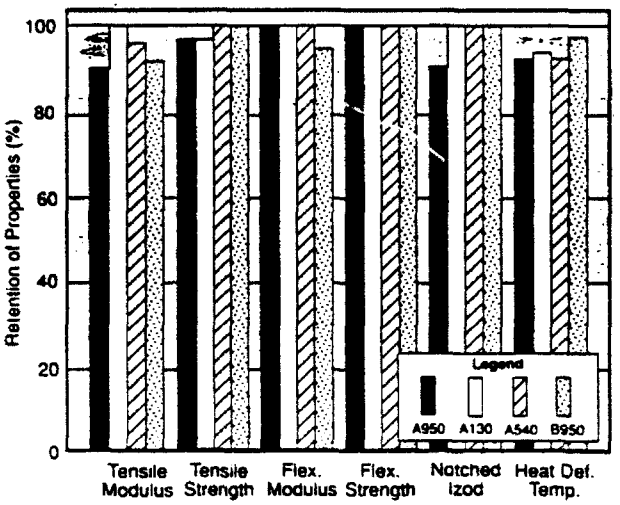


Figure 3.23 Hydrolytic Stability in Water and Steam @ 121°C and 15 psig

Weathering: Figure 3.24 presents the effects of 2000 hours exposure in a xenon arc weatherometer. Vectra materials show a high degree of property retention, more than 90% of the original values. Some minor chalking, however, has been observed in outdoor weathering tests lasting more than one year.

Figure 3.24 Weatherability of LCP Resins, 2,000 Hrs. in Weatherometer* (ASTM D2565)



*Xenon arc lamp, air temperature 125°C, 18 minute water spray every 202 minutes

Chemical Resistance: The resistance of Vectra A950 and other grades to common inorganic and organic solvents, acids, and alkalis is listed in Table 3.13. With a few exceptions, chemical resistance is good over a wide temperature range. In practice, of course, Vectra materials should be checked under actual use conditions, for example, by suspending test bars in the process stream

All chemical resistance data are based on average of five molded ASTM flexural test bars (5.0"x0.5"x0.125").

EPD RATING
A. Essentially no effect: Less than 5% change in mechanical properties and less than 2% change in weight and dimensions.
B. Some Change.
C. Not Recommended

MPE RATING system as suggested by Modern Plastics Encyclopedia 1986-87 page 422.
A. No significant effect; <0.5% & <10% change weight, dimension, and strength, respectively; slight discoloration.
B. Significant, but usually not conclusive: 0.5%-1.0%, 0.2%-0.5%, 10%-20%, change in weight, dimension and strength respectively; discolored.
C. Usually significant: >1.0%, 0.5% & 20% change in weight, dimension and strength, respectively; distorted, warped, softened or crazed.

Table 3.13 Chemical Resistance of Vectra Resins

The following table of chemical resistance should be used as a guide only. The data indicate the test conditions and resulting ratings. These conditions represent limits of test apparatus and not necessarily limits of use. It is strongly recommended that the end user test any material in the actual chemical environment or product stream before use to determine its suitability. Changes in concentration, temperature, mixtures, or contaminants can significantly affect results.

Reagent	conc (%)	Vectra Grade	Time, Days	Temperature, °F	(°C)	Rating EPD	MPE
Acetic Acid (glacial)	100	A950	30	245	(118)	A	A
	100	A625	120	73	(23)	A	A
Acetone	100	A950	180	133	(56)	A	A
	100	A130	180	133	(56)	A	A
	100	A625	180	133	(56)	A	A
Acetonitrile	100	A625	120	73	(23)	A	A
Antifreeze/Water	50	A950	30	122	(50)	A	A
	50	A950	30	250	(121)	B	B
	50	A150	30	250	(121)	C	C
	50	A422	30	250	(121)	C	C
	50	B950	30	250	(121)	B	B
	50	C950	30	250	(121)	B	B
	50	A150	90	250	(121)	C	C
	50	A422	90	250	(121)	C	C

Reagent	Conc. (%)	Vectra Grade	Time, Days	Temperature, °F	(°C)	Rating EPD	MPE
Brake Fluid:							
Castrol® TLX 988C	100	A950	30	250	(121)	A	
	100	A130	30	250	(121)	B	A
	100	A420	30	250	(121)	B	B
	100	A422	30	250	(121)	B	B
	100	B950	30	250	(121)	A	
	100	C950	30	250	(121)	A	
	100	A130	90	250	(121)	B	C
	100	A420	90	250	(121)	B	C
	100	A422	90	250	(121)	B	C
Dot 3	100	A130	30	250	(121)	B	B
Napa Brand	100	A420	30	250	(121)	B	B
	100	A422	30	250	(121)	B	B
	100	A130	90	250	(121)	B	B
	100	A420	90	250	(121)	B	B
	100	A422	90	250	(121)	B	B
Chlorine Gas (dry)	100	A950	60	73	(23)	A	A
	100	A130	60	73	(23)	A	A
	100	A625	60	73	(23)	A	A
Chlorine/Water (saturated solution)	—	A950	60	73	(23)	A	A
	—	A130	60	73	(23)	A	A
	—	A625	60	73	(23)	A	A
Chromic Acid	50	A950	30	158	(70)	A	A
	50	A130	30	158	(70)	A	B
	50	A625	30	158	(70)	A	A
	50	A950	60	158	(70)	A	A
	50	A130	60	158	(70)	B	B
	50	A625	60	158	(70)	A	A
	70	A950	30	190	(88)	A	B
	70	A130	30	190	(88)	B	C
	70	A625	30	190	(88)	B	C
Dimethyl Formamide	100	A950	60	150	(66)	A	A
	100	A130	60	150	(66)	A	A
	100	A625	60	150	(66)	A	A
Diphenylamine	100	A950	180	150	(66)	A	A
	100	A130	180	150	(66)	A	A
	100	A625	180	150	(66)	A	A
Diphenylcarbonate	100	A950	10	482	(250)	C	
Ethanol	100	A950	30	125	(52)	A	

Castrol® is a registered trademark of Burmah Castrol Inc.

Reagent	conc. (%)	Vectra Grade	Time, Days	Temperature, °F	(°C)	Rating EPD	MPE
Ethyl Acetate	100	A950	180	171	(77)	A	
	100	A130	180	171	(77)	A	
	100	A625	180	171	(77)	A	
Ethylene Diamine	50	A950	90	73	(23)	A	A
	50	A130	90	73	(23)	A	A
	50	A625	90	73	(23)	A	A
	50	A950	180	73	(23)	A	A
	50	A130	180	73	(23)	B	B
	50	A625	180	73	(23)	A	B
	100	A950	30	212		C	
Fluorinert® (FC-70)	100	A950	1	419	(215)	A	
	100	A130	1	419	(215)	A	
	100	C130	1	419	(215)	A	
Formic Acid	80	A950	30	216	(104)	A	
	80	A625	30	216	(104)	A	
	80	A950	270	216	(104)	B	
	80	A625	270	216	(104)	B	
	80	A950	455	216	(104)	C	
Freon® (R-12, R-22) dichlorodifluoromethane, chlorodifluoromethane	100	A950	30	175	(80)	A	
	100	A625	30	175	(80)	A	
Freon® 113 (@ Reflux)	100	A950	60	117	(47)	A	A
	100	A130	60	117	(47)	A	A
	100	A625	60	117	(47)	A	A
FUELS:	100	A950	30	250	(121)	A	
Fuel C, ASTM D471	100	A130	30	250	(121)	B	B
(50/50 Iso-octane/Toluene)	100	A422	30	250	(121)	A	A
	100	B950	30	250	(121)	A	
	100	B420	30	250	(121)	B	B
	100	C950	30	250	(121)	A	
	100	A130	90	250	(121)	B	B
	100	A422	90	250	(121)	B	B
	100	B420	90	250	(121)	B	B
M-85:	15	A130	20	250	(121)	C	C
(15% Fuel C+	15	A422	20	250	(121)	B	C
85% Methanol)	15	B130	20	250	(121)	B	C
	15	B420	20	250	(121)	B	C

Freon® is a registered trademark of E. I. du Pont de Nemours & Co. Inc.
Fluorinert® is a registered trademark of 3M Corporation, Inc.

