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Non-Metallic Transducer Mounting Brackets (AN/BQQ-5/6 Spherical Array Transducers)

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Failure of transducer metallic mounting hardware due to corrosion has a significant impact on the fleet in terms of maintenance costs and systems availability. An obvious solution to the corrosion problem is to avoid using metallic materials. The most stringent requirement of the mounting bracket is the ability to withstand explosive shock. Molded non-metallic TR-317 mounting brackets consisting of three different resin-filler material systems have passed explosive shock testing per MIL-S-901-D. The TR-317 transducers were held on the non-metallic brackets with commercially available non-metallic nuts. All of the non-metallic brackets survived the test. This report details the design requirements, material selection, material testing, finite element analysis, bracket design, and first-article testing of the non-metallic mounting brackets.

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NON-METALLIC TRANSDUCER MOUNTING BRACKETS (AN/BQQ-5/6 SPHERICAL ARRAY TRANSDUCERS)

INTRODUCTION

Spherical array sonar transducers require mounting brackets for installation in the array. Historically, metallic brackets have been used. Past metallic materials used in the brackets have included carbon steel, stainless steel, and aluminum bronze (Al-Br). Recent AN/BQQ-5 sonar dome inspections have revealed extensive corrosion occurring within two years of installing new mounting brackets. Most metals are subject to corrosion under certain conditions. The seawater environment found in submarine sonar domes is highly corrosive because of varying water conditions, oxygen content, pH levels and the existence of electrochemical potentials. Corrosion in transducer mounting brackets has been evident since the initial installations of spherical arrays. Attempts to control the dome's interior environment have been unsuccessful. Failure of transducer mounting hardware has had a significant impact on the fleet in terms of maintenance costs and reduced systems availability.

A solution to sonar bracket corrosion is to avoid using metallic materials. Recent test results of connector backshells manufactured with reinforced plastics have shown high strengths and long-life in seawater environments [1-7]. A non-metallic bracket design using materials similar to the reinforced plastic connector backshells could provide long-life transducer brackets needed to reduce fleet maintenance costs and to improve system availability. In addition, by demonstrating that non-metallic engineering materials satisfy the spherical array transducer bracket requirements a number of other fleet transducer bracket designs, such as the DT-276 transducer bracket in the AN/BQR-7 array, can be accomplished using the materials developed for the spherical array, thereby minimizing total design costs.

OBJECTIVES

The objectives of this engineering improvement program are to determine if a non-metallic transducer mounting bracket material can meet the performance requirements for the AN/BQQ-5/6 spherical array transducers and thus eliminate bracket corrosion problems, extend bracket service life beyond that of the transducer, and significantly reduce array maintenance and life-cycle costs.

APPROACH

The non-metallic bracket engineering improvement effort was divided into six major tasks:

- Design Requirements
- Material Selection
- Material Testing
- Finite Element Analysis
- Bracket Mold Design
- First-Article Testing

Each of these tasks is described in the following sections.

DESIGN REQUIREMENTS

The bracket design requirements task has concentrated on reviewing available specifications and drawings for the current TR-317 brackets and characterizing the stress history profile of the brackets in service. The following information has been obtained from the sources noted concerning specifications for performance requirements of the TR-317 mounting brackets:

1. Explosive shock stress exposure for water-backed systems is summarized as follows:

    - Peak over pressure: 25.2 MPa (3648 psi)
    - Maximum velocity: 4.3 to 10.4 m/s (14 to 34 ft/s)
    - Average acceleration to peak velocity: 1060 g to 8194 g
    - Applied force: 2.4 to 18.2 kN (530 to 4097 lb)

    The range in exposures is the result of device orientation during explosive shock and the higher values represent the pertinent requirements for bracket design.

2. The in-air mass of the TR-317 transducer was found to be a maximum of 25.7 kg (56.7 lbm) for a flooded transducer.

3. TR-317 bracket design drawings were supplied by Crane Division, Naval Surface Warfare Center.

Drawing Number	Description
88594-001916-001	Shock Support Assembly Standard TR-155( )/BQ Transducer
88594-001916-002	Shock Support Assembly Special TR-155( )/BQ Transducer
88594-001916-003	Standard Mounting Bracket Subassembly
88594-001916-004	Special Mounting Bracket Subassembly

4. Data to identify the strength requirements of the brackets during explosive shock have not been found. The rationale for tensile strength specifications for the brackets was evidently based on quality control procedures for acceptable castings of the aluminum-bronze alloy and not for ultimate strength needed to support the transducer in normal service or in explosive shock scenarios. If the casting exhibited the specified tensile strength and elongation, it was assumed that the bracket would be ductile enough not to crack during explosive shock. The bracket is required to sustain plastic deformation during explosive shock.

5. Torque requirements for installing brackets is stated in ASW Test No. 426-2-1821 Rev. C as:

   - Bracket installation nut: 4.5 ± 0.57 N-m (40 ± 5 in-lb)
   - Transducer securing nut: 19.6 to 22.3 N-m (173 to 197 in-lb)

In addition to reviewing the fleet's documentation on bracket strength requirements, the mission profile for the TR-317 transducer was also reviewed and those items which impact bracket design are summarized. The mission profile for the TR-317 brackets is taken from normal SSN service exposures in the sonar dome. Exposures that significantly affected material selection and which wereused for material properties screening include:

1. Temperature in air:

   - Maximum: 70°C for 450 h/yr
   - Minimum: -30°C for 180 h/yr

2. Temperature in water:

   - Maximum: 32°C for 960 h/yr
   - Minimum: -2°C for 960 h/yr
   - Long term: 25°C for 6840 h/yr

3. Applicable Vibration Specification:

   - MIL-STD 167-1

This report uses both English and S.I. units. The S.I. units are used in the text and, whenever possible, in figures and tables. However, because the engineering design drawings, specifications, and references provided to this project use English units, some test and analysis results are presented in English units.

MATERIAL SELECTION

Material selection has centered on candidate non-metallic bracket materials and pultruded-rod reinforcement materials. The selection process for each of these material types is discussed in the following sections.

Non-Metallic Bracket Materials

The initial bracket material selection method consisted of performing a survey of the general field of non-metallic materials. Textbooks, trade journals, material databases, and manufacturers' properties data were reviewed to identify categories of materials appropriate for use in sonar bracket applications. Table 1 lists these categories of non-metallic materials, the manufacturers' names, and important material properties.

A more restrictive material selection method was then used to narrow the field of prospective non-metallic material candidates. The following selection criteria was used to identify candidates for more extensive material testing:

1. commercially available at a reasonable cost,
2. injection moldable,
3. high tensile strength, and
4. high impact strength.

The most severe loads experienced by the brackets are due to explosive shock. High tensile strength and high impact strength were deemed important selection criteria if a non-metallic bracket was going to be able to survive explosive-shock loads. In general, a material was considered to have a high tensile strength if it exceeded 137.9 MPa (20 ksi) and to have a high impact strength if it exceeded a notched Izod impact strength of 106.8 J/m (2 ft-lbs/in). The last column of Table 1 shows some of the materials that were selected and the reason for rejecting the other initial material candidates.

Table 2 provides a summary of the manufacturers' material properties for the candidates selected using the material selection method described above. After discussions with the technical representatives from each of the resin system manufacturers, it became evident that, in general, the highest tensile and impact strengths are achieved by using long glass fibers at high loading ratios (50% to 60%). For this reason two additional candidate materials were added which have 60% long glass fiber content, Verton and Celstran. Additional review of the manufacturers' material properties data identified two other potential candidates with excellent mechanical properties, Isoplast and Vectra A-515.

Other filler materials such as carbon, graphite, Kevlar, and mineral fillers used in the resin systems identified in Table 2 were investigated as potential candidates. A review of manufacturers' data showed that no significant improvement in tensile strength or impact strength was found in using these fillers instead of glass fibers. In most cases, glass fibers (especially long glass fibers at high loading ratios) showed substantially higher mechanical properties. Table 3 presents a comparison of some selected mechanical properties of the various filler materials.

Seven non-metallic material candidates were selected for potential use in TR-317 molded mounting brackets. Extensive material testing was performed to verify published material properties and to determine unpublished material properties data. All of the candidate materials were molded into TR-317 standard mounting brackets and subjected to short-term testing and evaluation. This short-term testing, consisting of material strength and environmental exposure tests, was used to narrow the candidate list to three materials for long-term testing, such as creep, accelerated life testing (ALT), etc.

Pultruded Rod Reinforcement Materials

The incorporation of a metal rod insert into the bolt sections of the TR-317 molded bracket has been considered as a method for strengthening the bracket in this area. However, the use of a metal reinforcing rod is counter to the goal of producing an entirely non-metallic bracket. Because of this restraint, the use of a high-strength non-metallic rod was evaluated.

Non-metallic unidirectional fiber pultruded composite rods have been available with thermoset matrix resins for a number of years. These unidirectional fiber glass/thermoplastic rods have tensile strengths comparable to stainless steel. The thermoplastic pultruded rod is now becoming more commercially available with a variety of matrix/reinforcement combinations. For initial evaluation in the thermoplastic brackets, pultruded fiberglass/nylon 6,6, and fiberglass/TP polyurethane were evaluated as reinforcements for the bolt sections in the brackets.

Table 1 – Material selection criteria

Type	Manufacturer (Trade Name)	Tensile Strength (psi)	Tensile Modulus (psi x 10^6)	Flexural Strength (psi)	Flexural Modulus (psi x 10^6)	IZOD Impact (ft lb/in) (notched)	Processing	Reason for Rejection
PPS (glass)	Phillips (Ryton Rayton)	10,000 to 16,000		15,000 to 26,000	1.7 - 2.2	0.6 - 1.3	Injection Moldable	Low Tensile & Impact Strength
Polycarbonates (glass)	Compound Tech, Inc.	12,000 to 17,000	0.8 - 1.2	20,000 to 24,000	0.7 - 0.9	2 - 4	Injection Moldable	Low Tensile Strength
"	PPG CR-39							
PPO (glass)	LNP GE (NORYL)	16,000 to 20,000	—	21,000 to 25,000	0.8 - 1.2	2.3	—	Low Tensile Strength
Liquid Crystalline Polyester (glass)	Ethyl (Xydar)	10,000 to 14,000	1.7 - 1.9	14,000 to 20,000	1.2 - 1.4	0.8 - 1.6	Injection Moldable	Low Tensile & Impact Strength
PBI (Unfilled)	Hoescht Celanese (Celazole)	23,000	0.85	32,000	0.95	0.5	Sintering process in finished parts only	Not Injection Moldable Low Impact Stength

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Table 1 – Material selection criteria

Type	Manufacturer (Trade Name)	Tensile Strength (psi)	Tensile Modulus (psi x 10^6)	Flexural Strength (psi)	Flexural Modulus (psi x 10^6)	IZOD Impact (ft lb/in) (notched)	Processing	Reason for Rejection
PAI (filled)	Amoco (Torlon)	20,000 to 32,000	1.5 - 3.2	40,000 to 50,000	1.6 - 2.8	1.5		Molding Difficulties
Ether-Imide (filled)	GE (Ultem)	20,000 to 32,000	—	31,000 to 48,000	1.0 - 2.8	2.0		Selected
PEEK (glass)	ICI Fiberite (Victrex) LNP RTP	13,000 to 24,000		28,000 to 34,000	1.0 - 1.5	1.5 - 2.1		Low Tensile Strength
Ether Sulfones (mineral/glass filled)	ICI Fiberite (Victrex) GE (Udel)	14,000		21,000	1.2	0.9		Low Tensile & Impact Strength
Epoxy (glass or Kevlar)	Amoco ICI Fiberite Ciba (prepreg only) Dow	8,000 to 75,000	4	18,000 to 63,000	3.0 - 4.0	0.3 - 0.45 34 (Kevlar)	some prepregs.	Not Injection Moldable Low Impact Strength
Phenolics	ICI Fiberite	5,000 to 16,000		7,500 to 25,000	0.75 - 3.0	0.4 - 1.4 (20 - long glass fiber)	Injection or Transfer or Compression Moldable	Low Tensile & Impact Strength

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Table 1 – Material selection criteria

Type	Manufacturer Trade Name	Tensile Strength (psi)	Tensile Modulus (psi x 10^6)	Flexural Strength (psi)	Flexural Modulus (psi x 10^6)	IZOD Impact (ft lb/in) (notched)	Processing	Reason for Rejection
Melamines	ICI Fiberite	5,000 to 8,000		8,000 to 20,000	1.9 - 2.2	0.5 to 20 fiber length dependent	Compression or Transfer Moldable	Low Tensile Strength Not Injection Moldable
Polyimides (filled)	Hysol DuPont Allied American Cyamamid Fiberite	14,000 to 21,000		20,000 to 37,000	2-3.1	0.4 - 22	Transfer or Injection or Compression Moldable	Low Tensile Strength
PMR-15	Hysol	11,000		16,000	1.7 - 2.1	0.81		Low Tensile & Impact Strength
Bismaleimides (prepregs only/ glass)	Hexcel	—		94,000	4.1	—	—	Not Injection Moldable
Nylon 66 [long (10 mm) glass fiber]	ICI (VERTON)	30,000 to 42,000	1.6 - 2.8	46,000 to 62,000	1.5 - 3.0	6.0 - 7.0	Injection Moldable	Selected
Bisoxazoline-Phenolics (glass cloth)	Ashland Chemical	65,000	4.1	110,000	4.5		Pre-preg Laminates, RTM	Not Injection Moldable

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Table 2 – Summary of manufacturer's material property data

MANUFACTURER	MATERIAL (FILLER)	TYPE	TENSILE STRENGTH (Ksi)	COMPRESSIVE STRENGTH (Ksi)	TENSILE MODULUS (Msi)	NOTCHED IZOD IMPACT (ft-lbs/in)	ELONGATION AT RUPTURE (%)	SPECIFIC GRAVITY
DOW	ISOPLAST 101 (40% LONG GLASS)	POLYURETHANE	28	—	1.4	8	2	1.5
DOW	ISOPLAST 101 (60% LONG GLASS)	POLYURETHANE	35	—	2.3	13	1	1.7
ICI	VERTON RF-700 10 HS (50% LONG GLASS)	NYLON 6, 6	37	—	—	6	4	1.57
GE	ULTEM 2300 (30% GLASS)	POLYETHERIMIDE	24.5	30.7	1.3	2	3	1.51
HOECHST/ CELANESE	VECTRA A-515 (15% MINERAL FILL)	AROMATIC POLYESTER	27	11.5	1.7	6.7	3.9	1.52
ICI	VERTON RF-700 12 HS (60% LONG GLASS)	NYLON 6, 6	42	—	—	7	3	1.7
POLYMER COMPOSITES	CELSTRAN N66G60-01-4 (60% LONG GLASS)	NYLON 6, 6	40.5	46	3	11	1.7	1.69

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Note: Material properties were measured at room temperature. The notched Izod impact tests used one-eighth inch test bars.

Table 3 – Comparison of some selected mechanical properties of filler materials

MATERIAL		FILLER	TENSILE STRENGTH (Ksi)	TENSILE MODULUS (Msi)	NOTCHED IZOD IMPACT STRENGTH (ft-lb/in)
VECTRA	C150	50% Glass	24.0	3.0	1.6
	A230	30% Carbon	28.0	4.5	1.2
	A515	15% Mineral	27.0	1.7	6.7
	A625	25% Graphite Flake	23.5	1.5	1.8
ULTEM	2300	30% Glass	24.5	1.3	2.0
	3254	20% Mineral	14.6	—	0.6
CELSTRAN	N66G60	60% Long Glass	40.5	3.0	11.0
	N66K35	35% Kevlar	17.2	1.1	2.8

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MATERIAL TESTING

Material testing was performed on the candidate non-metallic bracket materials and the pultruded-rod bracket reinforcement materials. The results from these tests are presented in the following sections.

Non-Metallic Bracket Materials

The non-metallic bracket material testing consisted of performing tensile, Izod impact, ultimate toughness, water absorption, Thermal Mechanical Analysis (TMA) and Dynamic Mechanical Analysis (DMA) tests. These tests and their results are discussed in the following sections.

Tensile Tests

Tensile specimens for each candidate material group were obtained from the manufacturers and tested after equilibration in the following environmental conditions:

Condition 1 :	Dry/Room Temperature*
Condition 2 :	Dry/70°C*
Condition 3 :	3.5% Salt Water/Room Temperature
Condition 4 :	3.5% Salt Water/70°C

* Note: Dry for these tests is defined as not exposed to water, but conditioned to the relative humidity level at the time of the test.

Figures 1 through 3 summarize the tensile test results. Figures 4 through 10 illustrate the results of the tensile tests performed thus far as a function of stress vs strain. As was expected, samples pulled in the dry/room temperature condition generally had higher ultimate tensile strengths compared to samples tested under the other conditions, with the exception of Vectra A-515. Vectra A-515 was the only material found to have a higher ultimate tensile strength when tested dry-hot, as compared to dry/room temperature. The Isoplast materials and the Ultem 2300 exhibited higher strengths after exposure to 70°C salt water as compared to exposure to 70°C alone. In contrast, the nylon 6,6 samples (Verton and Celstran) showed better performance in the dry-hot condition compared to the 70°C samples exposed to salt water.

Figures 1 and 2 compare the ultimate tensile strength and elongation at rupture results for each material in the various exposure conditions. With the exception of Verton and Vectra A-515, all of the materials tested showed a reduction in percent elongation at rupture following exposure to either the wet-hot or dry-hot conditions. Manufacturer supplied tensile data are notably higher than those obtained under condition 1. The cause of this discrepancy is the technique used to condition the samples prior to testing. The manufacturers typically mold the tensile specimen and immediately contain it in order to isolate it from atmospheric moisture. The specimens tested under condition 1 were conditioned at room temperature and normal relative humidity.