Reagent	conc. (%)	Vectra Grade	Time, Days	Temperature, °F (°C)	Rating EPD	Rating MPE
Sour Gas	100	A950	30	250 (121)	A	
70/30 Heptane Toluene	100	A130	30	250 (121)	B	B
Copper ion, t-Butyl Hydroperoxide	100	A422	30	250 (121)	B	A
	100	B950	30	250 (121)	A	
	100	B420	30	250 (121)	B	B
	100	A130	90	250 (121)	B	B
	100	A422	90	250 (121)	B	B
	100	B420	90	250 (121)	B	B
Unleaded gasoline	100	A950	30	250 (121)	A	
	100	A130	30	250 (121)	A	C
	100	A422	30	250 (121)	A	B
	100	B950	30	250 (121)	A	
	100	B420	30	250 (121)	A	C
	100	A130	90	250 (121)	A	C
	100	A422	90	250 (121)	A	B
	100	B420	90	250 (121)	A	C
Unleaded gasoline w/10% Methanol	90	A130	30	200 (93)	B	B
	90	A422	30	200 (93)	B	B
	90	A625	30	200 (93)	B	B
	90	B420	30	200 (93)	A	B
	90	A130	90	200 (93)	B	C
	90	A422	90	200 (93)	B	B
	90	A625	90	200 (93)	B	B
	90	B420	90	200 (93)	B	B
	90	A950	30	250 (121)	B	
	90	A130	30	250 (121)	C	C
	90	A422	30	250 (121)	B	C
	90	B950	30	250 (121)	B	
	90	B420	30	250 (121)	B	C
	90	A130	90	250 (121)	C	C
	90	A422	90	250 (121)	C	C
	90	B420	90	250 (121)	B	C
Hexane		A625	10	73 (23)	A	
Hexafluoroisopropanol		A950	10	73 (23)	C	
Hydrochloric Acid	37	A950	30	190 (88)	A	C
	37	A130	30	190 (88)	B	A
	37	A625	30	190 (88)	A	A
	37	C950	30	190 (88)	A	
	37	A950	60, 90, 120	190 (88)	B	C
	37	A130	60, 90, 120	190 (88)	B	C
	37	A625	60, 90, 120	190 (88)	B	C
Hydrochloric Acid (Anhydrous)	100	A950	30 180	73 (23)	C	

Reagent	conc. (%)	Vectra Grade	Time, Days	Temperature, °F	(°C)	Rating EPD	MPE
Iso-Octane	100	A625	120	73	(23)	A	—
Methanol @ Reflux	100	A950	30	148	(64)	A	—
	100	A130	30	148	(64)	B	B
	100	A422	30	148	(64)	B	C
	100	B950	30	148	(64)	A	—
	100	B420	30	148	(64)	B	C
	100	A130	90	148	(64)	B	B
	100	A422	90	148	(64)	B	C
	100	A420	90	148	(64)	B	C
Methylene Chloride	100	A950	180	104	(40)	A	—
	100	A130	180	104	(40)	B	—
	100	A625	180	104	(40)	A	—
Monochloroacetic Acid	100	A950	180	122	(50)	A	—
	100	A130	180	122	(50)	A	—
	100	A625		122	(50)	A	—
Morpholine (200 PPM/ Steam)		A130	10	270	(132)	A	—
Nitric Acid	50	A625	120	73	(23)	A	—
	50	A950	30	158	(70)	A	A
	50	A130	30	158	(70)	A	A
	50	A625	30	158	(70)	A	A
	50	A950	60	158	(70)	A	A
	50	A130	60	158	(70)	A	B
	50	A625	60	158	(70)	A	A
	70	A950	30	190	(88)	B	C
	70	A130	30	190	(88)	C	C
	70	A625	30	190	(88)	B	C
Nitrobenzene	100	A950	30	150	(66)	A	—
Nitroglycerin	100	A950	30	150	(66)	A	—
Oil, Motor Oil 10W-30	100	A950	30	250	(121)	A	—
	100	A130	30	250	(121)	B	B
	100	B950	30	250	(121)	A	—
	100	C950	30	250	(121)	A	—
	100	C130	30	250	(121)	B	B
	100	A130	30	250	(121)	B	B
	100	C130	30	250	(121)	B	B
Oil, Silicone	100	A950	30	392	(200)	A	—
Pentafluorophenol	100	A950	10	140	(60)	C	—

Reagent	conc. (%)	Vectra Grade	Time, Days	Temperature, °F	(°C)	Rating EPD	MPE
Phenol	100	A950	180	212	(100)	A	
	100	A130	180	212	(100)	B	
	100	A625	180	212	(100)	A	
Skydrol®	100	A950	30	160	(71)	A	
	100	B950	30	160	(71)	A	
Sodium Hydroxide	5	A950	30	73	(23)	A	A
	5	A130	30	73	(23)	A	A
	5	A515	30	73	(23)	A	A
	5	A625	30	73	(23)	A	A
	5	A950	90	73	(23)	A	A
	5	A130	90	73	(23)	A	A
	5	A515	90	73	(23)	A	A
	5	A625	90	73	(23)	A	B
	5	A950	7	158	(70)	A	A
	5	A130	7	158	(70)	A	A
	5	A515	7	158	(70)	A	A
	5	A625	7	158	(70)	B	C
	5	A950	30	158	(70)	A	B
	5	A130	30	158	(70)	B	C
	5	A515	30	158	(70)	B	C
	5	A625	30	158	(70)	B	C
	5	A950	60	158	(70)	B	C
	5	A130	60	158	(70)	B	C
	5	A515	60	158	(70)	B	C
	5	A625	60	158	(70)	B	C
	10	A950	30	73	(23)	A	A
	10	A130	30	73	(23)	A	A
	10	A515	30	73	(23)	A	A
	10	A625	30	73	(23)	A	A
	10	A950	90	73	(23)	A	A
	10	A130	90	73	(23)	A	A
	10	A625	90	73	(23)	B	C
	10	A515	90	73	(23)	A	A
	10	A950	30	190	(88)	B	
	10	A130	30	190	(88)	C	
	10	C950	30	190	(88)	A	
	30	A950	30	190	(88)	C	
	30	A130	30	190	(88)	C	
	30	A625	30	190	(88)	C	
	30	C950	30	190	(88)	C	

Skydrol® is a registered trademark of Monsanto Corporation, Inc.

Reagent	conc. (%)	Vectra Grade	Time, Days	Temperature, °F (°C)	Rating EPD	Rating MPE
Sulfuric Acid	50	A950	60	190 (88)	A	A
	50	A130	60	190 (88)	A	A
	50	A625	60	190 (88)	A	A
	70	A950	5	375 (190)	C	
	70	A130	5	375 (190)	C	
	70	A625	5	375 (190)	C	
	70	C950	5	375 (190)	C	
	93	A950	8	73 (23)	B	
	93	A515	8	73 (23)	B	
	93	A625	8	73 (23)	B	
	93	B950	8	73 (23)	C	
	93	A950	30	250 (121)	C	
	93	A130	30	250 (121)	C	
	93	A625	30	250 (121)	C	
	93	C950	30	250 (121)	C	
Tetrahydrofuran	100	A625	120	73 (23)	A	
Toluene	100	A950	180	232 (111)	A	
	100	A130	180	232 (111)	A	
	100	A625	180	232 (111)	A	
Transmission Fluid, Dexron® II	100	A420	30	300 (149)	A	B
	100	A422	30	300 (149)	B	B
	100	A625	30	300 (149)	A	A
	100	B420	30	300 (149)	B	A
	100	C130	30	300 (149)	A	A
	100	A420	90	300 (149)	B	B
	100	A422	90	300 (149)	B	B
	100	A625	90	300 (149)	A	A
	100	B420	90	300 (149)	B	A
	100	C130	90	300 (149)	A	A
Trichloroethane	100	A950	90	150 (66)	A	
Urea	46	A950	60	190 (88)	B	
	46	A130	60	190 (88)	C	
	46	A625	60	190 (88)	B	
Water, Liquid	100	A950	60	250 (121)	A	
	100	A130	60	250 (121)	B	
	100	A625	60	250 (121)	B	
Water, Steam	—	A950	60	250 (121)	B	
	—	A130	60	250 (121)	B	
	—	A625	60	250 (121)	A	

Dexron® is a registered trademark of Burmah-Castrol Inc

Radiation Resistance: The effects of exposing neat resins, Vectra A950 and B950, to Cobalt 60 radiation at various dosage levels are shown in Tables 3.14 and 3.15. Even at 500 Mrad exposure, both grades have excellent retention of properties.

Table 3.14 Effect of Radiation on Mechanical Properties Vectra® A950

Vectra® A950	Dosage (Mrads)				
	0	25	100	250	500
Tensile Strength ASTM D638, kpsi	27.1	26.0	25.8	25.9	26.3
Tensile Modulus ASTM D638, Mpsi	1.5	1.5	1.5	1.6	1.6
Ultimate Elongation ASTM D638, %	4.8	3.8	3.9	3.8	3.9
Flexural Strength ASTM D790, kpsi	22.9	23.4	23.2	23.1	23.4
Flexural Modulus ASTM D790, Mpsi	1.2	1.3	1.3	1.4	1.5
Heat Deflection Temperature ASTM D648, @264 psi, °F (°C)	360 (182)	356 (180)	356 (180)	356 (180)	336 (169)

Above are actual data from one tested lot. These are typical values, not to be used for specification purpose.

Table 3.15 Effect of Radiation on Mechanical Properties Vectra® B950

Vectra® B950	Dosage (Mrads)				
	0	25	100	250	500
Tensile Strength ASTM D638, kpsi	26.6	25.9	28.0	27.9	27.8
Tensile Modulus ASTM D638, Mpsi	2.7	2.7	2.7	2.8	2.7
Ultimate Elongation ASTM D638, %	1.3	1.3	1.4	1.3	1.3
Flexural Strength ASTM D790, kpsi	34.1	34.7	33.7	33.9	35.1
Flexural Modulus ASTM D790, Mpsi	2.0	2.0	2.0	2.2	2.2
Heat Deflection Temperature ASTM D648, @264 psi, °F (°C)	392 (200)	392 (200)	392 (200)	387 (197)	374 (190)

Above are actual data from one tested lot. These are typical values, not to be used for specification purpose.