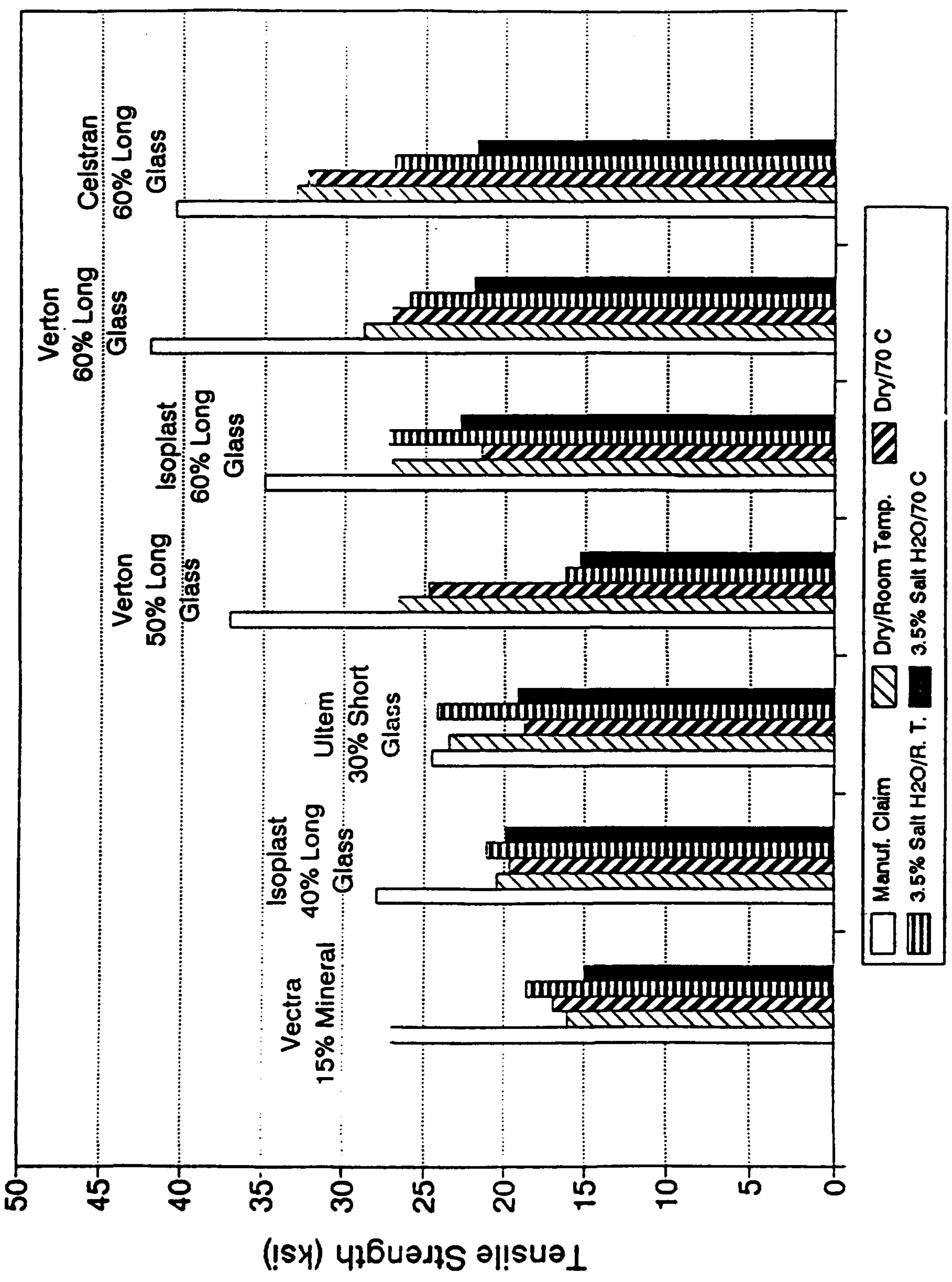


Fig. 1 – Ultimate tensile strength for non-metallic materials

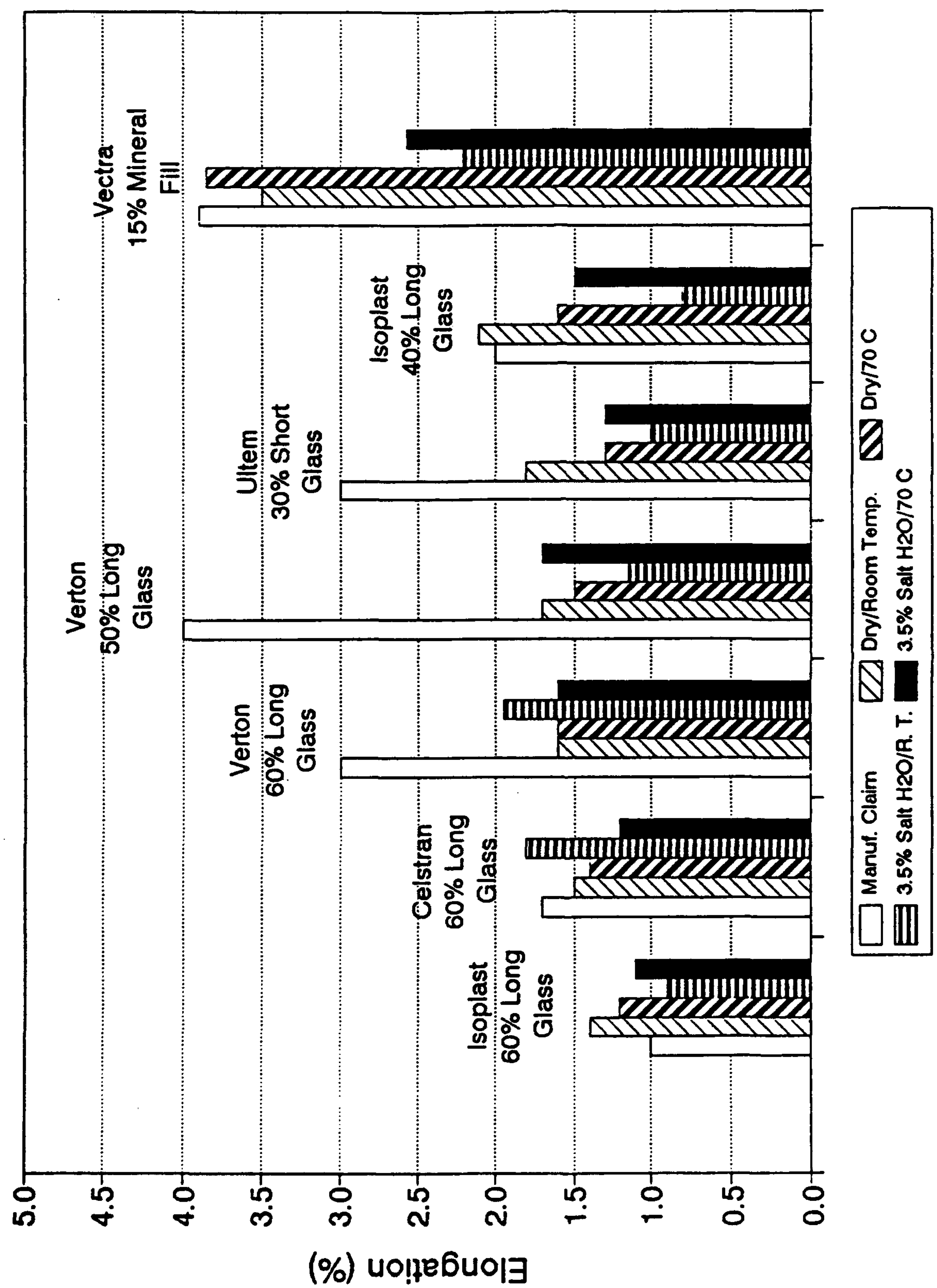


Fig. 2 – Percent elongation at rupture for non-metallic materials

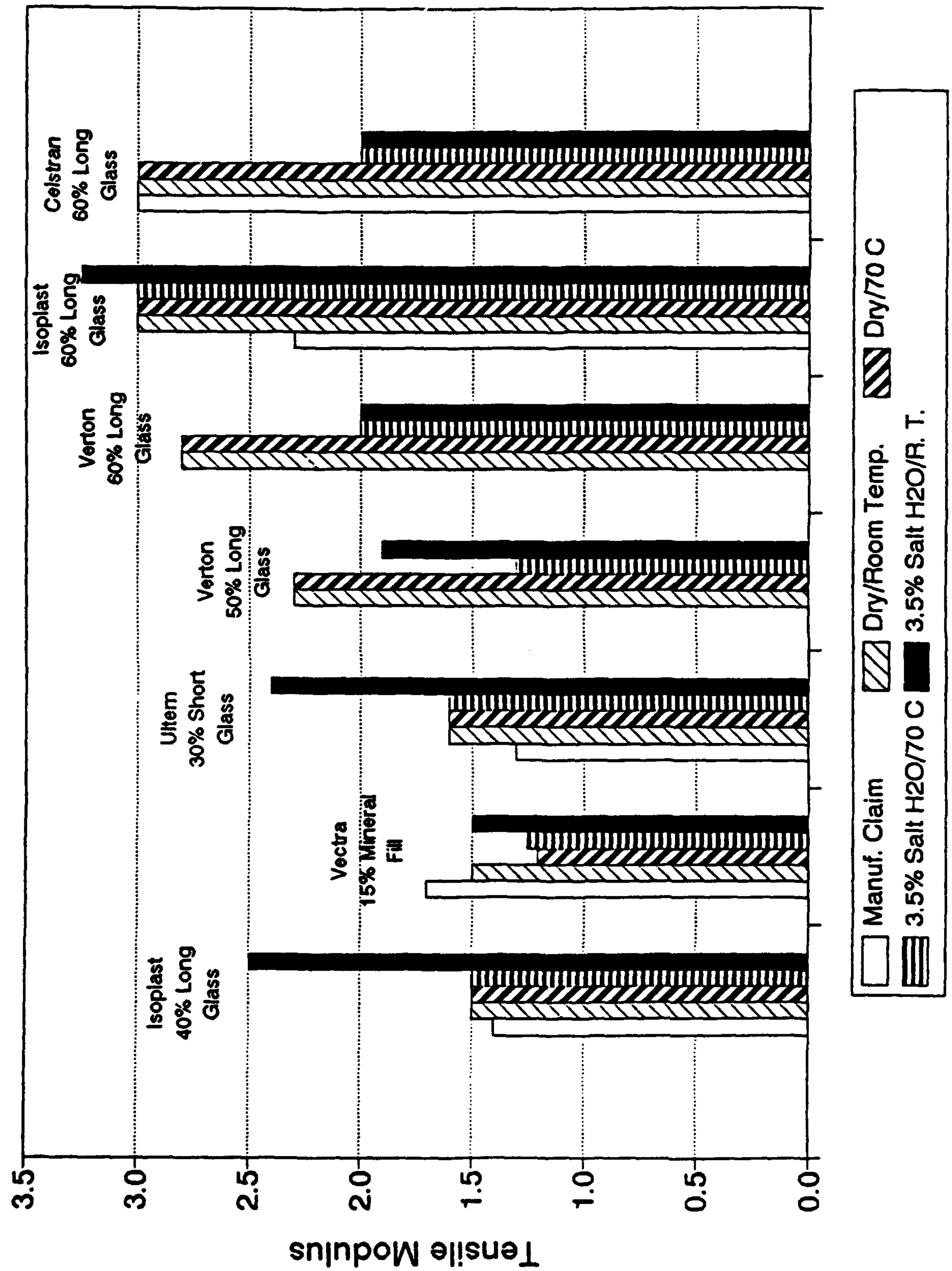
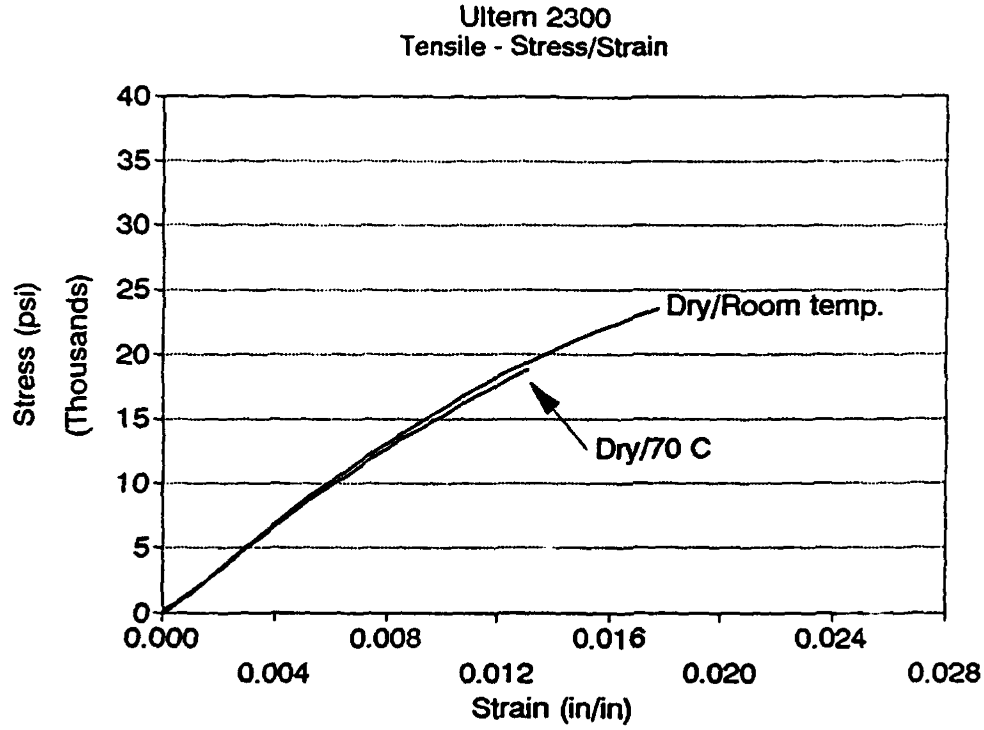


Fig. 3 – Tensile modulus for non-metallic materials



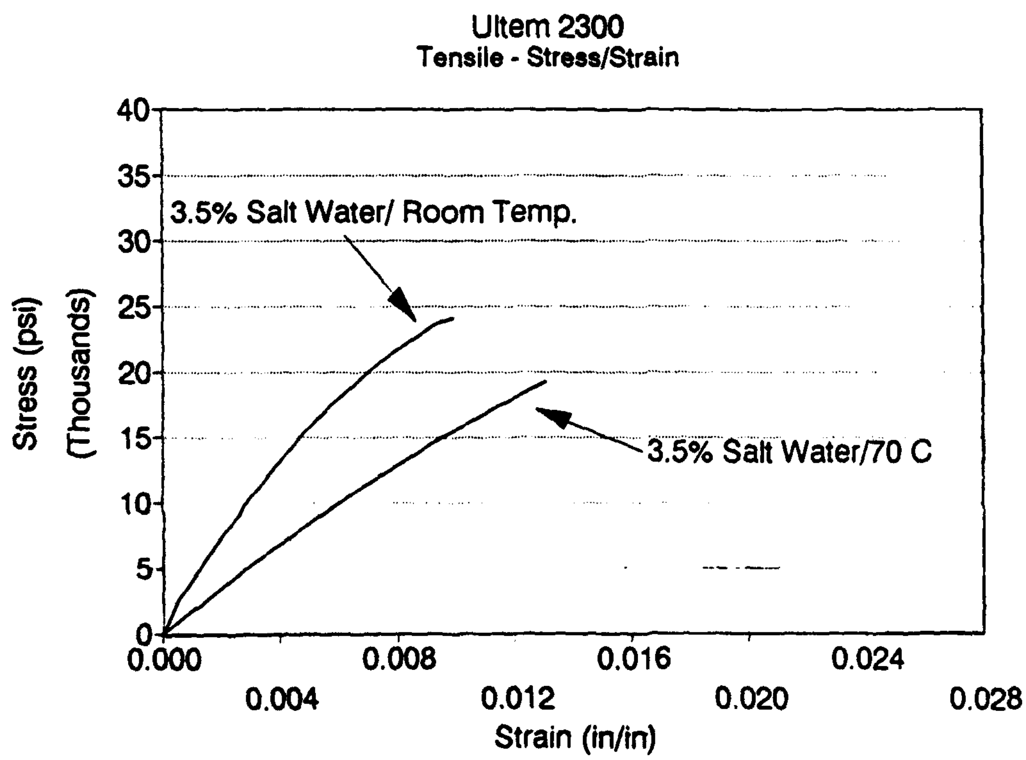
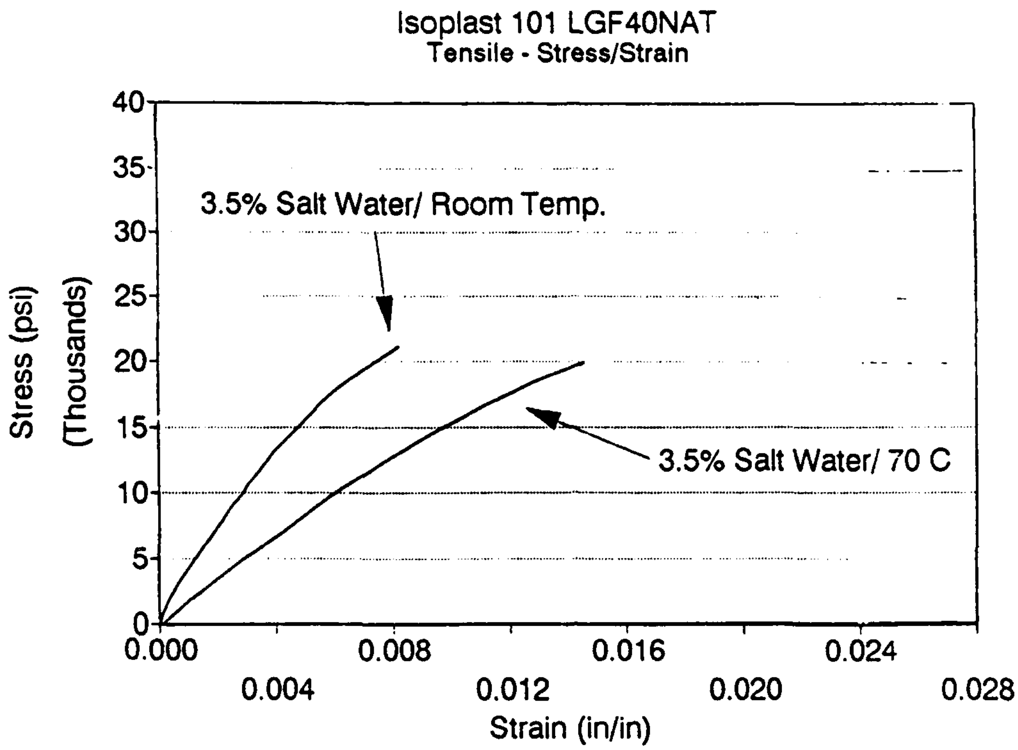


Fig. 4 – Stress-strain plots for Ultem 2300



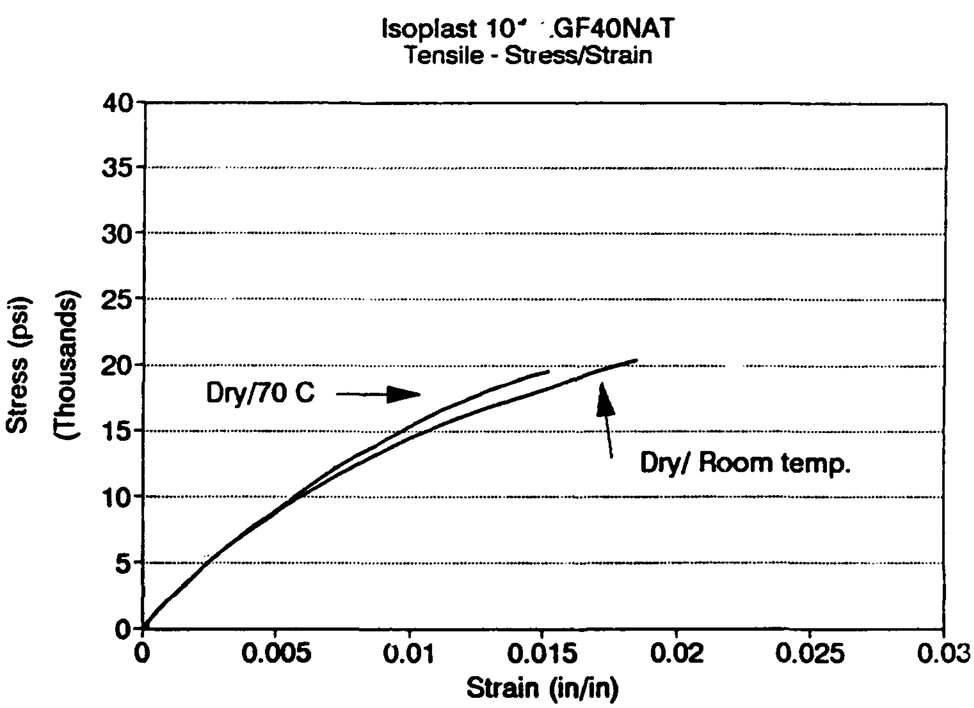
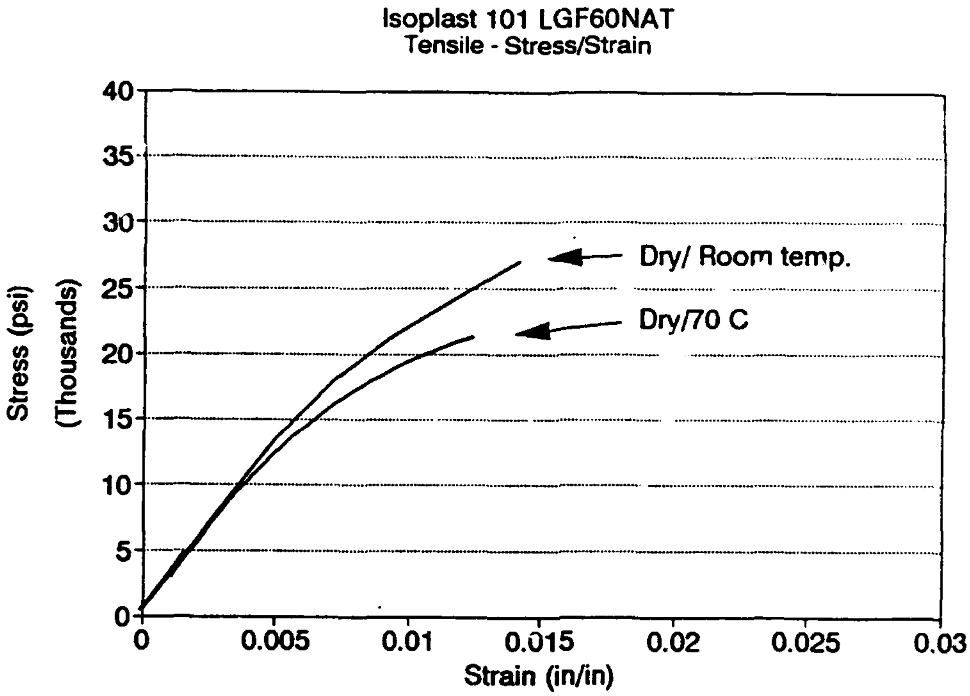


Fig. 5 – Stress-strain plots for Isoplast 101 LGF40NAT



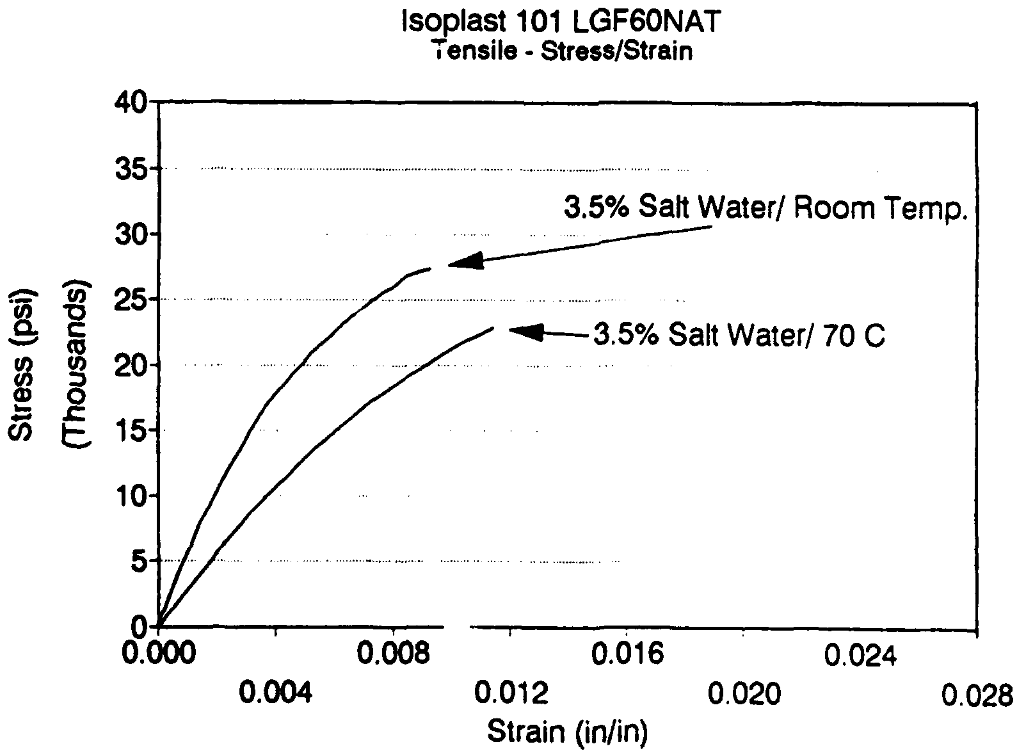
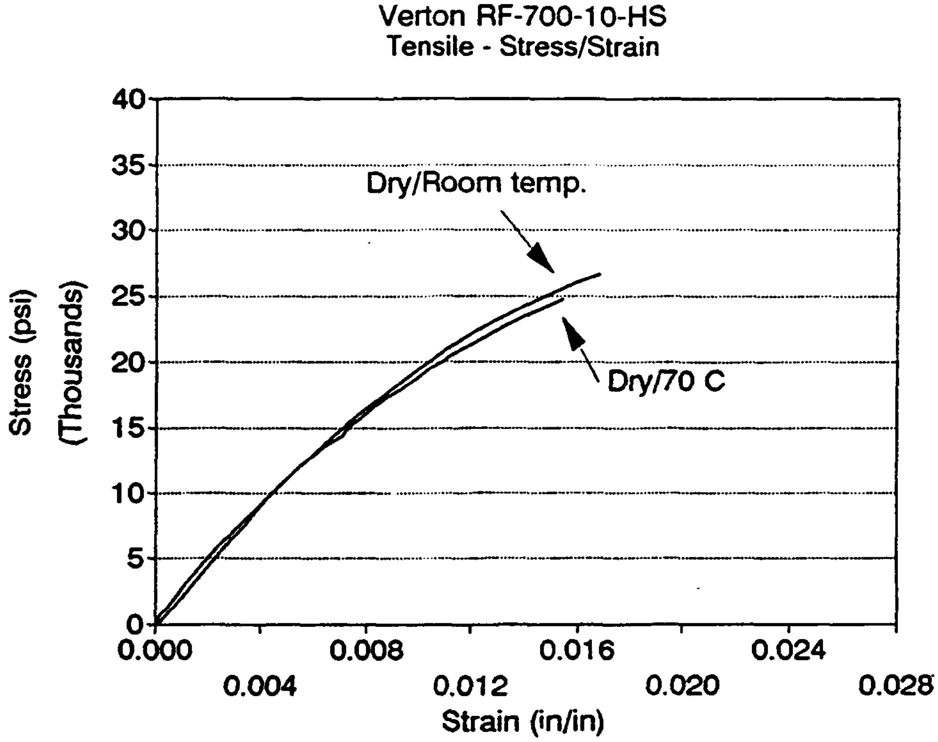


Fig. 6 – Stress-strain plots for Isoplast 101 LGF60NAT



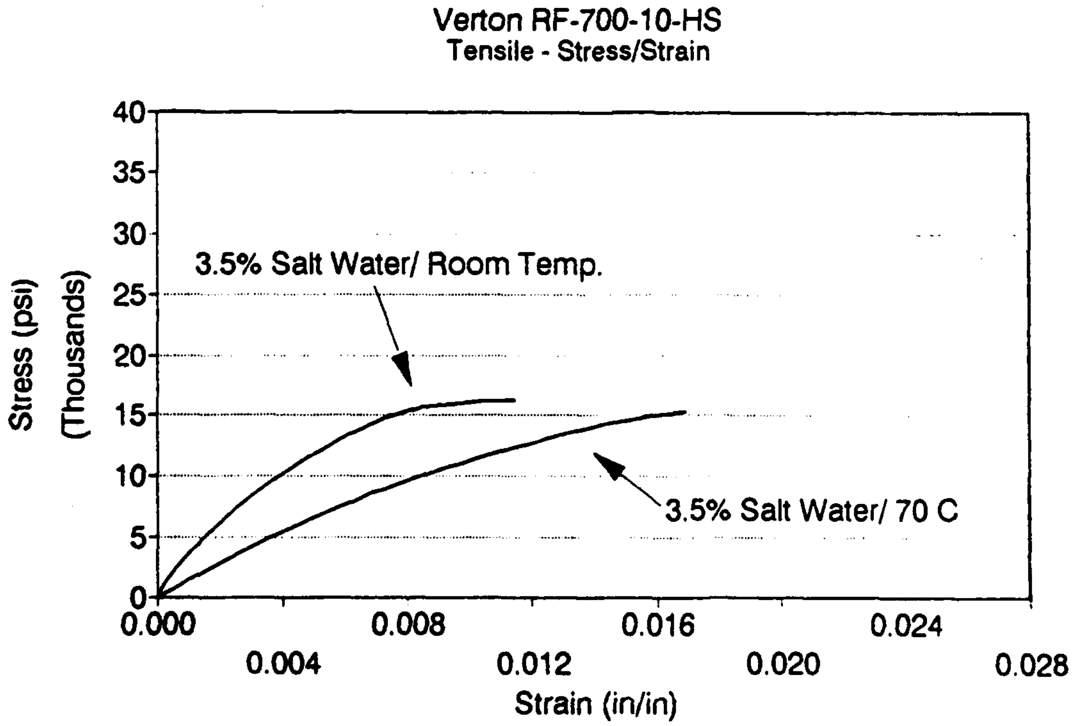
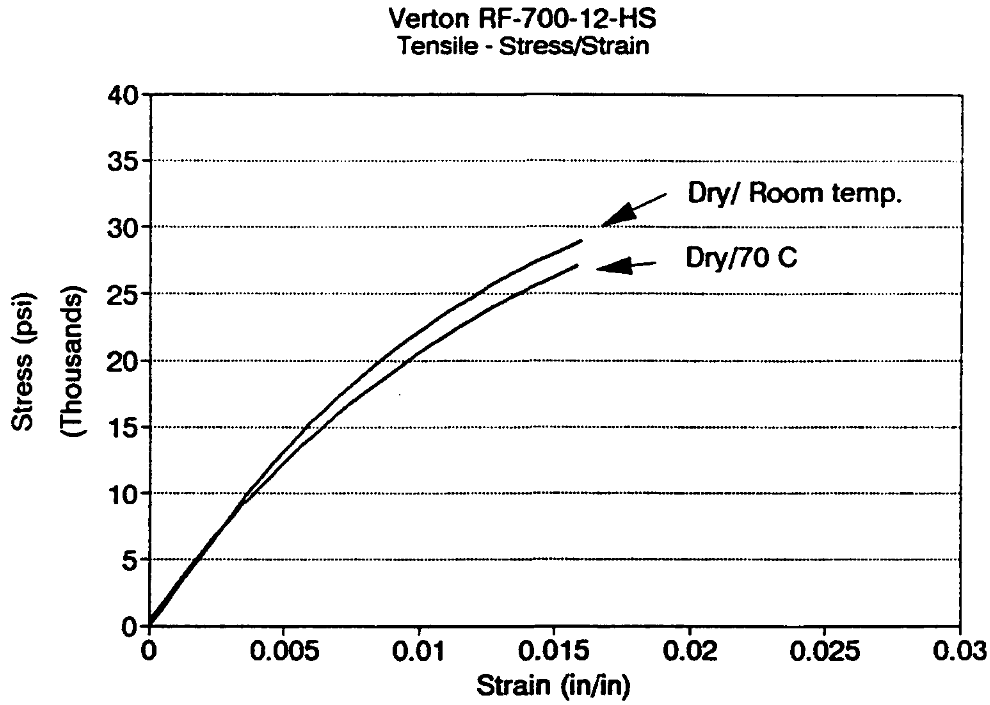


Fig. 7 – Stress-strain plots for Verton RF-700-10-HS



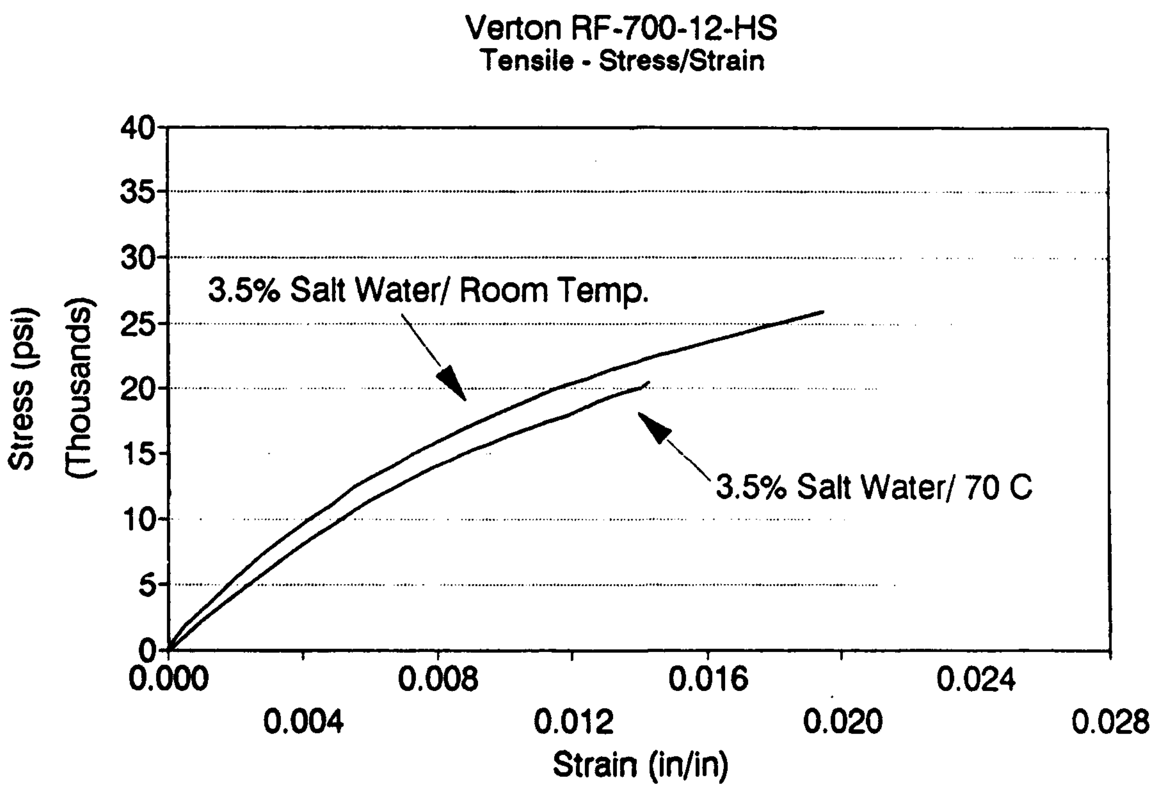
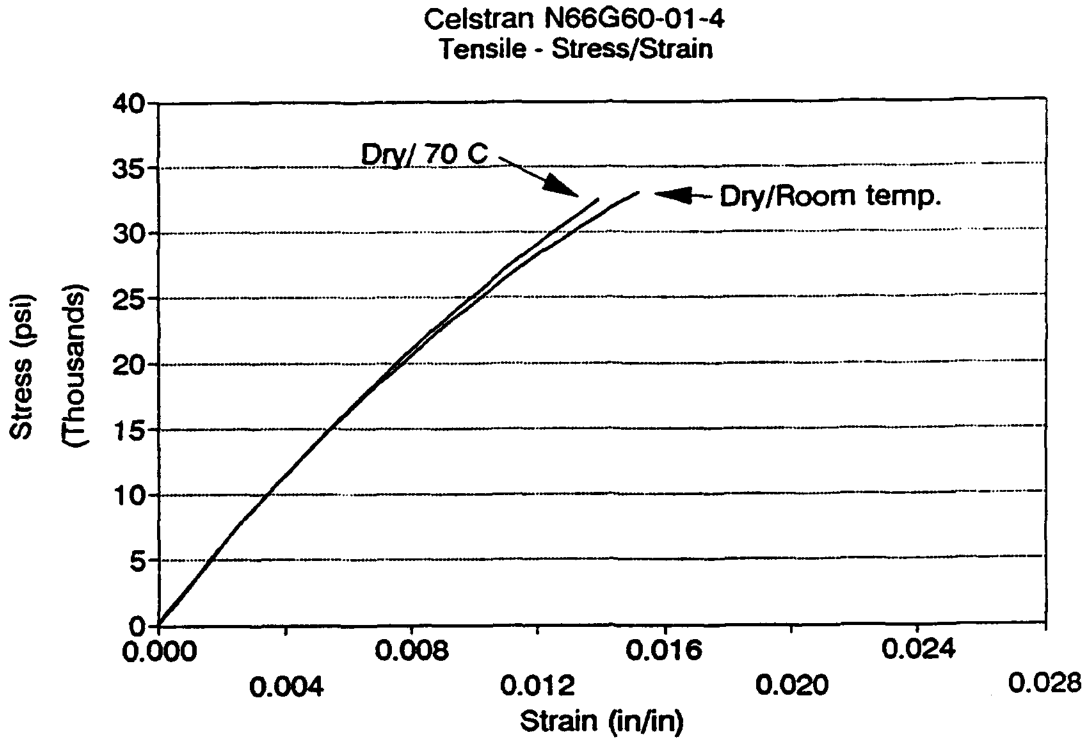