Agency Approvals

Underwriters Laboratories

Extensive Underwriters Laboratories ratings are available for Vectra LCPs. For details, please consult the UL "Yellow Cards." More current data are available through your Vectra resin technical representative. In general, Vectra LCPs with glass reinforcement are rated UL94 V-0 down to 1/32 in. (0.8mm), while the systems with mineral and mixed fillers are UL94 V-0 to 1/16 in. (1.6 mm). Glass-reinforced Vectra variants are recognized with relative thermal indices over 200°C (see Table 3.7 for details).

Military Specifications

Both the 30 and 50% glass-fiber-reinforced Vectra LCPs (i.e., A130, A150, C130,) are approved under the U.S. Navy's Mil-M-24519, GLCP-30F or GLCP-50F designations.

USP Biocompatibility

Vectra B950 and A950 meet the requirements of the USP Type VI plastic.

Other

For confirmation on compliance with other regulatory classifications, specifications, or categories, please contact your Vectra resin technical service engineer.

Processing

Some General Precautions/Safety

No particular hazards have been identified when injection molding Vectra materials, provided standard industry safety practices are followed. Vectra LCPs are inherently stable materials. If heated to excessively high temperatures, however, LCPs can decompose and give off decomposition products, as will most polymers. If insufficient ventilation allows concentrations to build up, these could be harmful. It is, therefore, recommended that adequate ventilation be provided.

To avoid thermal decomposition, evolution of fumes, and pressure buildup in the barrel, melt temperatures should not exceed 350°C (660°F) for the A and B Series, and 370°C (700°F) for the C Series resins. These temperatures are well above the normal processing range. The melt should not remain more than ½ hour above 330°C (625°F) for the A and B Series resins, or above 355°C (670°F) for the C Series. This readily permits temporary machine stoppage for process adjustment. For more extended shutdowns, the system temperature should be lowered below 260°C (500°F). Other important precautions are:

- The operator should allow adequate machine heat up time for the barrel to reach the molding temperature for ½ hour before feeding the pellets or rotating the screw.
- The operator should wear safety eye protection, especially during purging.
- The operator should use proper gloves and other appropriate protective garments for handling hot dies and to prevent molten material from contacting the skin.
- The injection unit should be retracted during shutdown to avoid nozzle/sprue bushing freeze-up.

Material Safety Data Sheets (MSDS) are available for all Vectra resin formulations. These should be consulted for further details regarding specific compounds.

Equipment Types

Vectra resins have been molded without difficulty in many different types of reciprocating screw molding machines. As with most materials, the machine should be sized so that the shot weight falls between 50% and 75% of the machine rating. Small shots from large machines should be avoided to prevent excessive thermal degradation of the polymer.

Because Vectra materials are fast cycling, a machine should have a high plasticating capability to achieve optimum cycle times. Although screw design is not critical for Vectra resins, some general characteristics are preferred:

1. A long feed section with deep flights (approximately ⅓ to ½ the screw length).
2. A short transition zone (less than ⅓ of the screw length).
3. A fairly high compression ratio (at least 3:1) to provide good mechanical working.

All grades of Vectra LCPs have low melt viscosity so **clamp forces** of at least 1.5 – 2.5 tons per projected square inch of cavity area are recommended to prevent flashing. A properly functioning **check ring** on the screw is a necessity. It should be checked periodically by making sure the cushion is maintained at the end of each shot. Malfunctioning **check rings** usually result in variable and partially filled parts.

Conventional free-flow type **nozzles** work well and are commonly used for Vectra resins. Small orifice diameters or nylon type nozzles with a back taper are advantageous in controlling drooling. Nozzles should be as short as possible and have a **heating band** with an **independent controller**. If drooling or stringing occurs, reducing the nozzle temperature usually alleviates the problem.

Storage

Vectra resin is shipped predried and packaged in moisture-resistant containers. Resin should be stored on pallets in a dry place where the container will not be damaged. Open containers should be resealed immediately to avoid contamination and minimize moisture pickup. If the container has been previously opened, Vectra resins should be redried before molding.

Drying Conditions

Although Vectra LCPs do not absorb high percentages of moisture (Table 5.1), it is recommended that exposure to ambient air be kept to a minimum.

Vectra resin and regrind should be dried before molding. This reduces the possibility of hydrolytic degradation. The following procedure produces an acceptable moisture level:

- Using a dehumidifying air drier (hopper or tray) or vacuum drier, dry the resin at 150 – 163°C (300 – 325°F) for no less than 4 hours (allow time for the pellets to heat up).
- The dewpoint of the air should be at or below 0°C(32°F).
- To limit moisture regain, a hopper drier is preferred during processing. An acceptable alternate is a closed hopper purged with dry inert gas.
- Longer periods of drying, up to 24 – 36 hours, do not damage the resin.

Table 5.1 Equilibrium Moisture Content of Unfilled Vectra Resin

Exposed at 50% RH @ 73°F (23°C)		
A950	0.01%	(100 ppm)
B950	0.04%	(400 ppm)

Molding Techniques

When switching to LCP from another material, Vectra materials may be introduced directly to the molding machine cylinder behind other polymers, provided the previous material is a low-viscosity resin and is stable at Vectra resin processing temperatures. If it is not, or if it has a very high viscosity and may be difficult to purge, it is suggested that polypropylene or high-density polyethylene be used first to purge the material and then set temperatures for molding the LCP. When the cylinder is at temperature, Vectra resins can be fed to the machine, and molding may begin when it is flowing cleanly from the nozzle.

Different grades of Vectra resin can be molded by using one grade to purge another without an intermediate polymer. Again, when the new material is flowing cleanly, molding may start.

Molding Conditions

The conditions required to mold satisfactory parts of Vectra LCPs vary, depending on the part design, the mold, the machine, and the specific Vectra compound being molded.

Typical settings, which may be used as a guide for starting a molding cycle, appear in Table 5.2. Stock temperatures should be checked with a pyrometer to ensure that the melt temperature is in the desired range. After the molding machine has been on cycle for at least 5 minutes, the barrel should be retracted and a single purge shot made. The temperature of the polymer may be measured with a pyrometer with a fast-response needle probe.

Measuring the melt temperature from a machine that has not been on cycle tends to result in misleading measurements. Temperatures should be carefully adjusted to stay within the ranges recommended in Table 5.2.

The molding machine should be sized so that the shot weight falls between 50% – 75% of the machine rating, including allowance for about a ⅛ in. cushion.

If molded parts will be exposed to temperatures above 215°C (420°F), such as electronic components in vapor-phase or infrared reflow soldering, it is critical that Vectra LCPs not be overheated during processing. For optimum performance, the melt temperatures should be at or below the recommended stock temperature and the melt residence time minimized to about 3 minutes or less. Suck-back or decompression is not recommended.

If the molded parts will not be exposed to high temperatures, the melt temperatures can be raised for easier filling, better weld line strength, and improved surface finish.

Table 5.2 Typical Temperature Settings

Cylinder	Vectra A Series	Vectra B Series	Vectra C Series
Feed Zone	545°F (285°C)	570°F (300°C)	600°F (315°C)
Intermediate	545°F (285°C)	570°F (300°C)	605°F (320°C)
Front Zone	545°F (285°C)	570°F (300°C)	605°F (320°C)
Nozzle	555°F (290°C)	555°F (290°C)	605°F (320°C)
Stock	555°F (290°C)	555°F (290°C)	605°F (320°C)

Note: For formulations other than the Vectra A, B, and C Series, please consult a Vectra technical representative.

Mold Temperatures: Vectra materials mold well over a wide range of mold temperatures. Generally, molding is conducted with mold temperatures between 30°C and 150°C (85°F and 300°F), with temperatures of 80 – 110°C (175 – 230°F) being most common. Hot water temperature control is generally satisfactory.

Injection Pressure: The optimum injection pressure varies with the specific resin formulations as well as part design, mold design, and other machine settings. All Vectra LCP formulations have low viscosities and generally require pressures much lower than those of other thermoplastic materials. Typically, injection pressures are about half those of comparably filled semicrystalline resins (PBT, PET, and PPS). It is suggested that molding be initiated by using a very low pressure. This reduces the possibility of the first part sticking in the mold. Most moldings have utilized pressures on the material of between 1000 and 5000 psi. If necessary the injection pressures can be increased gradually. To fill very thin sections, the injection rate can be increased to shear thin the melt viscosity.

Cycle Times: Cycle times depend on the size, shape, wall thickness, and complexity of the molded part, as well as the machine settings and mold design. In addition to low melt viscosity, all Vectra LCP grades have a low heat of fusion and a high thermal conductivity. This results in unusually fast cycle times. Cycle times are about half those of semicrystalline resins (PBT, PET, PPS).

Screw Speed: Screw speed should be adjusted so that the screw finishes retracting 1 – 2 seconds before the mold opens. Typical screw speeds are in the moderate range, with slower speeds preferred for fiber-reinforced grades.

Back Pressure: Back pressure on the screw is normally not needed and should be kept at zero or the minimum. This is especially important to minimize excessive shear and fiber breakage with fiber-reinforced grades.