Fig. 8 – Stress-strain plots for Verton RF-700-12-HS



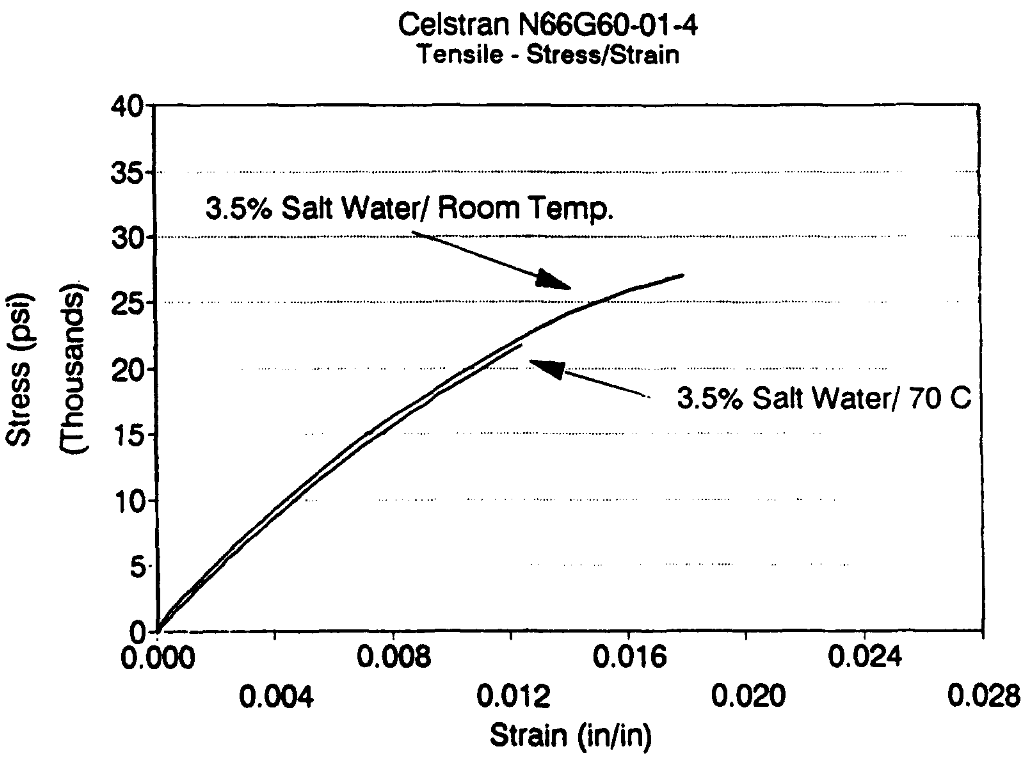
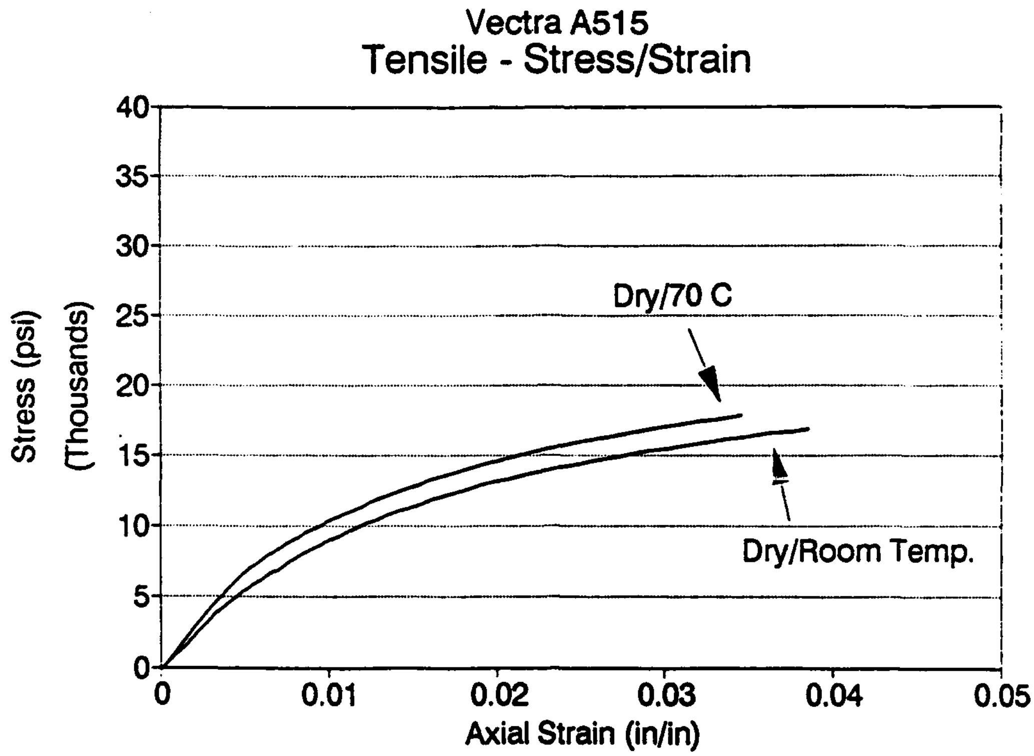


Fig. 9 – Stress-strain plots for Celstran N66G60-01-4



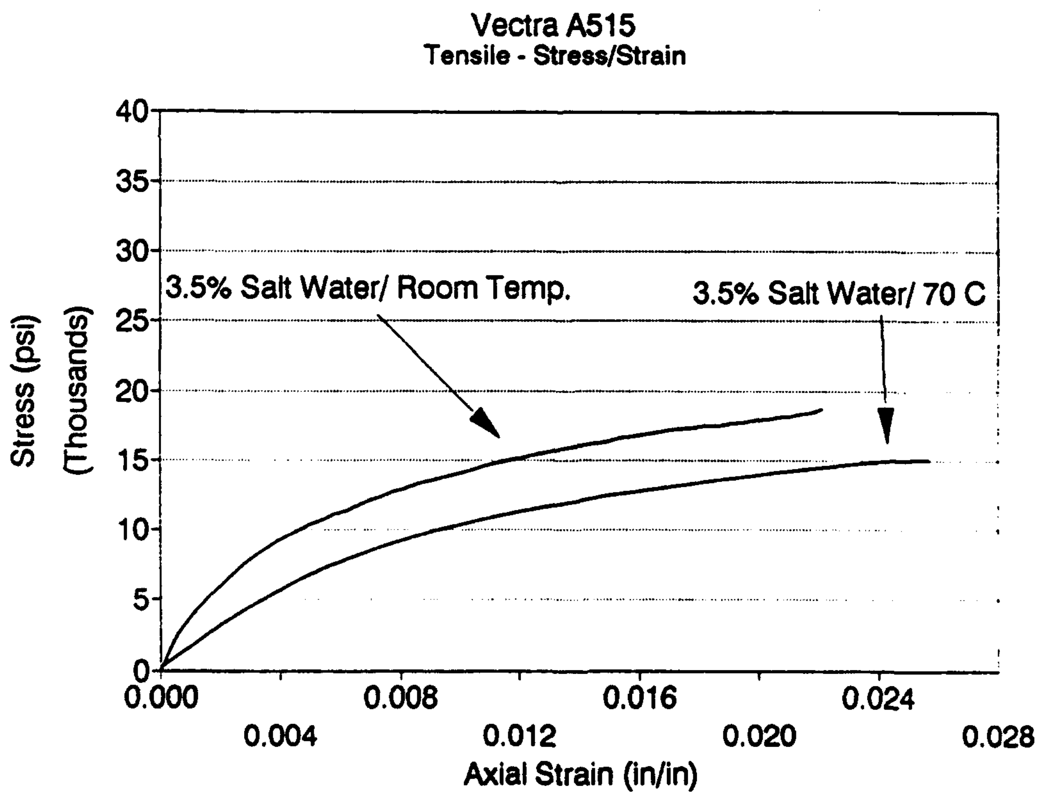


Fig. 10 – Stress-strain plots for Vectra A-515

The Isoplast materials maintained a higher percentage of tensile strength after salt water exposure compared to the Verton and Celstran (nylon 6,6) materials. Higher glass loading improves the dry tensile strength and appears to help preserve higher strengths in specimen exposure to 70°C salt water. Figure 3 illustrates the relationship between tensile modulus and percent reinforcement. All of the 60% glass-loaded materials had a notably higher tensile modulus compared to the less reinforced versions. Also, the nylon 6,6 materials retained significantly less tensile modulus after the hot-wet exposure than either the Isoplast materials or Ultem 2300. Vectra A-515, which exhibited the highest ultimate toughness of the non-metallic materials, was the only candidate to decrease in tensile modulus when tested in the dry-hot condition compared to the dry/room temperature condition.

The wet strength retention of the materials is contrasted in Fig. 11. The Isoplast and Ultem materials outperform the nylons, Celstran and Verton. It is worth noting that a lower glass loading seems to improve the wet strength retention of the Isoplast, while the higher glass loading seems to improve the wet strength retention of the nylon 6,6 systems. This may indicate that there are two separate primary ingression routes for moisture in the nylon 6,6 compared to the Isoplast polyurethane. The nylon 6,6 may be more susceptible to moisture permeation into the bulk polymer phase, while moisture penetration into the glass-resin interface may be the predominant mechanism occurring in the polyurethane composite.

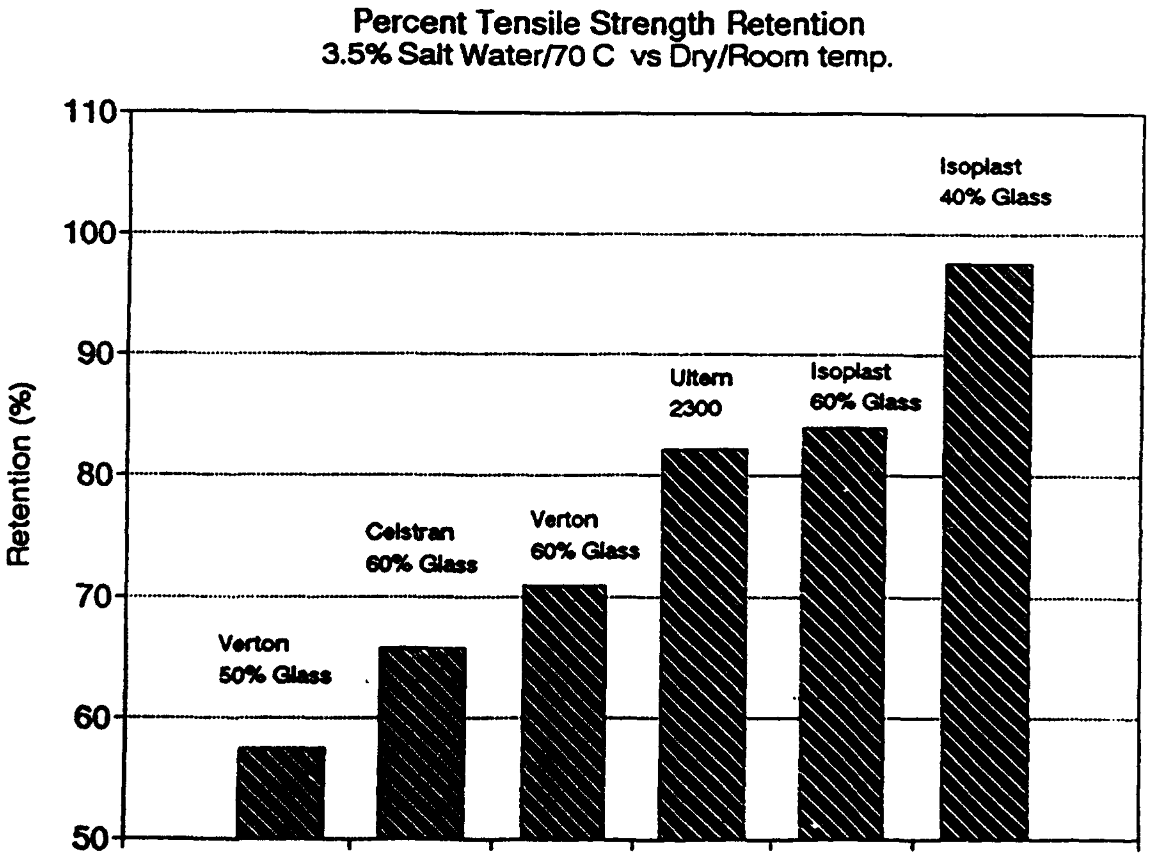


Fig. 11 – Wet-hot tensile strength retention

Impact Strength

The injection-molded non-metallic brackets must be able to survive high explosive-shock loads. In order for the brackets to qualify for use on board submarines the brackets must be able to survive the MIL-S-901-D explosive-shock test series. In fact, the highest loads experienced by the brackets are due to explosive shock. Therefore, the impact strength or toughness of the candidate non-metallic materials is of the utmost importance. One method of ranking a material's impact strength is to perform an ASTM standard Izod impact test. Another measure of a material's impact strength or toughness is to calculate the area under the stress/strain curve from zero to its ultimate strength. This measurement has been termed the ultimate toughness of the material. Both of these methods were used to compare the relative impact strengths of the candidate non-metallic materials.

Izod Impact Testing

Notched and unnotched Izod impact tests were performed on the candidate non-metallic materials at room temperature and at approximately 2°C. All impact bars were dry, but exposed to a relative humidity of approximately 60%. The tests were performed to ASTM standard D 256, Standard Test Methods for Impact Resistance of Plastics and Electrical Insulting Materials. The Izod impact bars tested were 6.4 cm (2.5 in) long, 1.3 cm (0.5 in) wide and 0.318 cm (0.125 in) thick. The non-metallic materials were tested at the cold temperature (2°C) because it was believed that these materials might become brittle at the lower temperature with a resulting loss in impact strength. Since the brackets are exposed to a seawater environment with a low temperature of approximately 4°C, the cold temperature tests provide a conservative estimate of the impact strength.

Figure 12 presents a summary of the averaged test results from the Izod impact testing of the candidate non-metallic materials and compares them to published manufacturer's impact strength claims. Notched impact strength results are more conservative than unnotched results and are considered more representative of the material's behavior. A comparison of the manufacturer's notched room-temperature results and the tested notched room temperature results show close agreement with the exception of the Ultem 2300 and the Vectra A-515. Both the Ultem 2300 and the Vectra A-515 showed much higher tested impact strengths than claimed by the manufacturer. The Vectra A-515 had the highest tested impact strength under all conditions. Its notched room-temperature impact strength was almost three times as high as the next highest candidate. The difference in impact strengths between the room temperature and cold conditions was not noticeable for most of the materials. Only the Ultem 2300 saw a consistent substantial reduction in its impact strength from the room temperature to cold temperature condition.

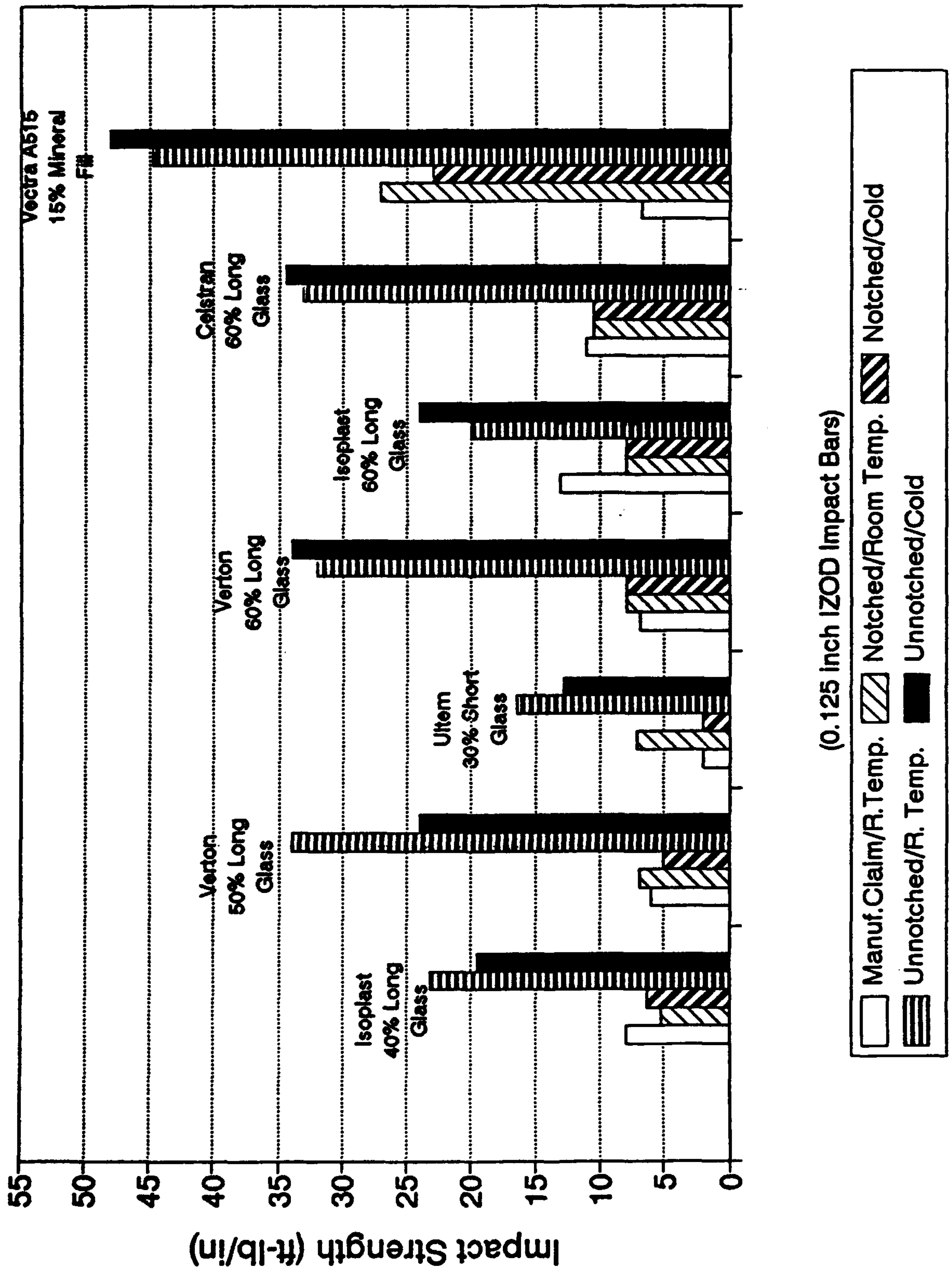


Fig. 12 – Izod impact strength

Although not supported by the manufacturer's impact strength claims, the Izod impact testing demonstrated that the Vectra A-515 clearly stood out from the rest of the candidates as the material with the best impact resistance. The long glass fiber materials with high loading (60%) such as the Celstran, Isoplasts, and Verton also demonstrated good impact resistance.

Ultimate Toughness Calculations

Tensile test data were used to calculate the area under the stress/strain curve for each of the non-metallic materials and for the Al-Br material. This area under the stress/strain curve provides another relative measure of a material's toughness or impact resistance. Figure 13 presents the ultimate toughness (area under the stress/strain curve) results for each of the non-metallic candidate materials for each of the conditions tested and the ultimate toughness of the current Al-Br material.

The Vectra A-515 stands out with a substantially higher dry ultimate toughness compared to the other non-metallic materials. The Vectra A-515 achieves a dry, room-temperature toughness of about 1.5 times as high as the next closest candidate (Celstran), and has almost 80% of the toughness of the Al-Br material. The other non-metallic materials have about the same dry, room-temperature toughness ranging from 1.55 to 1.89 MPa (225 to 275 psi). The Vectra A-515, Celstran 60%, and Verton 60% show good toughness retention at the dry, hot temperature condition. Surprisingly, the Isoplast 60% did not perform well under any of the tested conditions. This may have been caused by poor tensile test results due to difficulty in properly clamping the highly glass-loaded Isoplast in the Instron grips. In general, both the higher temperature and the wet soak conditions caused a substantial reduction in the ultimate toughness of the non-metallic materials.

Water Absorption Tests

Figures 14 through 18 demonstrate the water absorption characteristics of a selection of the reinforced thermoplastic candidate materials. The solutions used to determine the absorption properties were 3% salt water at three temperatures; 25°C, 40°C, and 70°C. Generally, the test temperature seems to have little effect on the equilibrium moisture content of these materials, although the rate of absorption did increase with temperature. However, a slight increase in equilibrium water absorption was observed between the 25°C tests and the 40°C tests.

The equilibrium water absorption values shown in Fig. 14 compare well with the percent tensile strength retention values given in Fig. 11. The Isoplast and Ultem materials retained more tensile strength after exposure to hot salt water. Concurrently, the Isoplast and Ultem had equilibrium moisture absorptions only half that of the nylon (Verton 50% long glass).

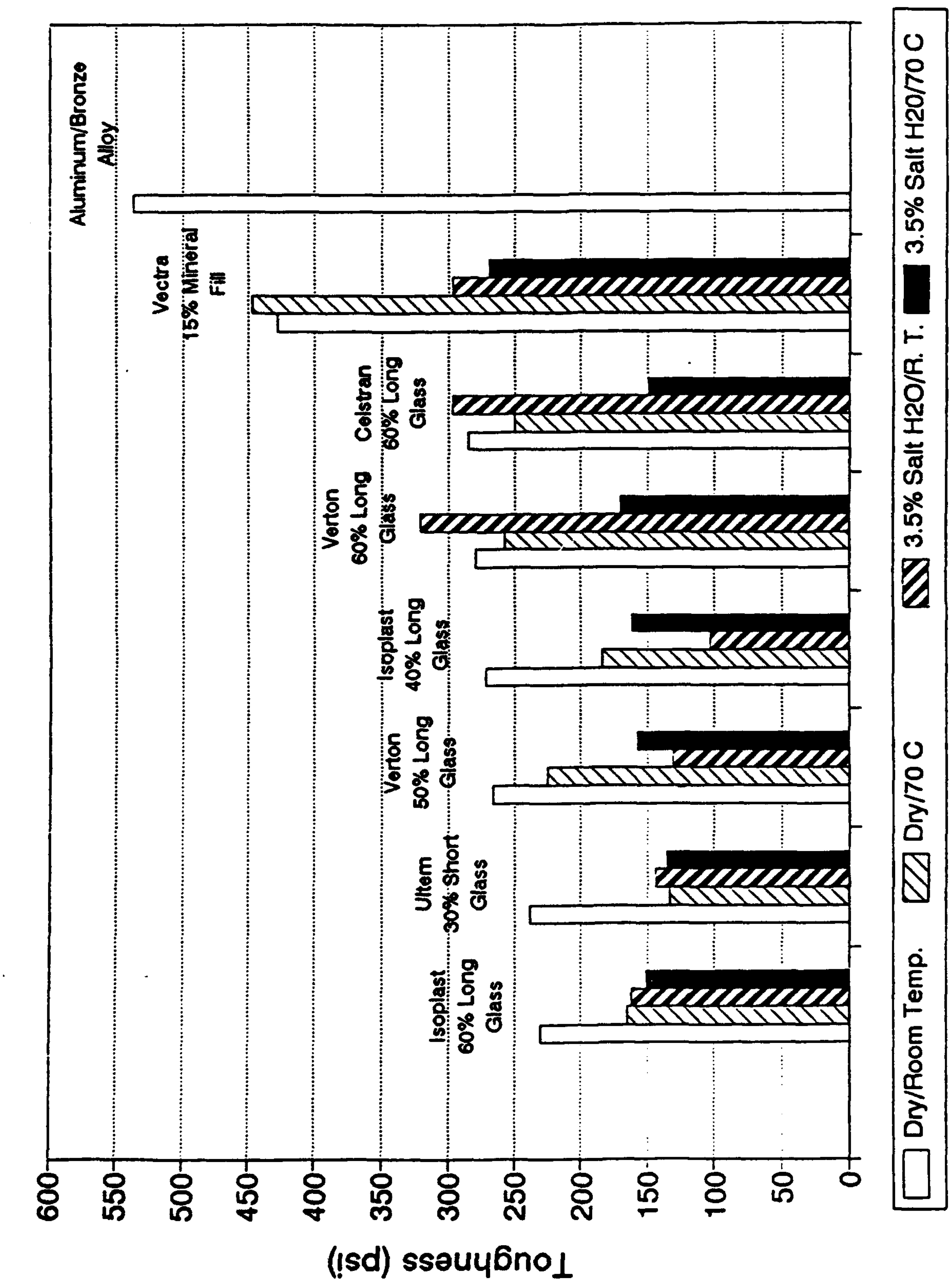


Fig. 13 – Ultimate toughness

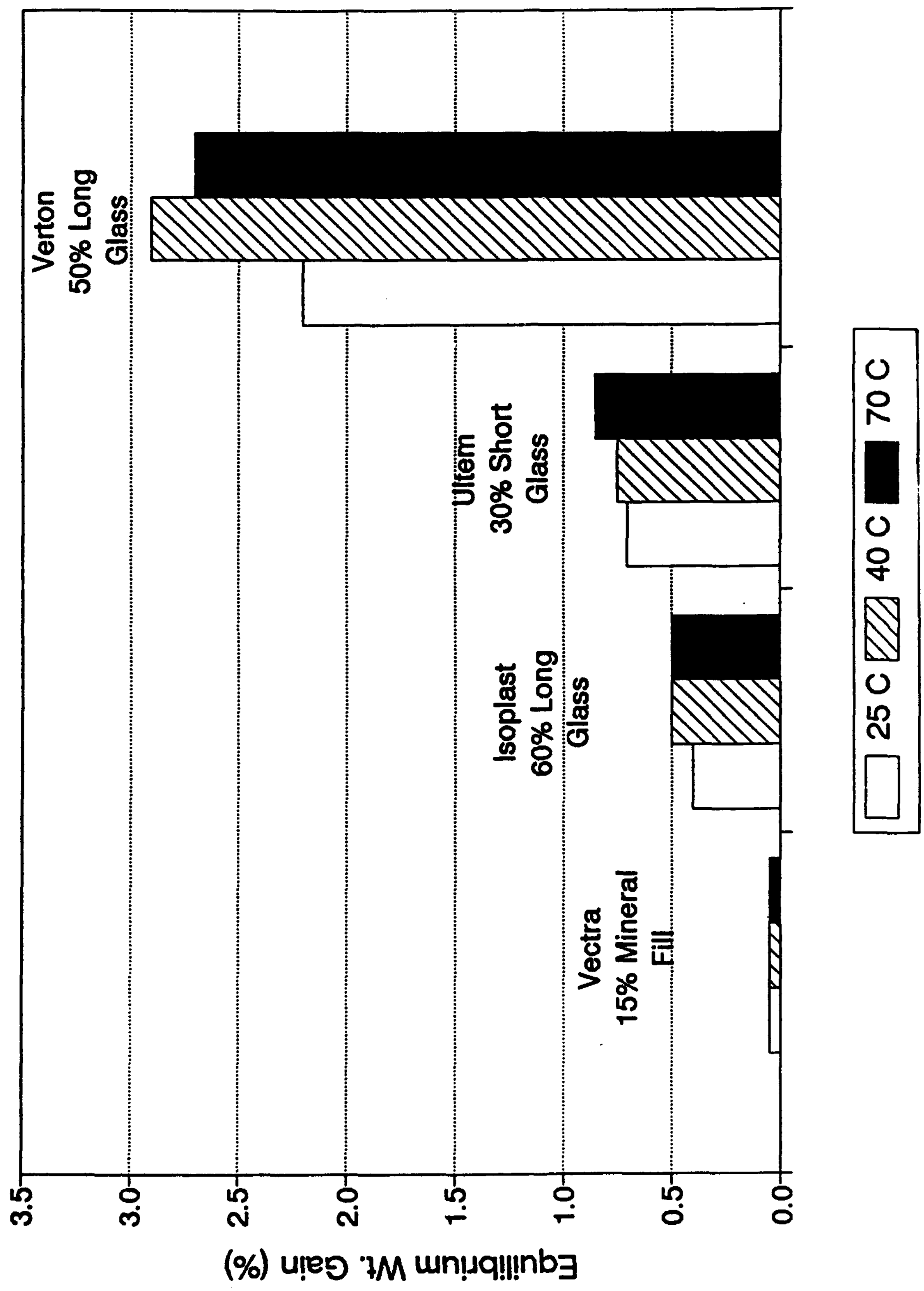


Fig. 14 – Moisture weight gain for selected non-metallic materials

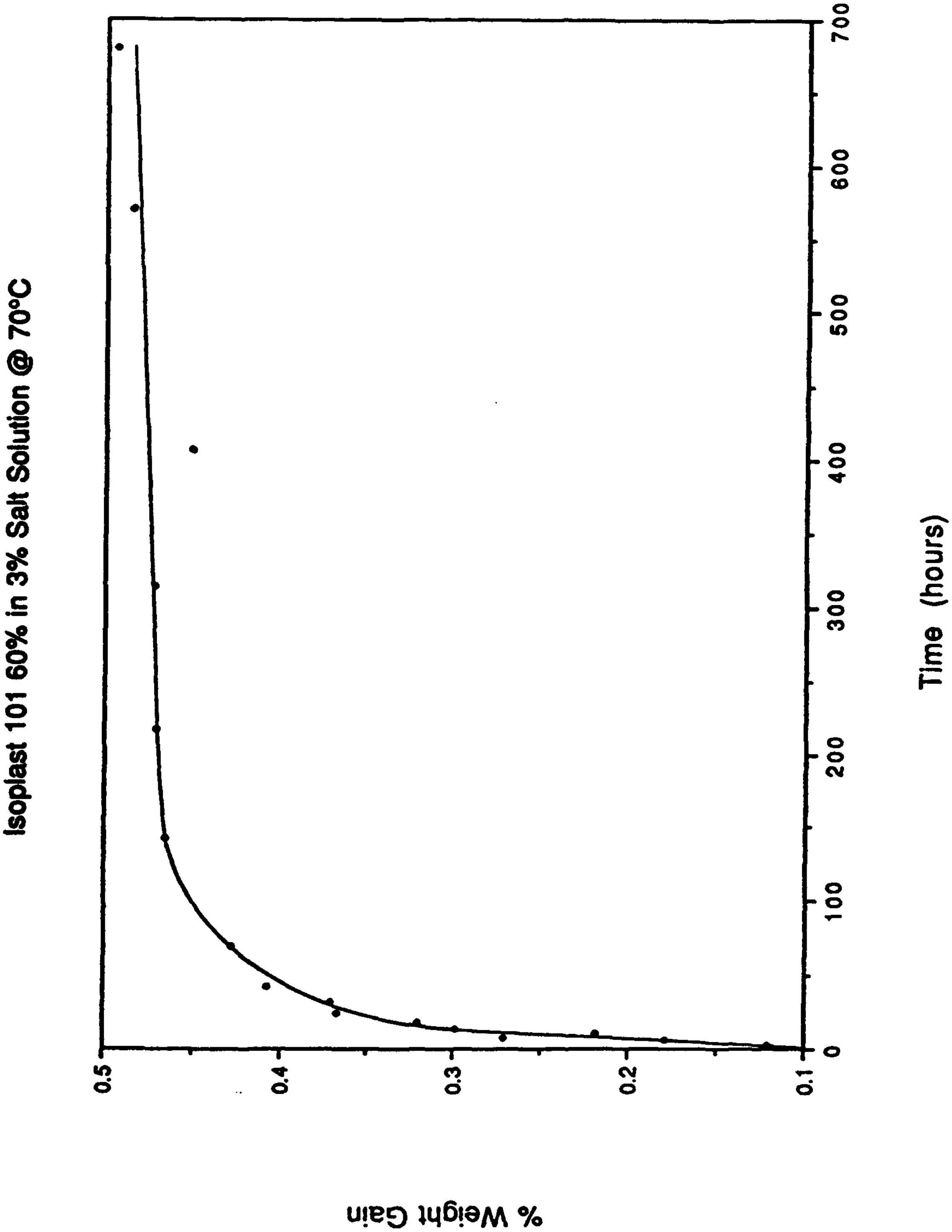


Fig. 15 – Moisture weight gain plot for Isoplast 60% *long glass*

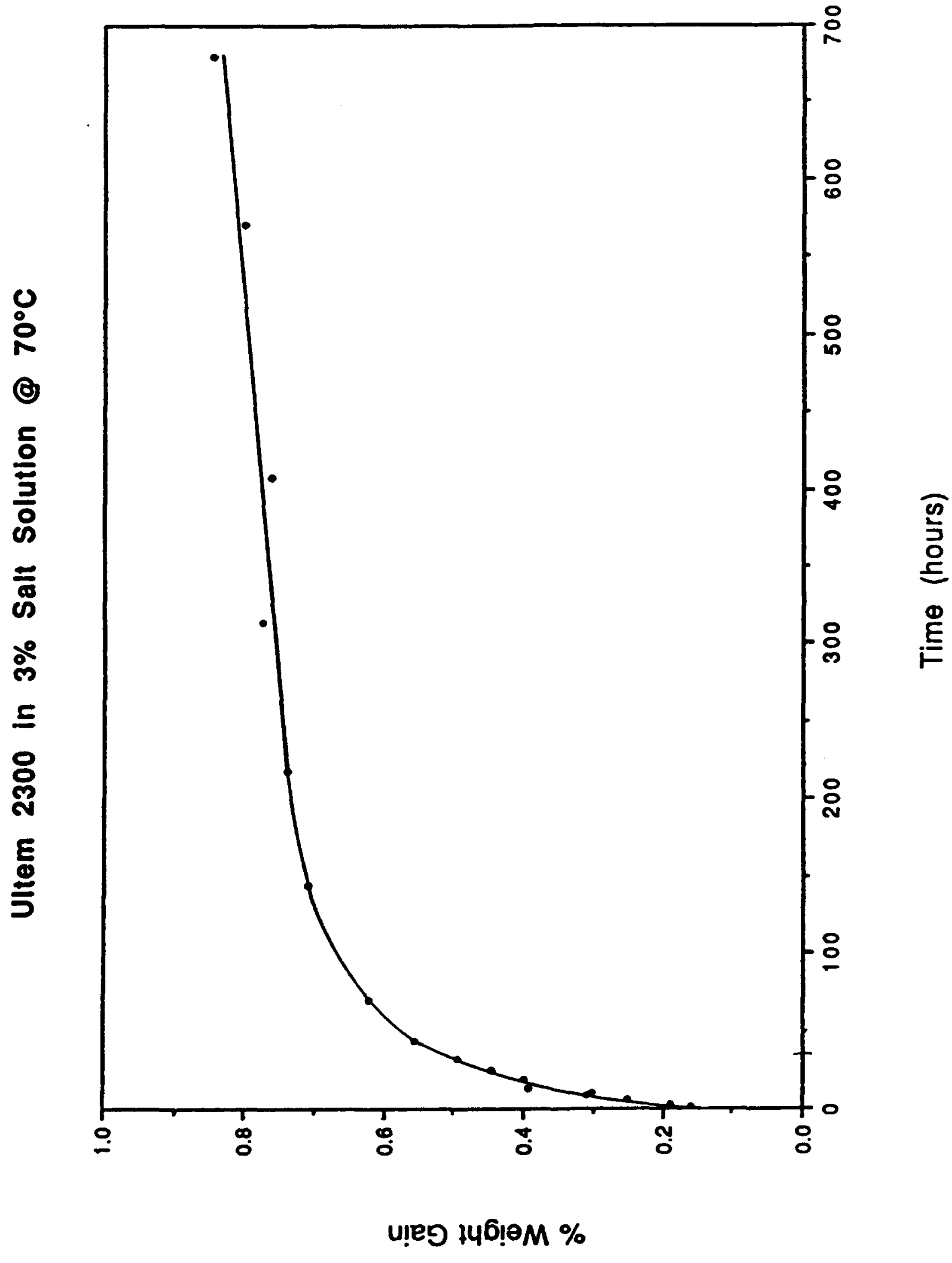


Fig. 16 – Moisture weight gain plot for Ultem 2300 30% glass

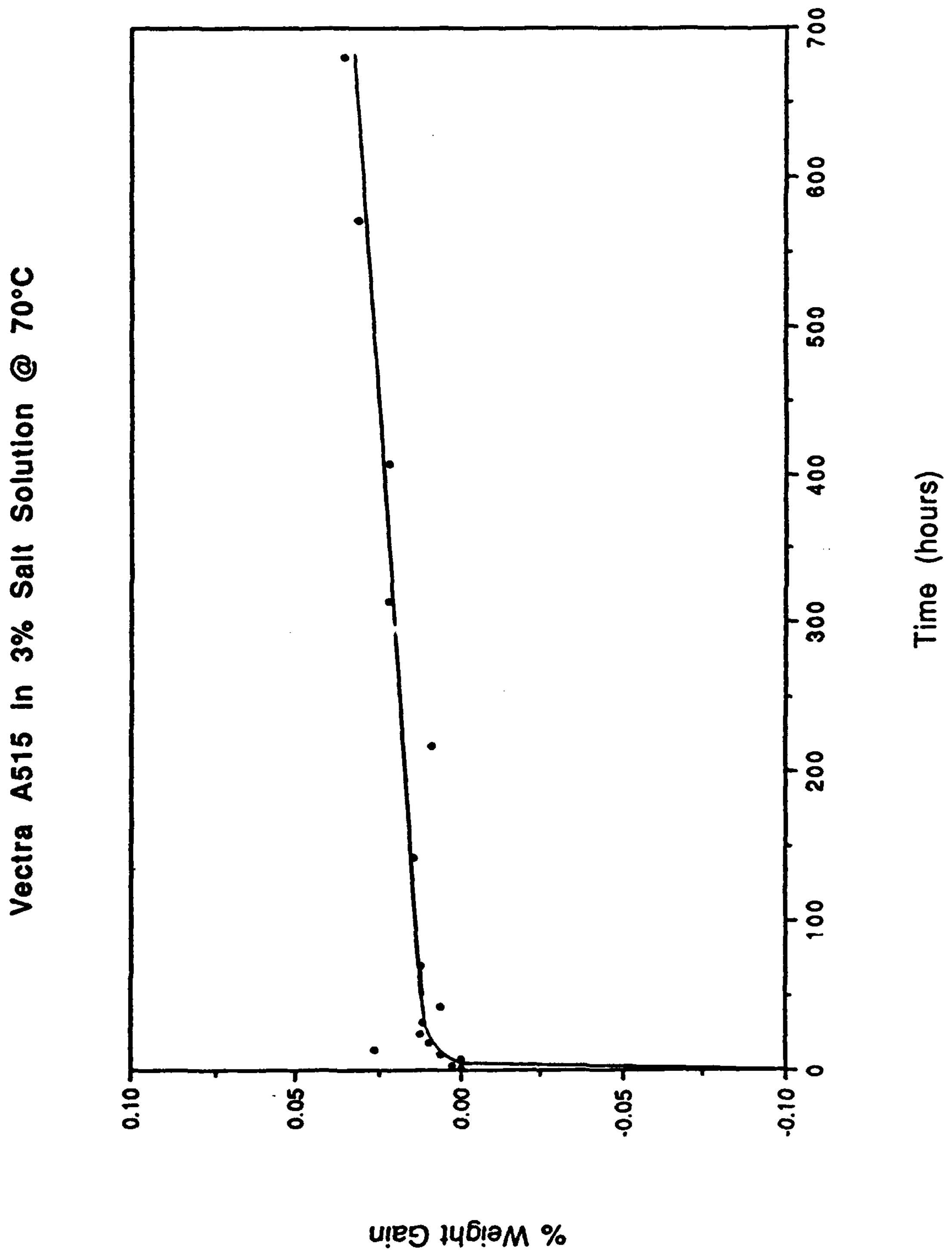


Fig. 17 – Moisture weight gain plot for Vectra A-515 15% mineral fill

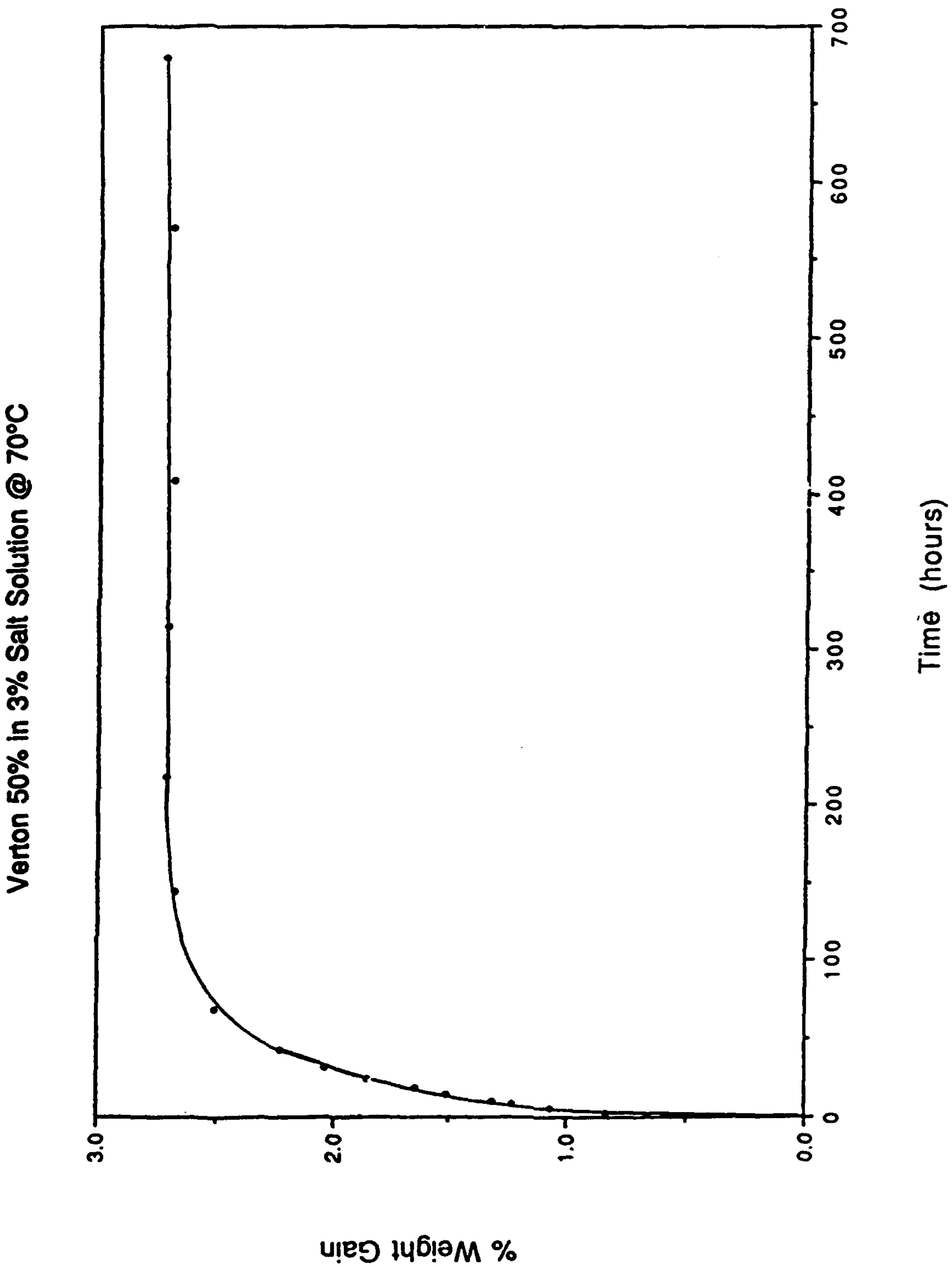


Fig. 18 – Moisture weight gain plot for Verton 50% long glass

Thermal Mechanical Analysis Results

The linear coefficient of thermal expansion (LCTE) of the candidates was measured with the use of a DuPont model 943 thermal mechanical analyzer (TMA). A 6.35-mm diam circular probe was used with a load of 10 g. This produced a force of 3.1 kPa on the test specimen. The samples were heated at a rate of 10°C/minute to 195°C, cooled to room temperature under load and heated at 10°C/minute to 195°C again. The purpose of the initial