Screw Decompression: Screw decompression is generally not recommended, provided temperatures are within the range suggested in Table 5.2, and the material is thoroughly dried. If nozzle temperature control does not reduce drool, then change to a nozzle type recommended in the equipment types section. If screw decompression becomes necessary, it should be set to a mimimum. Excessive decompression can pull air into the nozzle and result in splay marks or blisters on the surface of molded parts.

Shutting Down a Machine: After molding Vectra compounds, the machine should be shut down with an empty barrel. If Vectra material is to be used when the machine is reheated, it is not necessary to purge with another material. If a different polymer is to be molded on reheating, the Vectra resin should be purged with polypropylene or high-density polyethylene before turning off the cylinder heaters. In either case the barrel should be emptied completely before shutting off the heaters prior to machine shutdown.

Regrind

When recommended molding conditions are used, Vectra resins have excellent thermal stability.

In a laboratory study, Vectra resins retained 80 –100% of their strength and modulus after the fifth molding, using 100% regrind. Unfilled grades retained full notched Izod impact strength, but glass fiber reinforced grades showed reduced impact strength due to fiber breakage during processing (Table 5.3). A slight darkening of color has been observed after repeated moldings.

Though there is little change in properties after five moldings of 100% regrind, it is suggested that regrind be limited initially to 25% to maintain color uniformity and optimum mechanical properties. A level of 50% or more regrind may be acceptable, but parts should be tested to ensure satisfactory performance.

Conventional plastics granulators are suitable for regrinding Vectra LCPs. The blades should be sharp and set for the closest practical clearance. The screen hole size should be as large as practical. For best results, the sprues, runners, etc. should be fed to the grinder while still hot — right out of the mold. Regrind should be dried prior to molding. For more specific recommendations, consult your Vectra® resin technical service representative.

Table 5.3
% Property Retention of Vectra Resins after Fifth Molding*

Property	A950	B950	A130
Tensile Strength	85%	100%	80%
Tensile Modulus	85%	81%	82%
Tensile Elongation	100%	85%	100%
Flexural Strength	91%	85%	88%
Flexural Modulus	92%	80%	98%
Notched Izod Impact	100%	100%	50%

*Each molding 100% regrind

Chapter 6

Part Design

In most cases, designers and molders specify Vectra materials for their excellent dimensional stability and mechanical toughness with a broad processing window. Part design is the key consideration in optimizing both processing latitude and part performance. In general, all of the standard recommendations for good design of plastic parts are applicable when designing with Vectra LCPs. For instance, parts should be designed — and molds constructed to provide smooth, uniform flow of the polymer melt. In addition, the part design *must* control the resin's anisotropic properties — a fact that presents both opportunities and challenges. The direction of material flow in the mold influences mechanical properties of the molded parts. Thus, there is a strong link between part design, performance and end-use requirements.

Shrinkage: A number of factors affect shrinkage. The most important is orientation of the polymer due to part design and gate location. Thicker sections shrink more, especially in the transverse direction. The effects of melt and mold temperature, injection pressure and rate are modest relative to other polymers. Some typical shrinkage values are shown in Table 6.1.

Warpage: Smooth, uniform flow of the polymer melt is crucial to controlling warpage. Wall sections should be as uniform as possible since parts are subject to warping if there is a heavy wall on one side and a thin one opposite. As one would expect, there is very little warpage when parts are designed so that the resin flows evenly from one end to the other in a continuous, longitudinal path without weld lines.

Ribs, Corners, and Radii: Ribs designed into the sides of parts are an excellent means for reinforcing wall sections. At the same time however, they can disrupt the polymer flow in the mold, creating warpage or unexpected weld lines. When flow is in the same direction as the rib, the rib may be quite thick—100% of the thickness of the adjoining wall at the root. The polymer flows through the rib and wall in the same direction. When flow is perpendicular to the rib, the rib thickness should be less than the nominal wall. If not, the resin may then flow through the wall in one direction, then turn and flow down the rib. Should this occur, the result can be knit lines or warpage induced by differential shrinkage. Minimal warpage is attainable when the ribs are balanced on both sides of a part.

As a rule, rib height should be limited to double the adjoining wall thickness in order to minimize distortion by shrinkage. Ribs may be higher on parts where shrinkage is of less concern.

Thick ribs should be joined to the wall by fairly small radii: no more than 10 - 20% of the adjoining rib thickness is recommended. Larger radii may cause the transition area to act as secondary runners, causing the polymer flow to separate during cavity filling. Undesirable weld lines or back-filling may result.

One of the noteworthy features of LCPs is their layered structure formed when the material flows. The outer layers are composed of highly oriented molecules. This orientation of the molecules tends to follow the contour of corners in the part and provides reinforcement. Result: parts molded from Vectra resins tend to be significantly less notch sensitive than those made of other plastic materials. Naturally, designing generous radii is still good practice (to avoid excessive stress concentration) except

Table 6.1 Approximate Mold Shrinkage

⅛ in. x 4 in. Disk (Fan Edge Gate) in./in.		
Vectra Grade	Flow Direction	Transverse Direction
A950, B950, A422, A625	0.001	0.003
A130, A230, A420, C130	0.001	0.002
A150, C150	0.002	0.002
A410	0.002	0.003
A515, A540	0.002	0.004
B130	0.000	0.001
B230	0.000	0.000
C550	0.003	0.004

⅛ in. x ½ in. x 5 in. Flexbar (End Gated) in./in.		
	Flow Direction	Transverse Direction
A950, B950	0.000	0.006
A130, A540, C550	0.000	0.008
A150, A420	0.000	0.004
A230	0.001	0.004
A410, A625, A422	0.000	0.006
A515	0.000	0.012
B130	0.000	0.002
B230	0.002	0.002

½ in. x 5 in. Flexbar Shrinkage (in./in.) vs. Part Thickness				
Thickness, in.	1/32"	1/16"	⅛"	¼"
A130, Flow Direction	-0.001	0.000	0.000	0.000
Transverse Direction	0.003	0.003	0.008	0.012

when it might create a secondary runner. A satisfactory "rule of thumb" is an inside radius of 0.5 times the nominal wall thickness and an outside radius of 1.5 times the adjoining nominal wall thickness.

Knit Lines: Knit lines are the joint produced when independent melt fronts meet during injection. They are a potential problem in any fiber reinforced plastic due to the difficulty of mixing and orienting fibers across the interface. In an LCP, the rigid polymer chains also act like a fiber reinforcement: thus, knit line considerations are particularly important in the design.

For maximum strength, part design should avoid knit lines altogether. When knit lines are unavoidable, the part design should manipulate flow to improve performance. To direct flow, the designer should locate the gate carefully and adjust wall thicknesses. The melt tends to fill thick areas first — then to fill thin areas. The designer, therefore, may reduce wall thickness to retard filling in one area or increase it to act as a "flow-leader" in another.

These methods can modify flow to control the location and type of knit lines. Knit lines should be directed to areas of low stress such as a rib or thicker or wider section. Avoid butt knit lines formed where two flow fronts hit head-on and stop. If flow continues after the melt fronts meet, they can "meld" or mix and continue as a single front. An overflow well or tab may be added to the part edge at the knit line to improve an existing mold where part geometry cannot be changed. The overflow tab is then cut from the part and treated like sprues and runners.

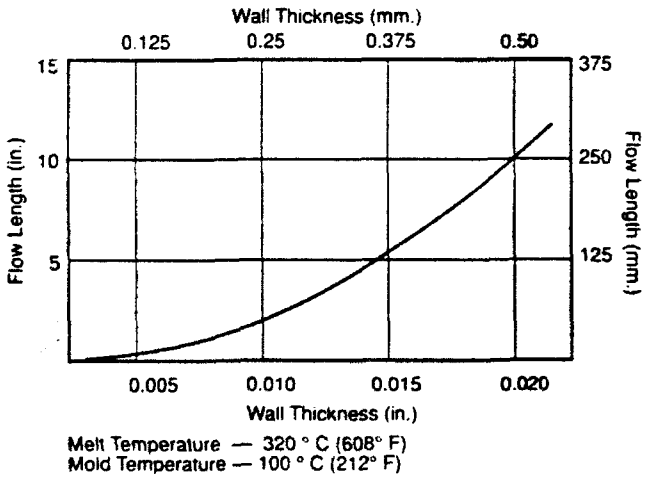


Figure 6.1 Nominal Wall Thickness vs. Flow Length (Actual Parts, Vectra® C130)

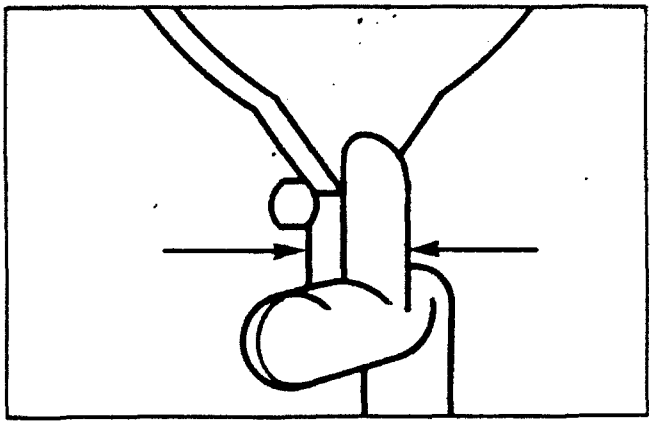


Figure 6.2 Fan Gate

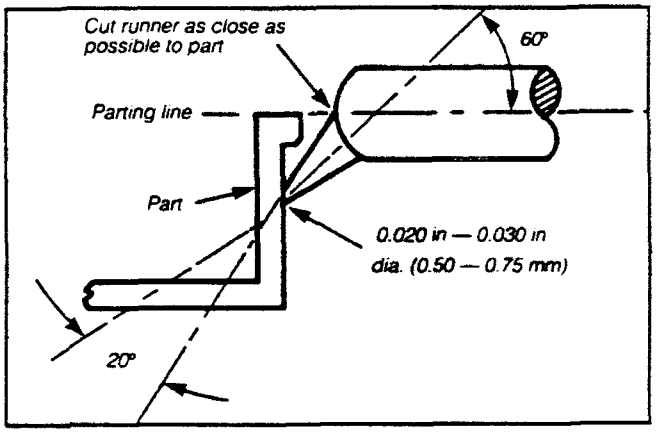


Figure 6.3 Submarine Gate

Gating: Because Vectra LCPs have such excellent flow characteristics, they fill mold cavities with much less injection pressure than most other polymers. Seldom is more than one gate required for filling; this means that gates can be located to take advantage of the polymer's orientation, rather than having their location dictated by flow limitations. Of course, a single gate is beneficial to minimize the number of weld lines and to provide continuous orientation from one end to the other. The maximum recommended flow length in a part depends on geometry, mold design, processing conditions, and the grade of Vectra LCP. A graph of the flow length that we consider practical for Vectra C130 is given in Figure 6.1.

Gate Design: Jetting is a phenomenon that results when plastic flows through a gate and into a cavity without sticking to the mold walls. It produces a ropelike flow, or "jet," which is then compressed in the part. Ideally, of course, the polymer should form a uniform flow front that fills the cavity smoothly. However, all plastics are subject to jetting and the techniques for controlling it are well known. Liquid crystal polymers have very little die swell when exiting a gate and, thus, are more prone to jetting than many other thermoplastics.

Techniques for controlling jetting are similar for all plastics. Edge gates should be large, generally 100% of the wall thickness. For three-plate molds, tunnel gates, and some edge gates, a smaller gate is practical—and sometimes necessary for a clean break—provided that the flow is directed against a core or cavity wall to control the jetting and force a uniform flow to develop.

In most cases, all standard methods of gating work well with Vectra resins, provided that knit lines and jetting are controlled by design. It should be kept in mind that LCPs are anisotropic and are stronger in the flow direction than the transverse direction. For this reason, tunnel gates should be located in the ejector side of the mold to push, rather than pull, the gate and runners from the mold. On three plate molds, gate diameters should be between 20% and 50% of the wall thickness to ensure that the gate breaks easily. Figures 6.2 and 6.3 illustrate some gate designs found to work well.

Fan gates have been found to be very useful for flat parts as a means to obtain easy fill and control orientation.

Circular parts should be center gated with a sprue or diaphragm gate to provide uniform flow without weld lines.

Vents: The low viscosity of Vectra materials dictates that shallow vents be used. A depth of 0.0005 – 0.001 in. (0.01 – 0.025 mm) is suggested.

Vents should be located in all sections of the mold where air may become trapped by the molten plastic. It is desirable to incorporate vents in many other areas as well, so all the air is not forced through a single small opening.

Draft Angles: LCPs exhibit very low shrinkage along with unusually high stiffness. Consequently, they typically eject easily from most cores. Parts have been molded with well-polished cores up to 16 in. in length without any draft. Even so, molding parts without draft should be considered only when there are no alternate options. A draft angle of 1/10 to 1/4 degree per side is suggested, however a draft angle of 1/2 degree per side is preferred.

The same factors that allow molding of LCPs with minimal draft may result in parts sticking in the mold if there are slight undercuts or rough areas. With some grades of Vectra resin, a near-zero flow-direction shrinkage can cause sticking on the cavity side of the mold rather than the core. Users should consult a Vectra resin technical specialist for recommendations on shrinkage allowance for the specific grade of material being considered and for the part geometry. Occasionally, a core may need to be roughened to pull the part from the cavity.

Mold Materials: Vectra resins have been found to be noncorrosive to molds, and all standard materials of mold construction are suitable.

Some fillers and reinforcements may be abrasive and tool steels should be selected and hardened as for other polymer systems containing similar additives. It is good practice to make high-wear components as replaceable segments, e.g., "sub" gates and cores behind a gate.

Chapter 7

Finishing Operations

Machining

Although the usual goal of designers is to produce plastic parts that can be used directly from the mold, there are times when it's advantageous to machine some dimensions—perhaps to avoid a complex mold configuration, to achieve particularly tight tolerance or to avoid knit lines in critical areas. Parts molded from Vectra LCPs machine easily when the following practices are used:

1. Use sharp tools.
2. Provide adequate cooling.
3. Allow enough chip clearance.
4. Support the work properly.

With Vectra resins, the stiffness, high thermal conductivity, and low coefficients of friction promote good machinability. Vectra resins are thermoplastic and will melt if the machining operations generate too much frictional heat.

Prototype Machining: Part properties of Vectra materials depend on the molecular orientation created by gating, mold design, and molding conditions. Extra care should be taken when machining prototypes for evaluation. A prototype may not have the same orientation as the final molded part, and therefore, mechanical, electrical, and other properties may not necessarily be identical. In general, prototypes should be molded to the final geometry rather than machined from bulk stock. Surface layer properties of most polymers, including LCPs, are different from their core properties. If machining is unavoidable, one should remove as little surface material as possible. If the design includes molded-in holes, drilling these holes in a prototype makes it impossible to evaluate the effect of weld lines in the production part.

Tooling: Dull tools tend to scrape rather than cut, yielding a poor surface finish and generating excess heat in the process. The best surface finishes are obtained with sharp tools, high tool speeds, and slow feed rates. Both machining speed and the feed rate should be uniform and uninterrupted. Cooling allows higher cutting speeds, especially on heavy cuts. Normally, an air jet is sufficient, but liquids may also be used. Vectra materials are not attacked, crazed, dissolved, or softened by any of the conventional cutting fluids.

In addition to having sharp cutting edges, there must be adequate clearance for chips. This eliminates problems with clogging and interference with the cutting operation. When there is a choice in tool selection, the machinist should pick one offering the greatest chip clearance, for example, drills with wide flute areas or saw blades with deep gullets. Unlike some plastics, Vectra resins containing abrasive fillers such as mineral, glass, or carbon fibers can be machined with standard high-speed steel tools, though carbide tools prolong tooling life during extended production runs.

Turning: Vectra LCPs are easily turned on a lathe. Tool bits must be sharp and should provide a rake angle of 5 – 15° with front and side clearance angles of 15 – 0°. A tip radius of at least 1/16 in. should be used for smooth finish cuts. Feed rates and cutting speeds for turning depend primarily on the nature of the cut and the desired finish. Roughing cuts may be made at the highest feasible rates without excessive heat buildup. For most work a peripheral part speed of 60 ft./min. is reasonable. Of course, a smooth finish cut calls for a somewhat higher turning speed and slower feed rate. As a guideline, a 1/2 in. diameter rod turned with a 1/16 in. tool tip radius at 1000 rpm and a 0.0017 in./rev. feed advance has an excellent surface finish.

Milling and Drilling: Standard helical-type milling cutters are satisfactory. Two-flute end mills are preferred for greater chip clearance. Using the suggested tool speeds listed in Table 7.1, Vectra materials can be cut without a coolant. An air jet may be desirable to keep chips from clogging the flutes. Feed rates should be adjusted to obtain the desired finish

For drilling, standard high-speed twist drills are best for all Vectra resin formulations. While special slow-spiral drills are available, they offer no advantages over standard drills designed for metals. Occasionally, burring may occur. This can be eliminated by clamping dummy pieces of plastic above and below the work. In any case, the work should be firmly supported and securely held. For deep holes, the drill should be raised frequently (about every 1/4 in. of depth) to clear the drill and hole of chips. A jet of compressed air helps to disperse chips and cool the drill.

Table 7.1 Suggested Drill and Milling Tool Speeds
(Part thicknesses up to ¼ in.)

Tool Diameter (in.)	Tool Speed, rpm	
	Unfilled Resins	Reinforced Resins
1/16	2300	2000
⅛	2000	1700
3/16	1800	1500
¼	1600	1300
⅜	1300	1000
½	1000	800

Threading and Tapping: Threads may be readily cut on a lathe, using the tool and cutting conditions previously outlined. Conventional taps and dies may be used with good results. These may be threaded either by hand or by machine; use gun-nose taps when machine tapping. A speed of about 180 rpm is suggested for sizes from 10 - 24 through ⅜ - 16. A special tap for plastics, with two flutes, is available and offers some advantages in greater chip clearance, but it is not essential for satisfactory results.

Sawing: Vectra resins may be sawed with almost any type of saw. To prevent binding of the blade, however, the saw teeth should have some degree of set, at least 0.005 in. offset per side. Coarse teeth and extra wide gullets for chip clearance are desirable for rapid cutting, while a finer blade gives a smoother edge. In general, the blade should have at least two teeth per part thickness; that is, a part ⅛ in. thick should be sawed with a blade having 16 teeth per inch. Bandsawing gives a good finish cut without cooling, using a blade speed of 4000 ft./ min. when the part is less than ¼ in. thick and the blade contains two teeth per thickness.