run is to remove any residual thermal stresses that may be present. The LCTE was calculated over a temperature range from 40°C to 80°C. Additionally, the amount of shrinkage on cooling after the initial run was noted. The data and results are shown in Figs. 19 through 27.

The TMA results presented in Fig. 19 compare the LCTE for the seven primary non-metallic candidates. The LCTE can be viewed as a measure of the dimensional stability of the non-metallic bracket materials as a function of temperature.

Generally, the polyurethane Isoplast materials demonstrate a lower LCTE than the Nylons (Celstran and Verton). Also, the expected inverse relationship between the LCTE and the percentage glass content for both the nylon and polyurethane materials is evident. Good thermo-dimensional stability of the modestly reinforced Ultem 2300 (30% short-glass) was also found, considering it has the lowest LCTE of the seven candidates tested. The LCTE of the 15% mineral filled Vectra A-515 lies between between the nylon and polyurethane materials.

Percentage shrinkage values derived from the TMA runs are presented in Fig. 20. A relationship between glass loading and shrinkage is not detectable in this data. The degree of shrinkage is presumably indicative of the amount of residual stress relieved in each material during the thermal cycle.

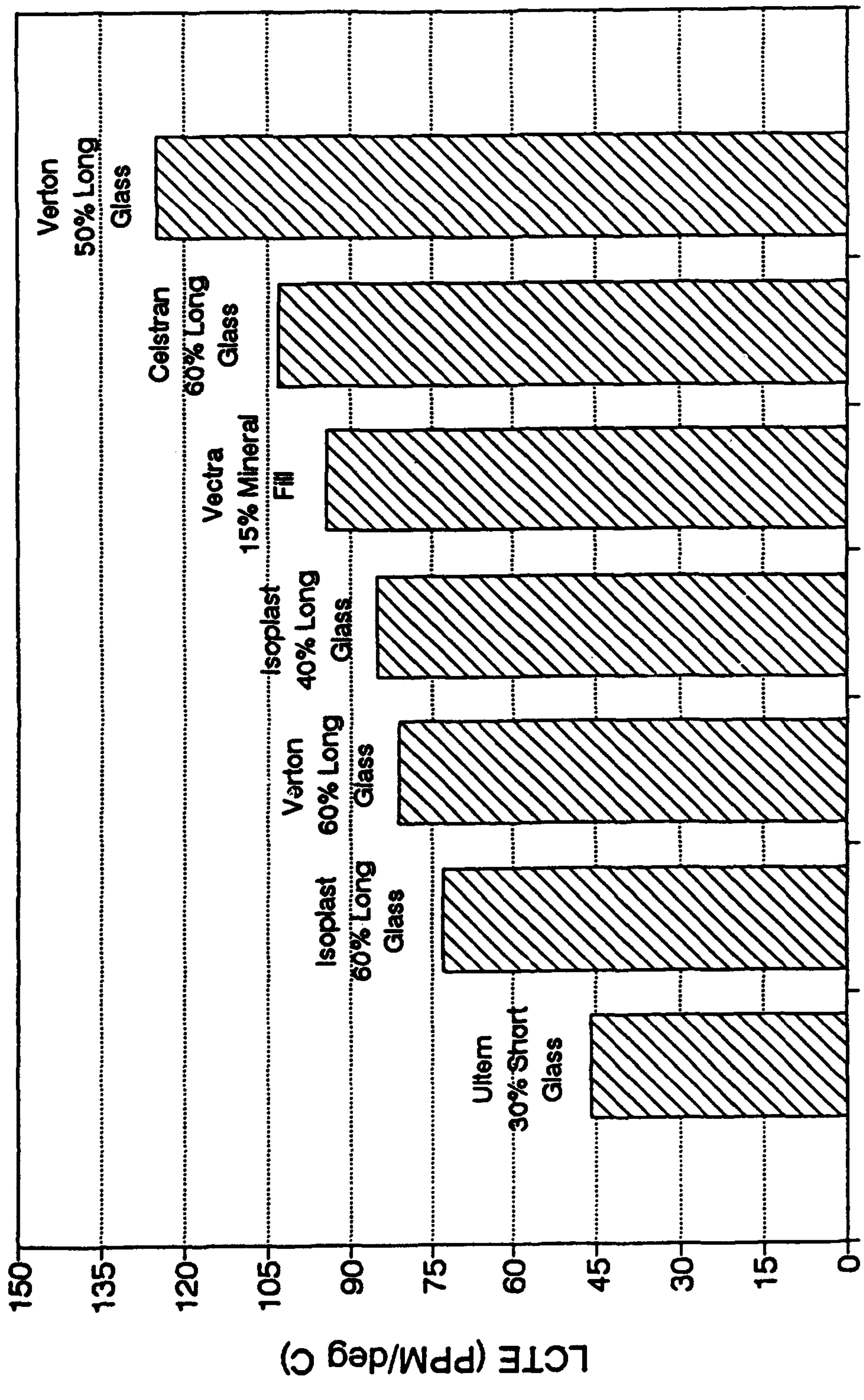


Fig. 19 – Linear coefficient of thermal expansion (LCTE)

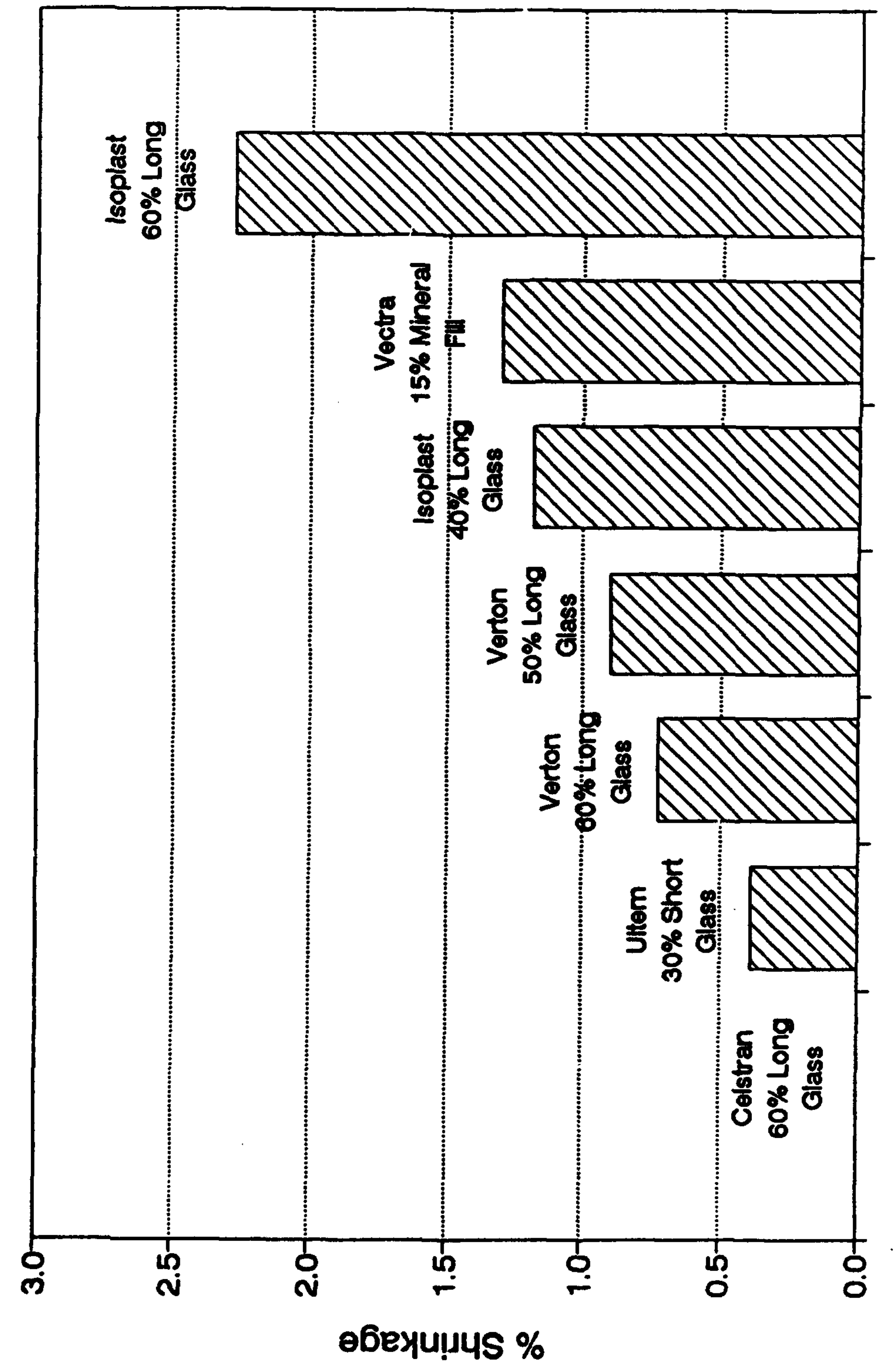


Fig. 20 – Percentage shrinkage

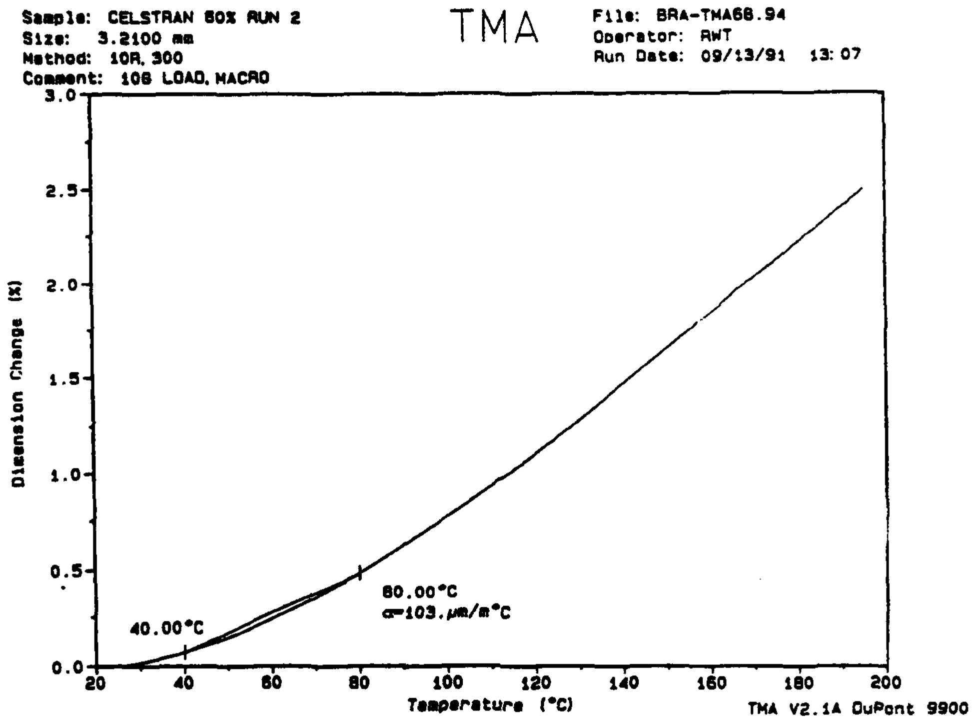


Fig. 21 – TMA plot for Celstran 60% long glass

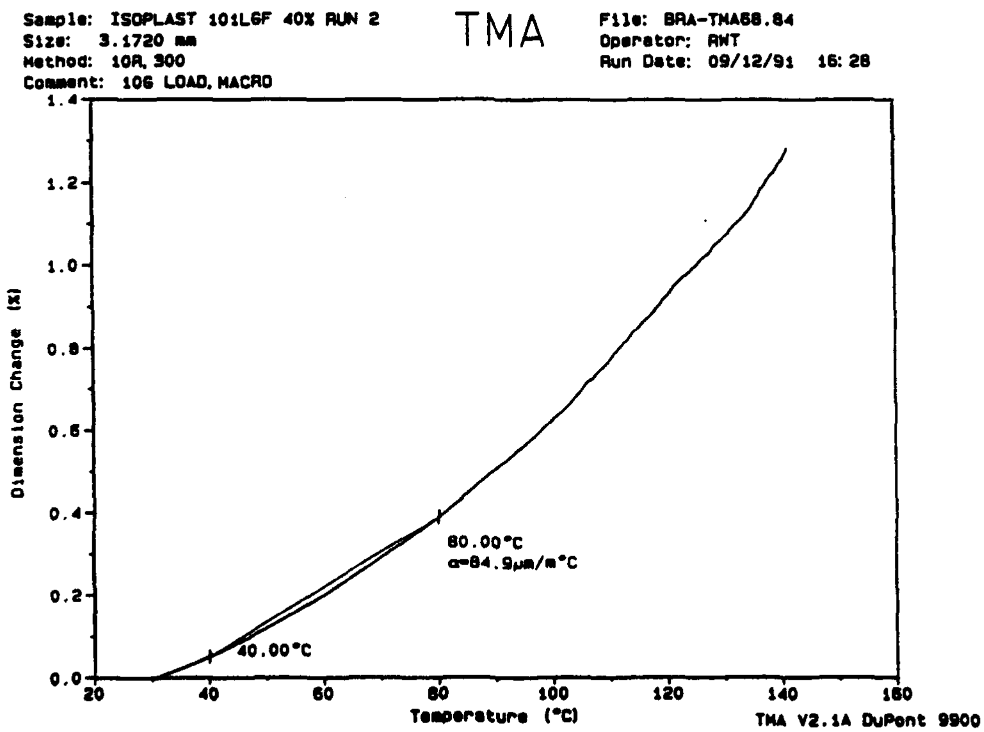


Fig. 22 – TMA plot for Isoplast 40% long glass

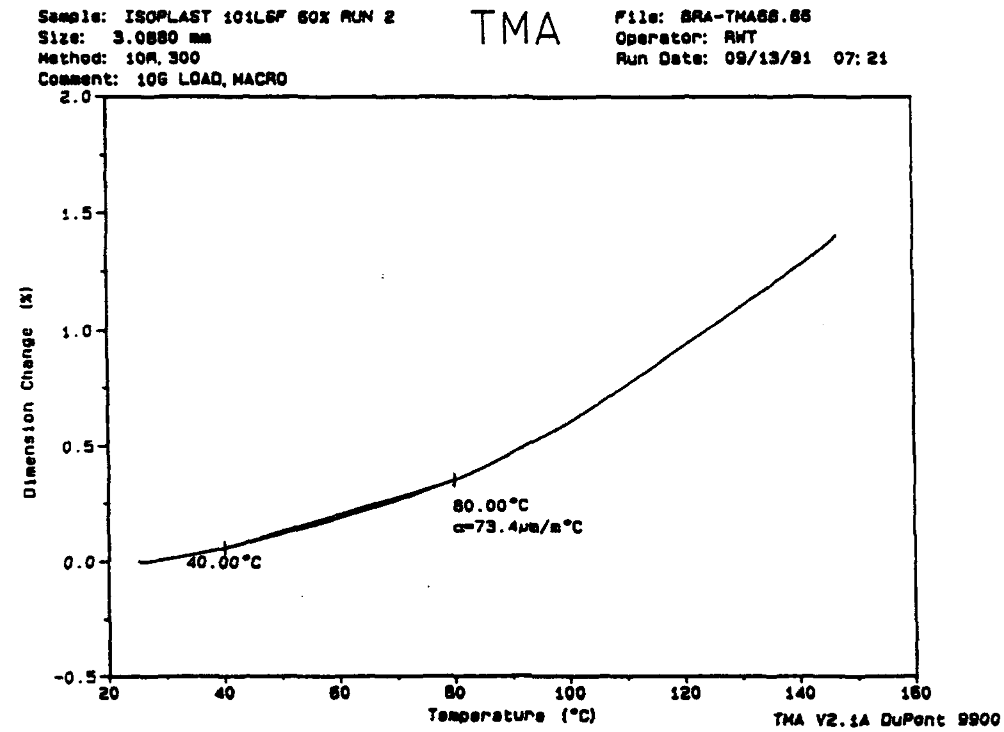


Fig. 23 – TMA plot for Isoplast 60% long glass

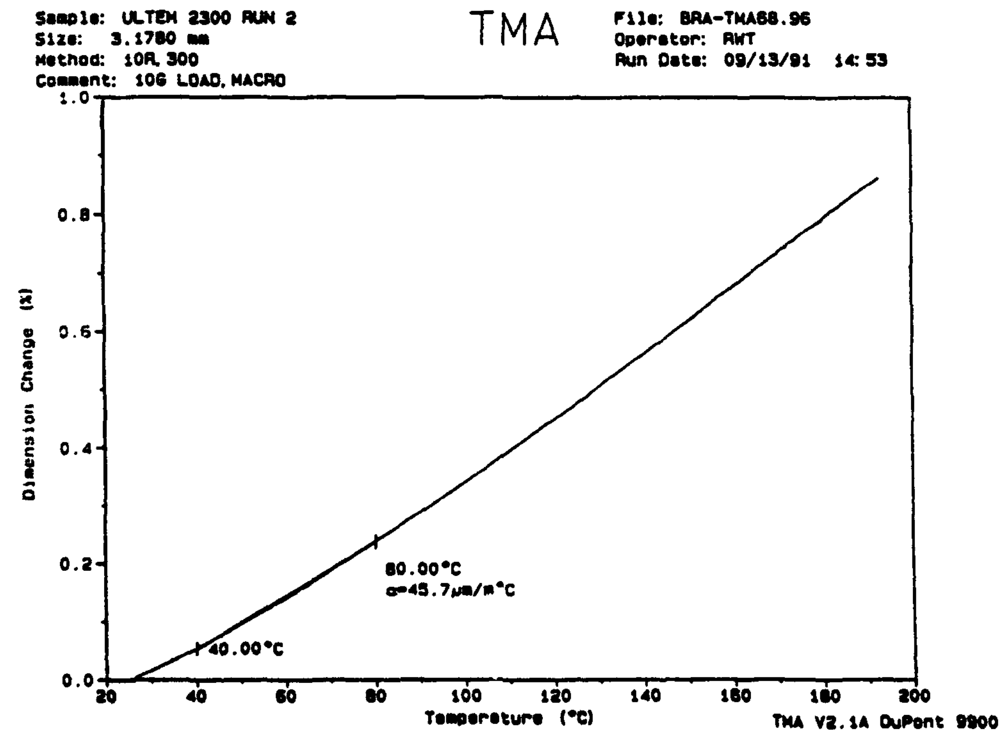


Fig. 24 – TMA plot for Ultem 2300 30% glass

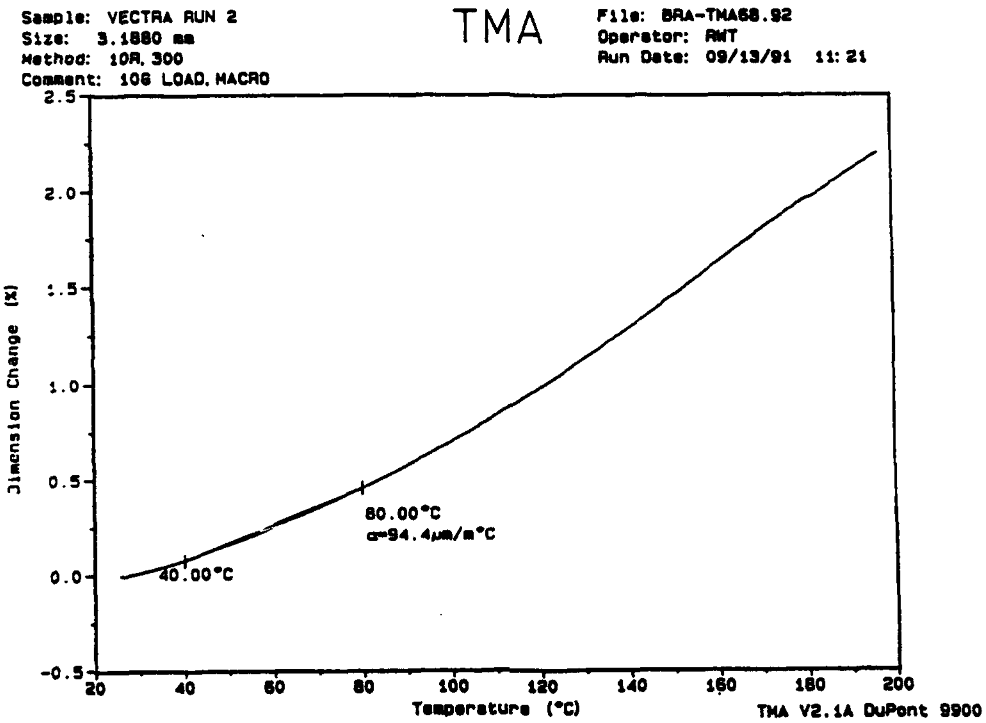


Fig. 25 – TMA plot for Vectra 15% mineral fill

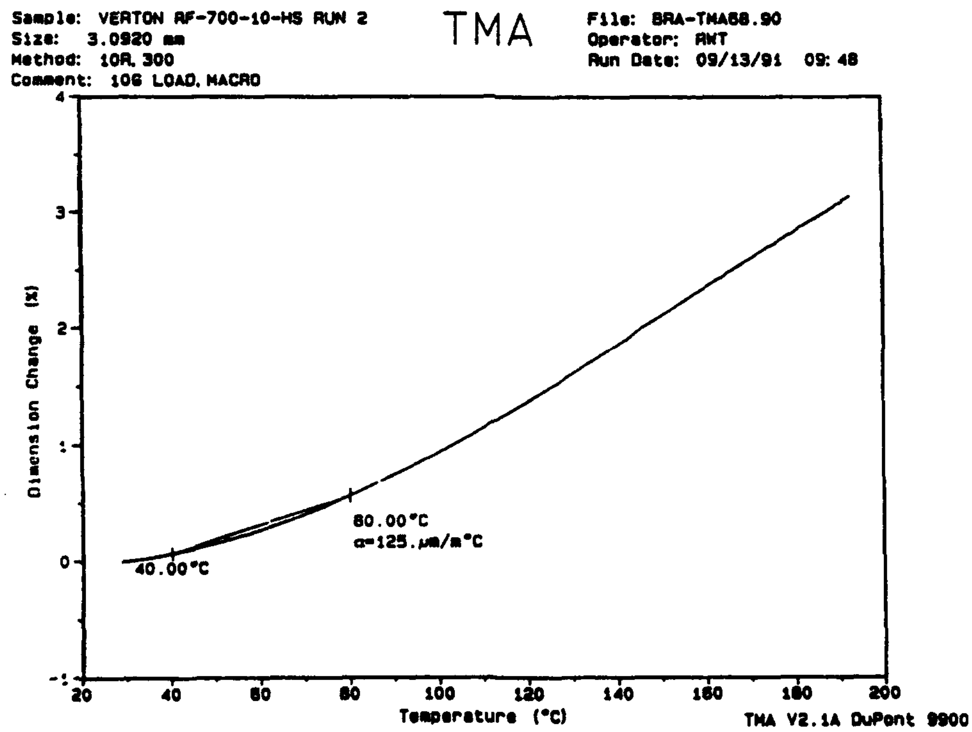


Fig. 26 – TMA plot for Verton 50% long glass

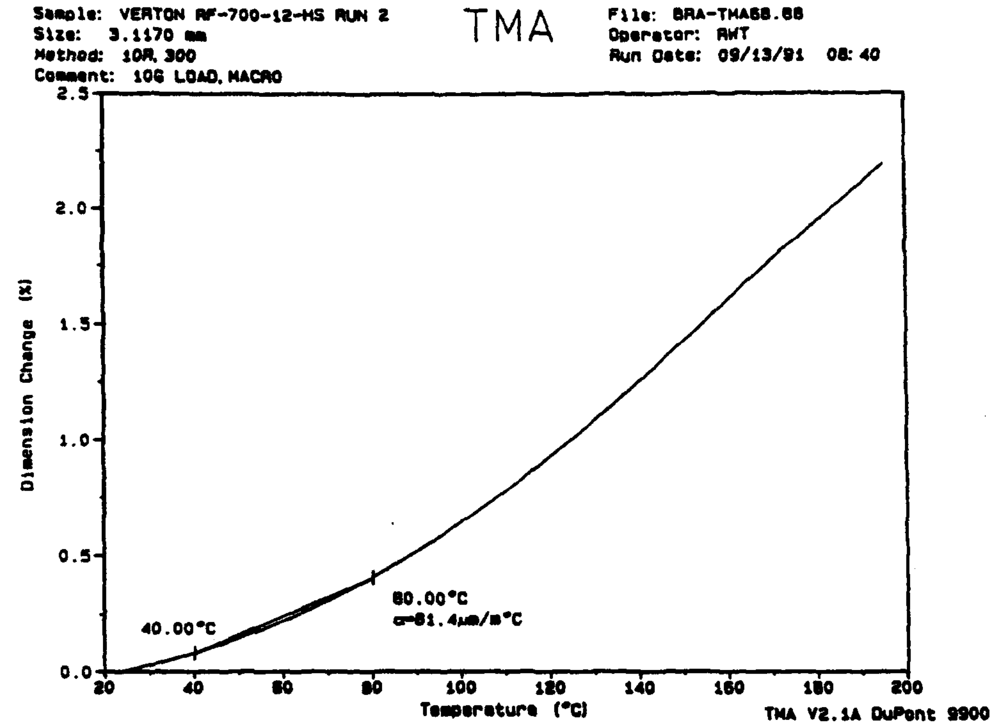


Fig. 27 – TMA plot for Verton 60% long glass

Dynamic Mechanical Analysis Results

The dynamic mechanical properties of the candidate materials were evaluated with the use of a DuPont model 983 dynamic mechanical analyzer (DMA). The oscillation was fixed at 1 Hz, the oscillation amplitude was 0.1 mm, and the sample length was about 20 mm. The data was collected from room temperature to an upper limit at which no oscillation could be maintained or to 300°C. The results of this analysis are presented in Figs. 28 through 38.

The flexural modulus values (E') presented in Fig. 28 offer a good relative comparison between the candidate materials. As was verified with the tensile modulus, there is a direct correlation between percent reinforcement and flexural modulus. The 60% glass-loaded materials had a higher modulus than the corresponding 40% or 50% loaded versions. The Vectra A-515 which contains only a mineral filter had the lowest E' of the materials tested.

The peak flexural loss modulus (peak E") values shown in Fig. 31 again illustrate the correspondence of high glass loading with decreased resiliency. Vectra A-515 and Ultem 2300 presented the highest E", and therefore the greatest degree of "lossy" behavior.