Some Precautions: No unusual hazards have been identified when machining Vectra materials, provided standard industry safety practices are followed, including the use of

- Appropriate safety eye protection to keep particles from entering the eyes.
- Proper protective garments to prevent exposing the skin to resin particles.
- Wet machining techniques or controlled ventilation to minimize generation of dust and particles. Where such controls are inadequate to maintain dust levels below recommended exposure levels, it is recommended that a properly fitted NIOSH approved respirator be used.

Material Safety Data Sheets are available for all Vectra resin products and should be consulted for further details regarding specific hazards and precautions.

Adhesives

Parts molded from Vectra LCPs can be effectively bonded by using commercial adhesives. In most cases, the bond strengths with unmodified surfaces are more than adequate for product assembly. When necessary, bond strength can be enhanced by surface treatments that improve wetting, for instance, light sanding, grit blasting, or Chromerge* acid etching. Oxygen plasma etching can be highly effective, provided bonding takes place while the surface is still active.

As with any molded plastic part, optimum adhesion is obtained when the surfaces are clean, the adhesive is fresh, and the application procedure supplied by the adhesive manufacturer is followed carefully. Do not use a mold release; it will interfere with good adhesion. Surfaces to be bonded should not be touched after cleaning, since an oil film may be left behind.

Some grades of Vectra LCPs provide greater bond strength than others. As a general rule, filled and reinforced grades have surfaces that give greater bond strengths than unfilled grades. Your Vectra resin technical service engineer can assist in selecting a suitable material for optimum adhesion.

Tables 7.2, 7.3, and 7.4 list typical lap shear strengths (ASTM D3163) obtained with various adhesives at three temperatures. Table 7.5 contains a representative list of adhesives and their manufacturers. Before specifying these or any other adhesive, the user should make certain that all mechanical, thermal, electrical, chemical, and other properties of the adhesive are suitable for the applications and that these adhesives are still current products. Improved versions may be available from their manufacturers.

Warning: Chromerge* is a very strong oxidizing acid that can cause severe irritation, burns, and pain. It should only be used in accordance with the supplier's instructions. Consult the manufacturer's MSDS for complete data.

* Registered trademark of the Fisher Scientific Co.

Etching Acid	
Chromerge*	Fisher Scientific 50 Fadem Road Springfield, NJ 07081

Table 7.2 Lap Shear Strength Values, Tested at 22°C (72°F)

	Range of Values, psi	Average Values, psi
Adhesive Type	As Molded/ Surface Treated*	As Molded/ Surface Treated*
2 Part Epoxy	450-1,000/800-2,100	700 / 1,300
1 Part Epoxy	600-1,300/800-1,400	900 / 1,200
Cyanoacrylate	300-700/500-1,000	500 / 800
2 Part Acrylic	250-800/500-800	450 / 700

*Light sanding/grit blasting and solvent wash

Table 7.3 Lap Shear Strength Values, Tested at 100°C (212°F)

	Range of Values, psi	Average Values, psi
Adhesive Type	As Molded/ Surface Treated*	As Molded/ Surface Treated*
2 Part Epoxy	150-300/150-400	200 / 300
1 Part Epoxy	100-700/250-800	500 / 600
Cyanoacrylate	300/300-500	300 / 400
2 Part Acrylic	100-200/200-300	150 / 250

*Light sanding/grit blasting and solvent wash

Table 7.4 Lap Shear Strength Values, Tested at 150°C (302°F)

	Range of Values, psi	Average Values, psi
Adhesive Type	As Molded/ Surface Treated*	As Molded/ Surface Treated*
2 Part Epoxy	100-200/100-200	100 / 150
1 Part Epoxy	100-300/100-300	200 / 200
Cyanoacrylate	25-50/50-100	25 / 100
2 Part Acrylic	50/100	50 / 100

*Light sanding/grit blasting and solvent wash

Table 7.5 Adhesives for Bonding Vectra® LCP Resins

Two Part Epoxy	
Scotchweld® 1838 A/B Scotchweld® EU9323 B/A Scotchweld® 1XA 3568 B/A	3M/Adhesives, Coatings and Sealers Division 223-In, 3M Center St. Paul, MN 55144
REN® DA-556	REN Plastics 4917 Dawn Avenue E. Lansing, MI 48823
FUSOR® 310	Lord Corporation 2000 W. Grandview Blvd. Erie, PA 16514
CYBOND® 1110	American Cyanamid Co. Havre De Grace Maryland 21018
5 min. Epoxy	Cole-Parmer Co. 7425 North Oak Park Avenue Chicago, IL 60648
One Part Epoxy	
Scotchweld® 2214 Hi-Temp Scotchweld® EU 7823 Scotchweld® EC 3476	3M/Adhesives, Coatings and Sealants Division 223-IN, 3M Center St. Paul, MN. 55144
EPO-TEK® H35-175 (Electrically conductive)	Epoxy Technology, Inc. 14 Fortune Drive Billerica, MA 01821
ME-868-2® (Thermally conductive)	Amicon Corp. 25 Hartwell Avenue Lexington, MA 02173
1 Part Cyanoacrylate	
Permabond® 102	Permabond International 480 S. Dean Street Englewood, NJ 07631
2 Part Acrylic	
Permabond® 610/612	Permabond International 480 S. Dean Street Englewood, NJ 07631

® Registered trademark of their respective manufacturers

As testing was limited, there were no adhesives in the following categories identified as adequate:
Two Part Polyurethanes
One Part Polyurethanes
One Part ABS based

For the most up to date information, contact your Vectra® Technical Service Engineer. For additional information, call 1-800-833-4882 for Engineering Plastics Technical Information.

Ultrasonic Welding

When ultrasonically joining parts made of Vectra resin, a shear joint gives the best results. Other kinds of joint design such as the energy director, scarf, and butt joints result in much lower strengths. The shear joint should be designed conventionally for a high modulus material, that is, with about a 5 –15 mil (0.1 – 0.4 mm) interference and a 20 –100 mil (0.5 – 2.6 mm) depth. The strength of the bond is determined more by the depth of the joint than by the interference.

All high-melting plastics require high-energy input for welding. Vectra LCP is no exception. A 20 kHz machine is adequate for most welding application, though for parts that are less than 0.5 – 0.75 in. (13 –19 mm), a 40 kHz unit should be considered. Horn amplitudes are large, usually between 2 and 3.5 mils (0.05 and 0.08 mm) for a 20 kHz frequency and about half of that for a 40 kHz machine. Shear strength of the joint is 30 – 50% of the bulk material's strength when these guidelines are followed. Ultrasonics can also be used to stake bosses and to form rivet heads.

Plating and Other Metallizing

Consult your Vectra® resin technical service representative for information on resin grades and the chemistry recommended for metallizing by vacuum deposition, sputtering, and electroless or electrolytic plating with conventional chemicals.

Annealing

The normal heat deflection temperature of Vectra LCPs can be increased 30 – 50°C (55 – 90°F) through a simple annealing process. A summary of annealing conditions is given below. Specific conditions are available from your Vectra resin technical service engineer.

Vectra A and B resins:

1. Ramp from ambient to 250°C (480°F) in several hours.
2. Hold at 250°C (480°F) for 4 hours.
3. Cool to ambient temperature.

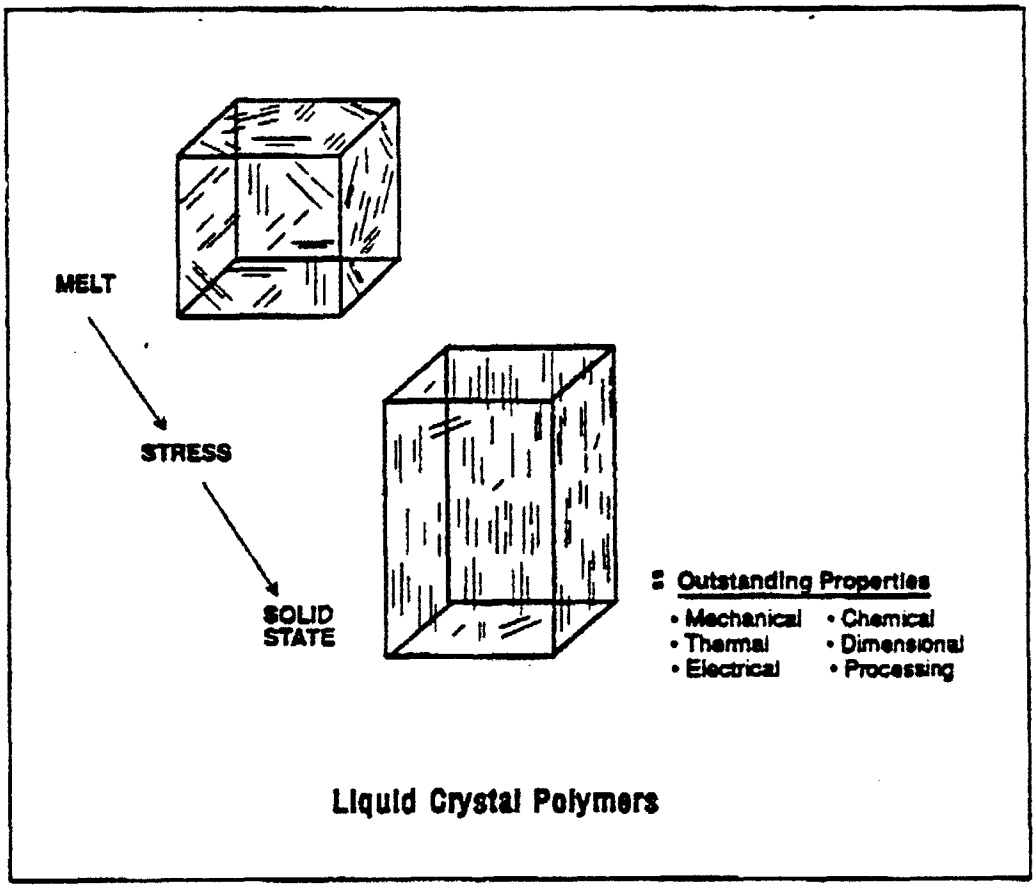
Vectra C resins:

1. Ramp from ambient to 270°C (520°F) in several hours.
2. Hold at 270°C (520°F) for 4 hours
3. Cool to ambient temperature

This manual has been prepared to provide the designer, processor, and applications engineer with information needed to use and apply Vectra Liquid Crystal Polymers. For questions about topics not included here, or when more information is required, please telephone the Engineering Plastics Technical Information Service: (908) 231-2062

DU PONT
Liquid Crystal Polymer

HX-4000 Series
Products and Properties Guide



Start with Du Pont

DU PONT

Description

DU PONT Liquid Crystal Polymers (LCP) are designed to provide very high heat distortion properties, exhibit excellent dimensional stability and maintain high mechanical properties over a wide temperature range. The HX-4000 series are wholly aromatic polyester resins which are easily moldable. These grades of DU PONT LCP are ideal for a wide range of applications including those in the automotive and electronic industries.

Properties

Typical properties of DU PONT HX-4000 series resins are shown in the accompanying table. These materials combine excellent flexural modulus (see **Figure 1**), heat distortion temperature and electrical insulation properties (see **Figure 2**), with outstanding dimensional stability due to their very low coefficient of thermal expansion. The exceptional fatigue properties are illustrated in **Figure 3**.

In addition to the excellent thermal properties, these resins have a high degree of resistance to a wide range of chemicals—including strong acids, bases and hydrocarbons.

Compositions

HX-4000	Unfilled
HX-4100	30% glass, high temperature grade
HX-4101	30% glass, high temperature grade V-0 at 0.79 mm (0.031 in.)
HX-4330	30% talc, high temperature grade

Applications

DU PONT HX-4000 series resins should be considered in applications requiring high temperature performance, retention of properties over a wide temperature range, dimensional stability, chemical resistance and excellent electrical properties. These resins are well suited for use in automotive, electrical/electronic, fiber optics, telecommunications and aerospace industries.

Suggested Application Areas

Electrical/Electronic

Surface Mount Components
Sockets/Burn-in Sockets
Connectors
Chip Carriers
Bobbins
Ceramic Replacements
Motor Parts and Insulations
Fiber Optics
Connectors
Guides
Pins
Closures

Automotive

Sensors
Lamp Sockets
Coil Forms
Chip Carriers
Fuel System Components
Transmission System Components
Pump Components
Ignition System Components

Aerospace

All Electronic Components
Imaging and Optoelectric Components
Sensor Devices
Composite Materials

Processing

DU PONT HX-4000 series resins exhibit good melt stability and feature low melt viscosities and, thus, are easily processed. They can easily fill long, thin wall sections and exhibit no flash. Due to the high freezing point, low heat of fusion and good thermal conductivity, the cycle time for these resins is significantly better than conventional crystalline resins—thus offering key improvements to productivity. The very low mold shrinkage of these resins is a plus factor in tool design and design tolerances.

Recommendations regarding processing conditions are available from your Du Pont Polymer Products representative or from any office listed on the back page.

TABLE 1
Typical Properties of Du PONT LCP Resins

		Method		Units		DU PONT			
	Property[1]	ASTM	ISO	SI	(English)	HX-4000	HX-4100	HX-4101	HX-4338
STRENGTH	Tensile Strength	D638	R527	MPa	(kpsi)				
	−40°C (−40°F)						140 (20.0)	135 (19.9)	110 (16.0)
	23°C (73°F)					90 (13.0)	150 (22.0)	155 (22.6)	110 (16.0)
	120°C (250°F)					75 (11.2)	110 (16.0)	110 (16.0)	90 (13.0)
	150°C (300°F)						85 (12.4)	70 (10.2)	75 (11.0)
	200°C (392°F)						40 (5.8)	50 (7.5)	40 (6.0)
	Elongation at break	D638	R527	%					
	−40°C (−40°F)						0.5	0.5	0.8
	23°C (73°F)					0.5	1.0	1.0	0.9
	120°C (250°F)					1.0	1.0	1.0	1.1
	150°C (300°F)						2.0	1.5	1.5
	200°C (392°F)						2.0	2.0	2.0
	Tensile Modulus	D638	R527	GPa	(Mpsi)				
	−40°C (−40°F)						23 (3.3)	22 (3.2)	14 (2.0)
	23°C (73°F)					21 (3.1)	18 (2.7)	19 (2.7)	14 (2.0)
	120°C (250°F)					11 (1.6)	13 (1.9)	13 (1.9)	
	150°C (300°F)						11 (1.6)	12 (1.7)	8 (1.2)
	200°C (392°F)						4 (0.6)	5 (0.7)	
	Shear Strength	D732		MPa	(kpsi)				
	−40°C (−40°F)						80 (11.9)	80 (11.8)	
	23°C (73°F)						75 (11.1)	70 (10.3)	
	120°C (250°F)						50 (7.6)	55 (8.2)	
	200°C (392°F)						30 (4.7)	30 (4.8)	
STIFFNESS & CREEP	Flexural Strength	D790	178	MPa	(kpsi)				
	−40°C (−40°F)						220 (31.6)	210 (30.7)	205 (30.0)
	23°C (73°F)					230 (33.1)	200 (29.0)	195 (28.5)	190 (27.5)
	120°C (250°F)					150 (22.1)	140 (20.5)	145 (20.8)	120 (17.5)
	150°C (300°F)						110 (16.0)	105 (15.5)	
	200°C (392°F)						55 (8.0)	55 (8.1)	40 (6.0)
	Flexural Modulus	D790	178	GPa	(Mpsi)				
	−40°C (−40°F)						20 (2.9)	20 (2.9)	15 (2.2)
	23°C (73°F)					16 (2.3)	19 (2.7)	18 (2.6)	14 (2.0)
	120°C (250°F)					11 (1.6)	14 (2.0)	14 (2.0)	10 (1.5)
	150°C (300°F)						12 (1.7)	12 (1.7)	
	200°C (392°F)						6 (0.9)	7 (1.0)	4 (0.6)
	Compressive Strength	D695	–	MPa	(kpsi)				
	−40°C (−40°F)						190 (27.5)	170 (24.7)	
	23°C (73°F)						170 (24.7)	155 (22.8)	
	120°C (250°F)						125 (18.1)	80 (11.6)	
	200°C (392°F)						40 (5.8)	25 (3.9)	
	Compressive Modulus	D695	–	GPa	(Mpsi)				
	−40°C (−40°F)							16 (2.26)	
	23°C (73°F)							7 (1.06)	
	120°C (250°F)							6 (0.79)	
	200°C (392°F)							3 (0.46)	
	Deformation Under Load 27.6 MPa (4000 psi)	D621	–	%					
	23°C (73°F)					0.60	0.30	0.45	
	50°C (122°F)					0.35	0.35		
	Heat Deflection Temperature	D648	75	°C	(°F)				
	1.8 MPa, (264 psi)					260 (504)	270 (520)	270 (520)	230 (445)
	0.46 MPa, (66 psi)					>275 (>527)	>275 (>527)	>275 (>527)	270 (520)

[1] These values are for natural color resins only. Colorants or other additives may alter some or all of these properties. The data listed here are preliminary and are based on limited manufacturing campaigns. Test data may be modified as more experience is gained. These typical properties should not be used to establish specification limits nor be used alone as the basis of design.

TABLE 1 (continued)
Typical Properties of DU PONT LCP Resins

	Property	Method ASTM	Method ISO	Units SI	Units (English)	DU PONT HX-4000	DU PONT HX-4100	DU PONT HX-4101	DU PONT HX-4330
TOUGHNESS	Izod Impact	D256	180	J/m	(ft-lb/in)				
	–40°C (–40°F)					85 (1.6)	65 (1.2)	60 (1.1)	
	23°C (73°F)					85 (1.6)	60 (1.1)	55 (1.0)	15 (0.3)
	Unnotched Izod Impact Strength	D256	180	J/m	(ft-lb/in)				
	–40°C (–40°F)					180 (3.4)	160 (3.0)	150 (2.8)	
	23°C (73°F)					200 (3.8)	175 (3.3)	165 (3.1)	
THERMAL	Melting Point	D3418		°C	(°F)	310 (590)	310 (590)	310 (590)	
	Coefficient of Linear Thermal Expansion[2]	D696							
	Machine Dir. –40°C to 150°C (–40°F to 300°F)			10^{-4}/°C	(10^{-4}/°F)	– 0.1 (– 0.05)	0.5 (0.3)	0.5 (0.3)	0.5 (0.3)
	Transverse Dir. –40°C to 150°C (–40°F to 300°F)			10^{-4}/°C	(10^{-4}/°F)	10.6 (5.9)	9.7 (5.4)	9.7 (5.4)	3.1 (1.7)
	Thermal Conductivity	C177		W/m•K	Btu-in/ h-ft²-°F		0.23 (1.6)	0.23 (1.6)	
FLAMMABILITY	UL Flammability[3]	UL-94	–	mm	(in)	V-0	V-0	V-0	V-0
	Thickness					0.79 (0.031)	3.18 (0.125)	0.79 (0.031)	1.59 (0.062)
	Oxygen Index	D2863		$\%O_2$			36	36	
	TEMP. INDEXING (All Provisional)	UL-746B		°C	(°F)		200 (392)	150 (302)	
MISCELLANEOUS	Specific Gravity	D972				1.29	1.51	1.51	1.55
	Water Absorption	D570	62						
	24 hr. 23°C (73°F)			%			0.04	0.03	
	6-month immersion			%			0.30	0.28	
	Hardness Rockwell M	D785	2039	points				100	
	Hardness Rockwell R							123	
	Taber Abrasion CS-17 Wheel 1000g			mg/1000 cycles			102	123	
	Mold Shrinkage[4] for 3.18 mm (0.125 in.) thickness								
	Flow			%		– 0.3	0.0	0.0	– 0.1
	Transverse			%		1.2	0.6	0.6	0.6

[2] Determined by Quartz Dilatometer method on 76.2 x 127 x 3.18 mm (3 x 5 x 0.125 inch) specimens.

[3] This small test does not indicate combustion characteristics under actual fire conditions. Data for HX-4100 and HX-4101 were obtained from Underwriters Laboratories. Test results on HX-4000 and HX-4330 are Du Pont data using the UL Test Procedure.

[4] Shrinkage determined on 76.2 x 127 x 3.18 mm (3 x 5 x 0.125 in.) specimen molded at 82°C (180°F) mold temperature.

TABLE 1 (continued)
Typical Properties of DU PONT LCP Resins

	Property	Method ASTM	Method ISO	Units SI	Units (English)	DU PONT HX-4000	DU PONT HX-4100	DU PONT HX-4101	DU PONT HX-4330
ELECTRICAL	Dielectric Strength, Short Time[a]	D149	–	kV/mm	(V/mil)				
	0.79 mm (0.031 in.)								
	23°C (73°F)						67.0 (1700)	65.5 (1670)	
	120°C (250°F)						53.5 (1360)	56.5 (1440)	
	150°C (300°F)						50.5 (1280)	47.0 (1200)	
	200°C (392°F)						45.0 (1140)	46.0 (1170)	
	245°C (475°F)						42.5 (1080)	44.0 (1120)	
	1.59 mm (0.062 in.)								
	23°C (73°F)						49.0 (1250)	50.0 (1270)	
	120°C (250°F)								
	150°C (300°F)						43.5 (1110)	38.0 (970)	
	200°C (392°F)						39.5 (1000)	32.5 (820)	
	245°C (475°F)						32.5 (820)		
	3.18 mm (0.125 in.)								
	23°C (73°F)					26.5 (670)	31.5 (800)	31.5 (800)	30.0 (760)
	120°C (250°F)								
	150°C (300°F)						29.5 (750)	30.0 (760)	25.5 (650)
	200°C (392°F)					23.5 (600)		25.0 (640)	23.5 (600)
	245°C (475°F)						25.5 (650)	24.5 (620)	
	Step by Step 3.18mm @ 23°C (0.125in @ 73°F)					18.5 (470)	18.5 (470)	17.0 (430)	
	Comparative Tracking Index	UL746A D3638		volts		155	150	130	
	Dielectric Constant								
	3.18 mm (0.125 in.)								
	1 kHz	D150	1325						
	23°C (73°F)					3.2	3.6	3.8	3.6
	120°C (250°F)						3.8	3.9	
	200°C (392°F)					3.5	3.9	4.2	3.9
	260°C (500°F)						4.0	4.3	
	1 MHz								
	23°C (73°F)					3.1	3.6	3.6	3.4
	120°C (250°F)						3.7	3.7	
	200°C (392°F)					3.3	3.8	3.9	3.7
	260°C (500°F)						3.9	4.0	
	Dissipation Factor								
	3.18 mm (0.125 in.)								
	1 kHz	D150	1325						
	23°C (73°F)					0.008	0.007	0.007	0.009
	120°C (250°F)						0.005	0.005	
	200°C (392°F)					0.008	0.010	0.010	0.011
	260°C (500°F)						0.015	0.027	
	1 MHz								
	23°C (73°F)					0.010	0.013	0.010	0.009
	120°C (250°F)						0.018	0.012	
	200°C (392°F)					0.021	0.019	0.016	0.015
	260°C (500°F)						0.012	0.009	
	Volume Resistivity	D257	1325	ohm-cm		10^{17}	10^{16}	10^{16}	
	Surface Resistivity	D257	1325	ohm-Sq		10^{16}	10^{16}	10^{16}	

[a] Determined with surrounding medium of KRYTOX® high temperature oil. Use of other mediums including air may alter some or all of these properties.

INJECTION MOLDING

DU PONT HX-4000 SERIES

LIQUID CRYSTAL POLYMERS

SCREW BACK PRESSURE

- Minimum

SCREW RPM

- 6-16 in/sec peripheral speed (e.g. 2 in screw: 60-150 rpm)

CYCLE

- Fast fill rate
- Fast set-up time (If not, check resin moisture)
- Overall - about 2/3 that of PET and PPS.

MELT STABILITY

- HX-4100 - Very stable (long hold-up times; cycle interruptions)
- HX-4101 - For cycle interruptions >20 minutes, purge machine

PURGE

- Fractional melt index polyethylene
- Keep screw turning at temperatures >600°F
- Wear protective gloves and safety glasses

SHRINKAGE

- 0.0% (!) - Direction of flow
- 0.6% - Transverse direction

VENTING

- 0.015 in (or greater) - Depth; 0.030-0.060 in - Land
- Relieve to 0.060 in or greater

DRAFT

- Generous (2-5 degrees per side?)

INJECTION MOLDING

DUPONT HX-4000 SERIES

LIQUID CRYSTAL POLYMERS

DRYING

- Overnight at 250°F
- 4 hours at 300°F
- <0.015% moisture required

REGRIND

- Limit to 20%
- Regrind shatters - need very sharp cutters
- Fines separation

MELT TEMPERATURE

- 640-660°F (Cylinder insulation may be needed)
- Use heavy gloves for melt temperature measurement

MOLD TEMPERATURE

- 170-300°F
- Lower temperatures for ejection of complex parts
- Higher temperatures for fill of long, thin parts

PRESSURES (INJECTION & PACK)

- 4,000-15,000 psi
- Lower pressures to improve ejection
- Higher pressures to improve fill and weld lines
- Maximum part weight for optimum weld line strength

FILL RATE

- Flow is very shear sensitive
- Fast: 1-3 seconds (0.3-1.0 seconds common for small shots)
- Capable of long flow in thin sections
- Zero flash

XYDAR® FC SERIES PROCESSING GUIDE

High-Performance Engineering Resins

XYDAR FC filled compounds are new general purpose liquid crystal polymer compounds that can be easily injection molded on conventional equipment and do not require vented barrels or ceramic heater bands. Ceramic heater bands may be advisable for very long production runs, however, because of their longer service life.

These FC compounds provide excellent flow for thin-wall and difficult-to-fill parts, and heavy wall components can be molded at fast cycles. Molds designed for other thermoplastics can be used for developmental evaluations.

Resin Drying

- XYDAR FC compounds are not hygroscopic but surface moisture must be removed by oven drying for 8 hours @ 300°F.
- Hopper dryers with desiccant beds are recommended.
- Incoming air to the hopper dryer should measure 300°F with a dew point of −20°F.

Machine

- XYDAR FC compounds can be run on standard injection molding machines *without modifications*.
- Nonvented or vented barrels can be used.
- Clamp pressure should be 2-4 tons per square inch of projected area.
- Shot size should be a minimum of 30% of the barrel capacity.
- Conventional screw designs are recommended, such as 20-24:1 L/D and 2.5-3:1 compression ratios.

Mold

- Molds should be heated to 200-500°F either by circulating hot oil or electric cartridge heaters.
- Cold slug wells are recommended.
- Both mold halves should be heated equally to avoid mismatch.
- Molds should be insulated from the mold platens to ensure adequate temperature control.

Processing Profile

Melt	Nozzle	Front Zone	Center Zone	Rear Zone	Hopper Dryer
750-850°F	720-770°F	720-770°F	670-740°F	660-710°F	300°F

Screw speed: 80-100 rpm
Injection pressure: 5,000-14,000 psi
Back pressure: 0
Mold temperature: 200-500°F