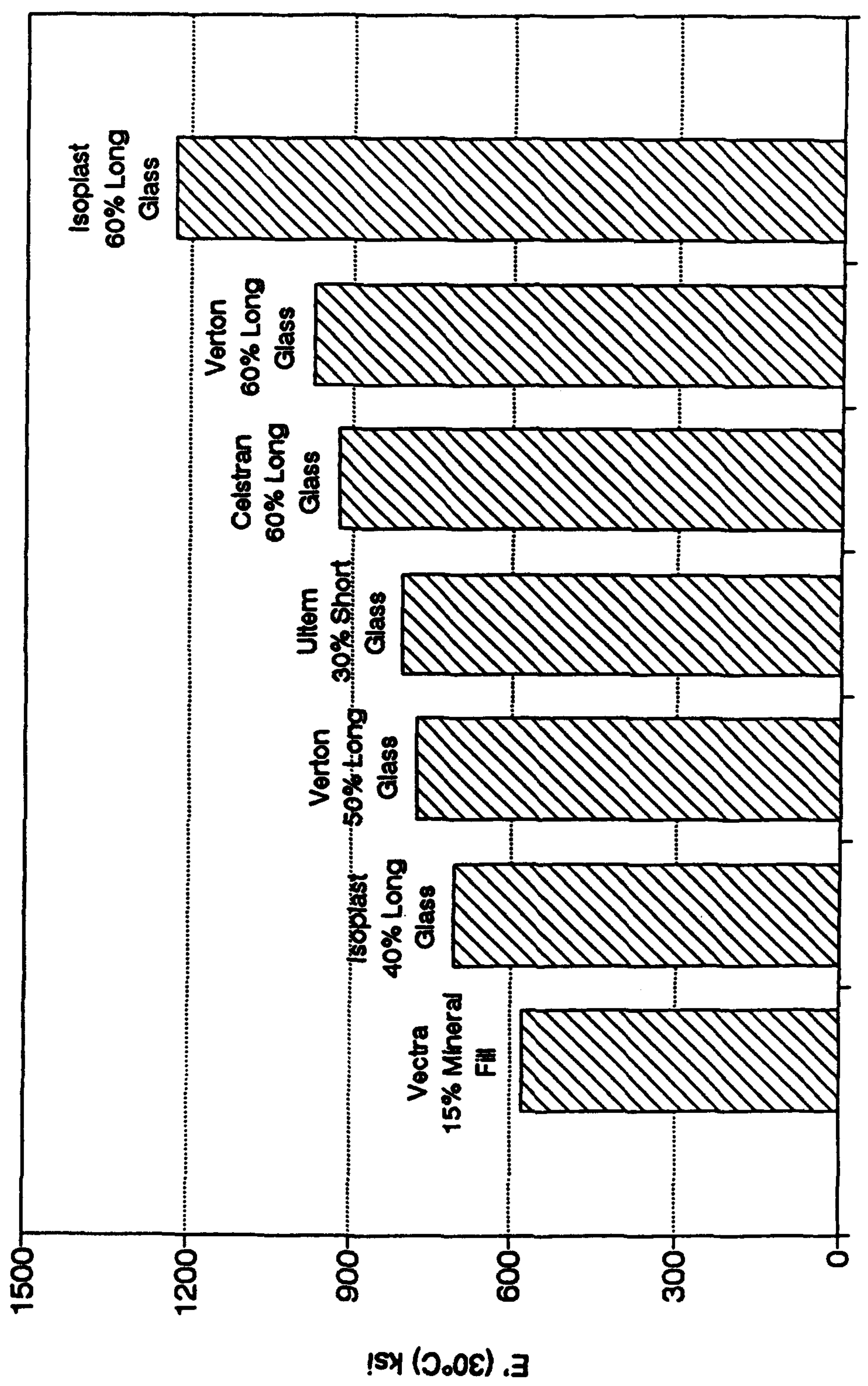


Fig. 28 – Flexural modulus (E') at 30°C and 1 Hz

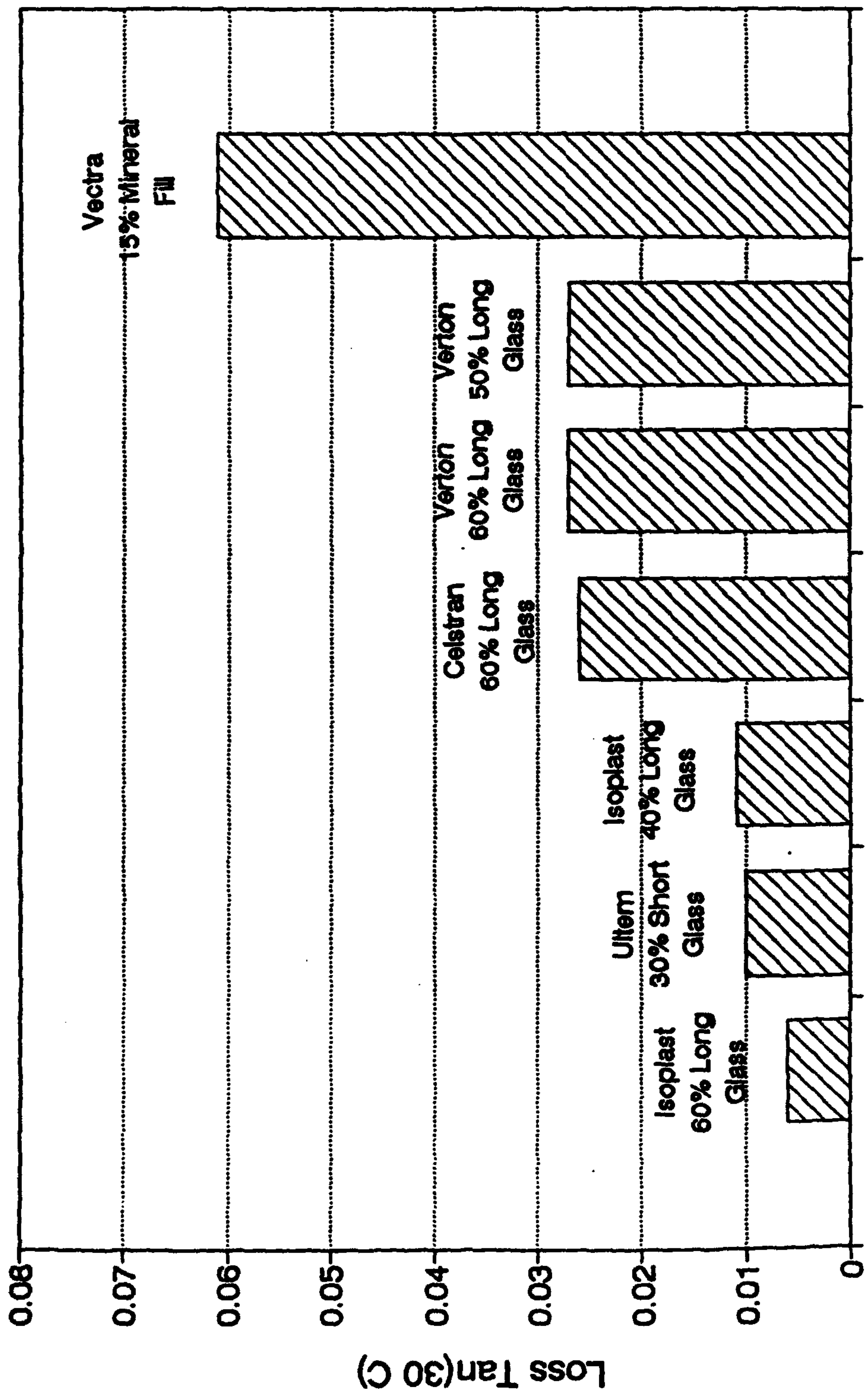


Fig. 29 – Loss tangent at 30°C and 1 Hz

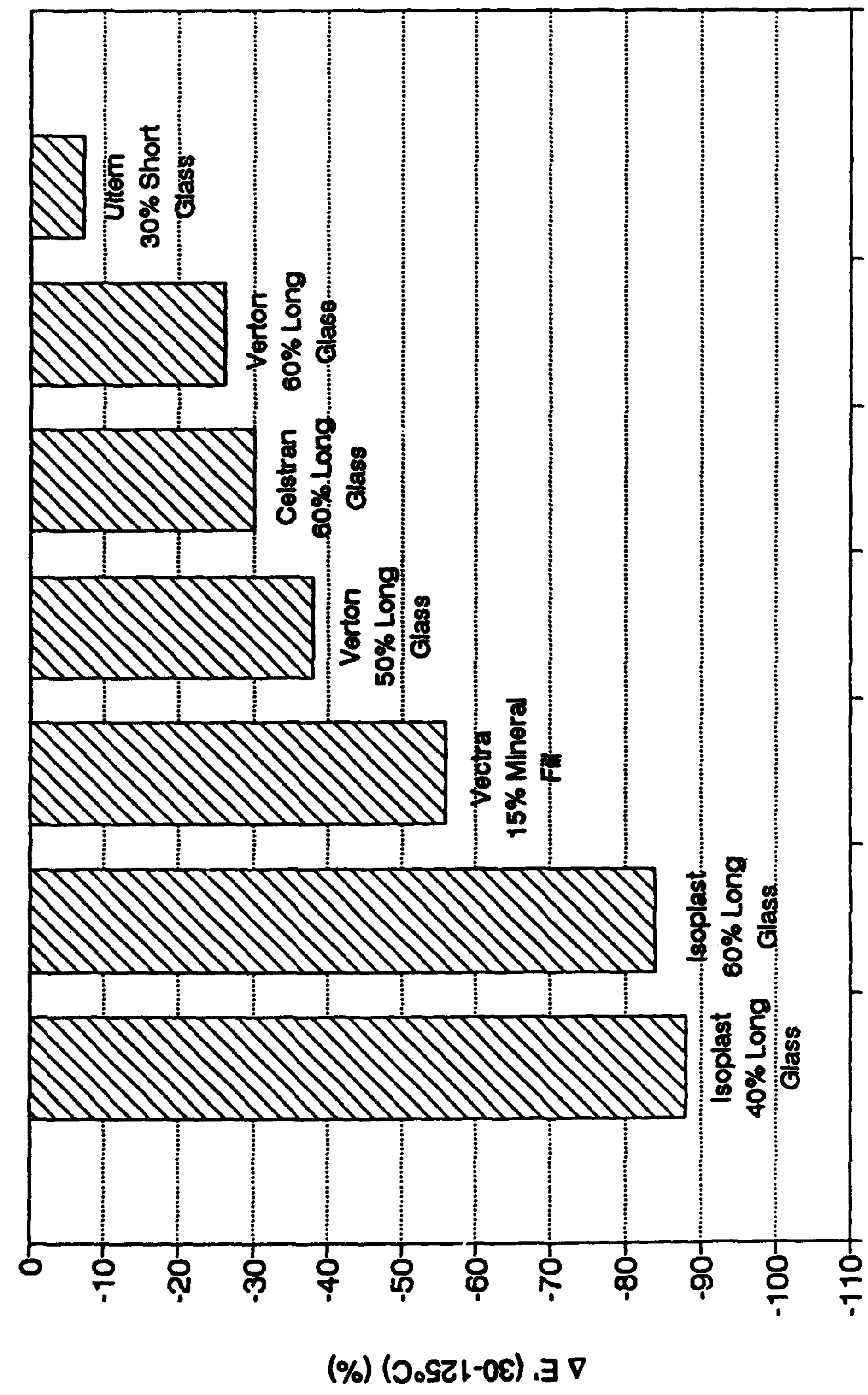


Fig. 30 – Percentage change in flexural modulus from 30 to 125°C (ΔE')

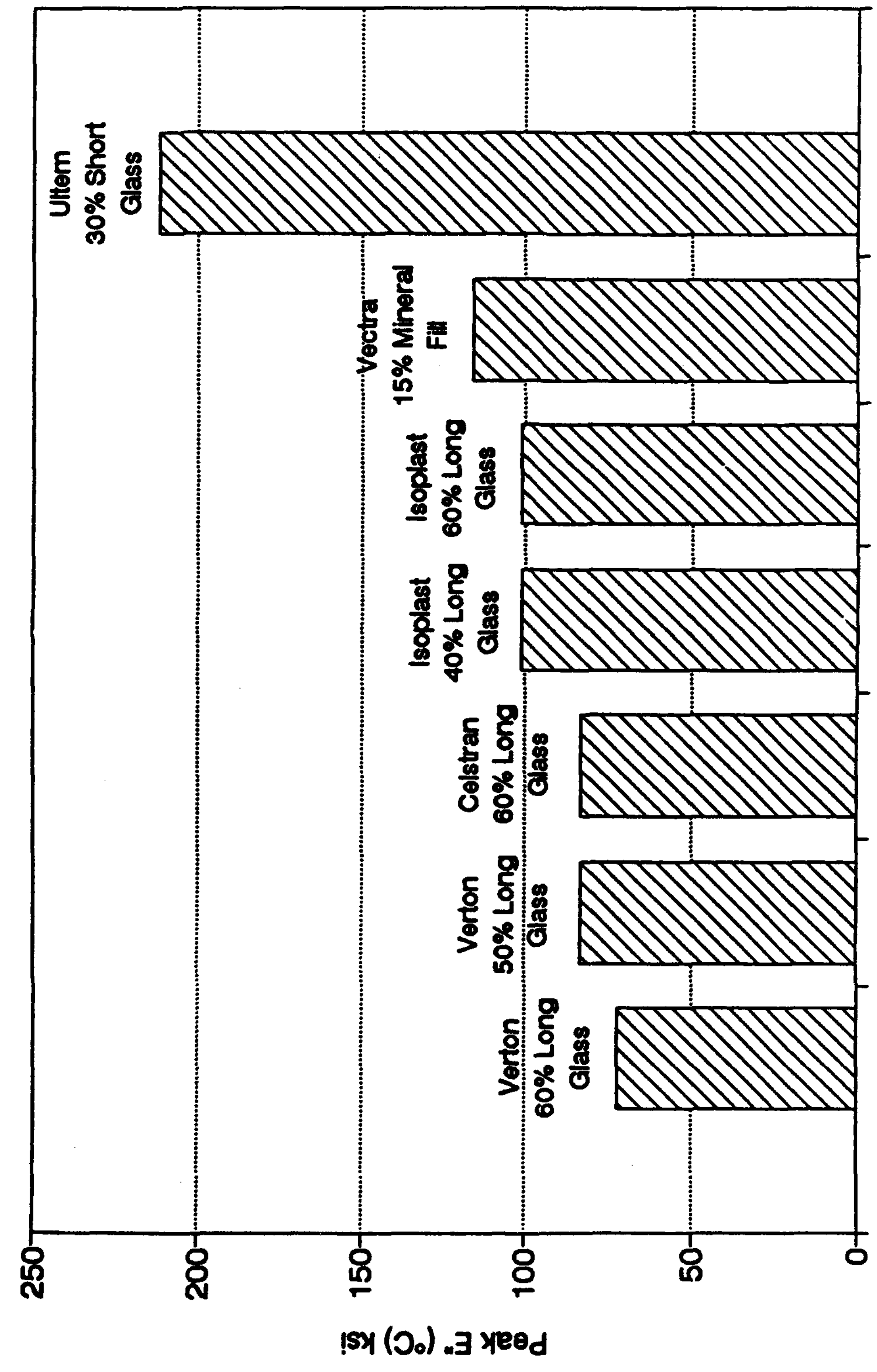


Fig. 31 – Peak flexural loss modulus (E")

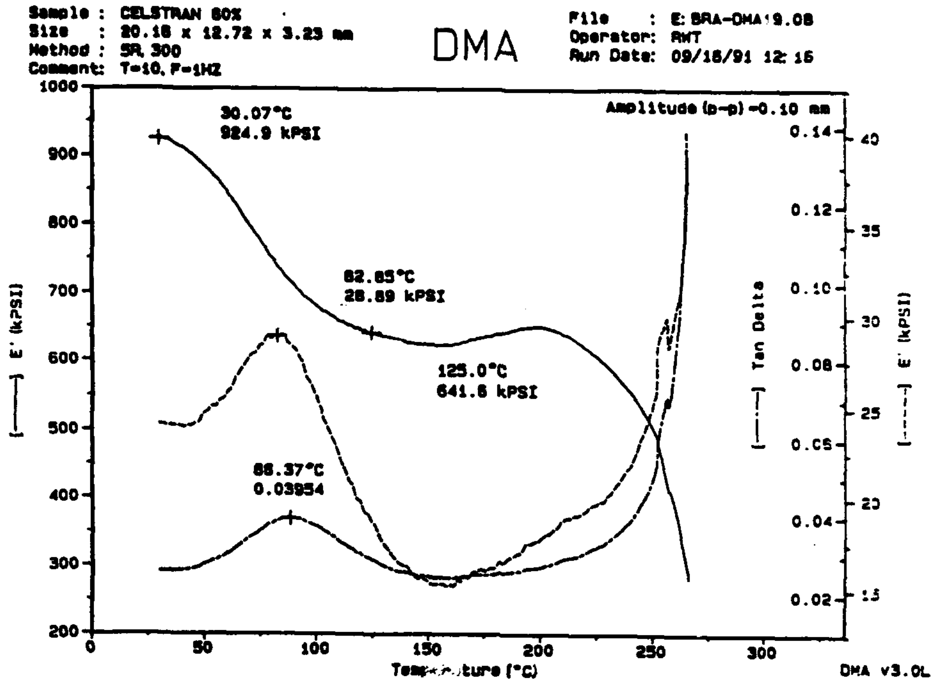


Fig. 32 – DMA plot for Celstran 60% long glass

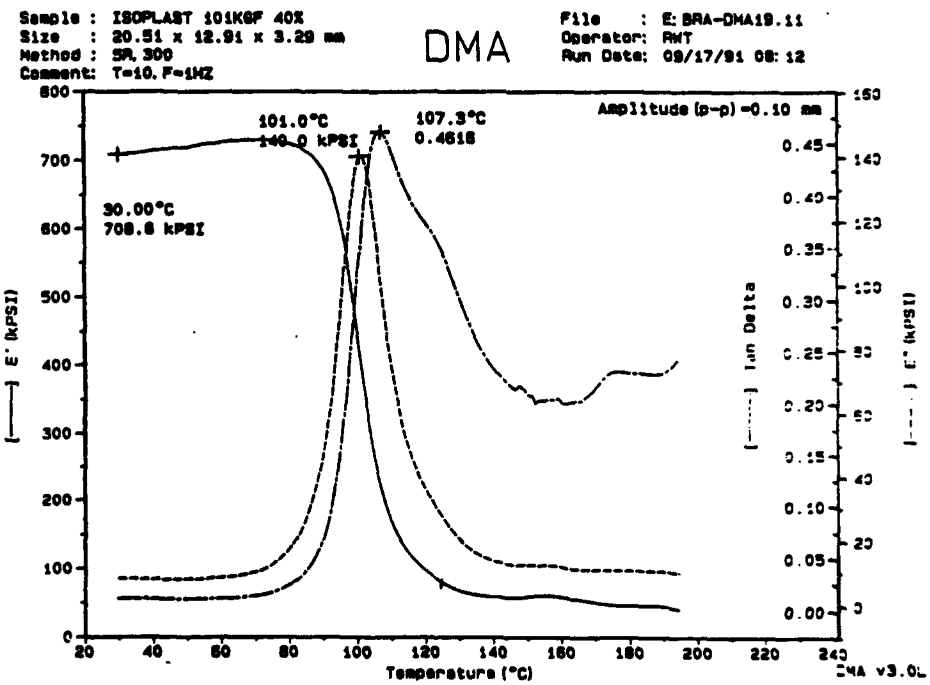


Fig. 33 – DMA plot for Isoplast 40% long glass

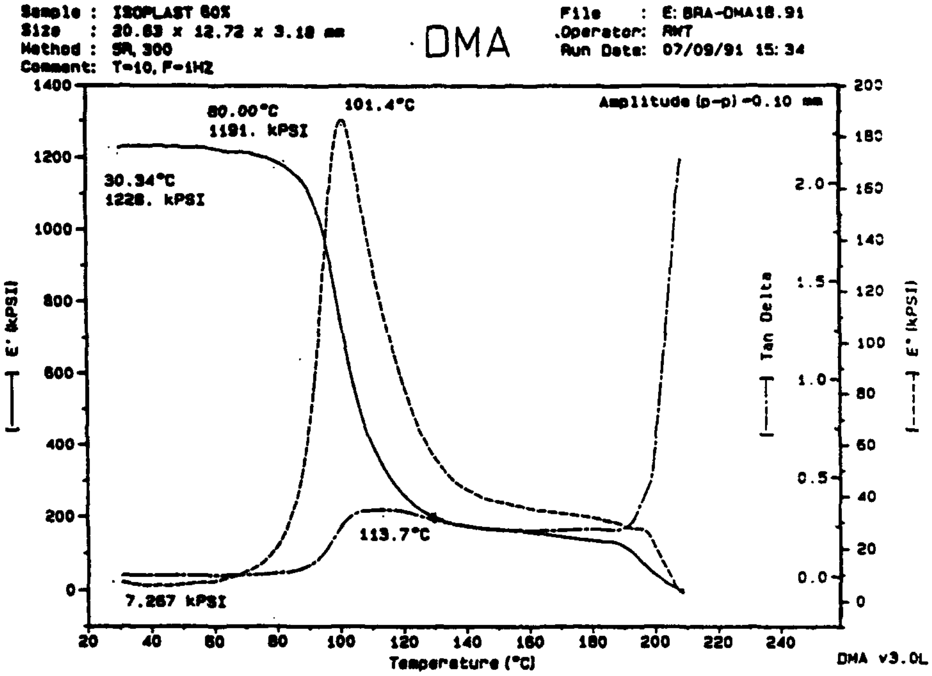


Fig. 34 – DMA plot for Isoplast 60% long glass

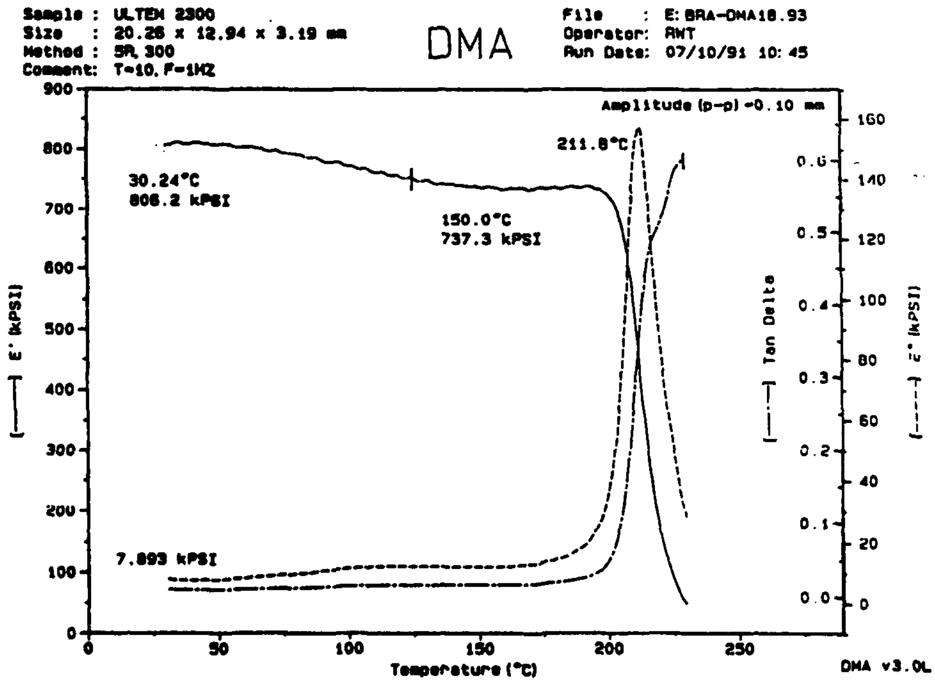


Fig. 35 – DMA plot for Ultem 2300 30% glass

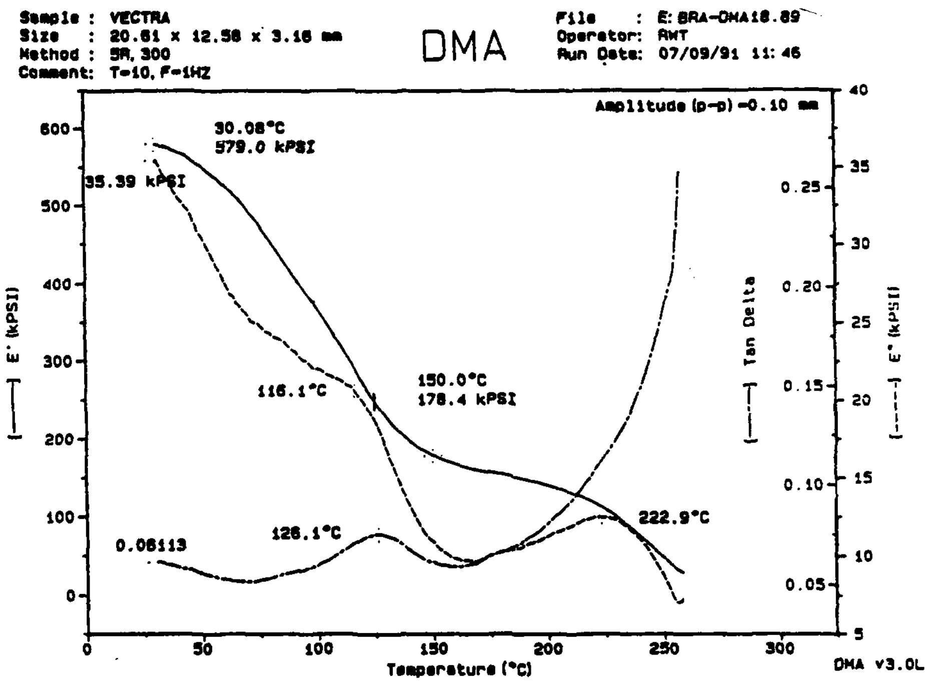


Fig. 36 – DMA plot for Vectra 15% mineral fill

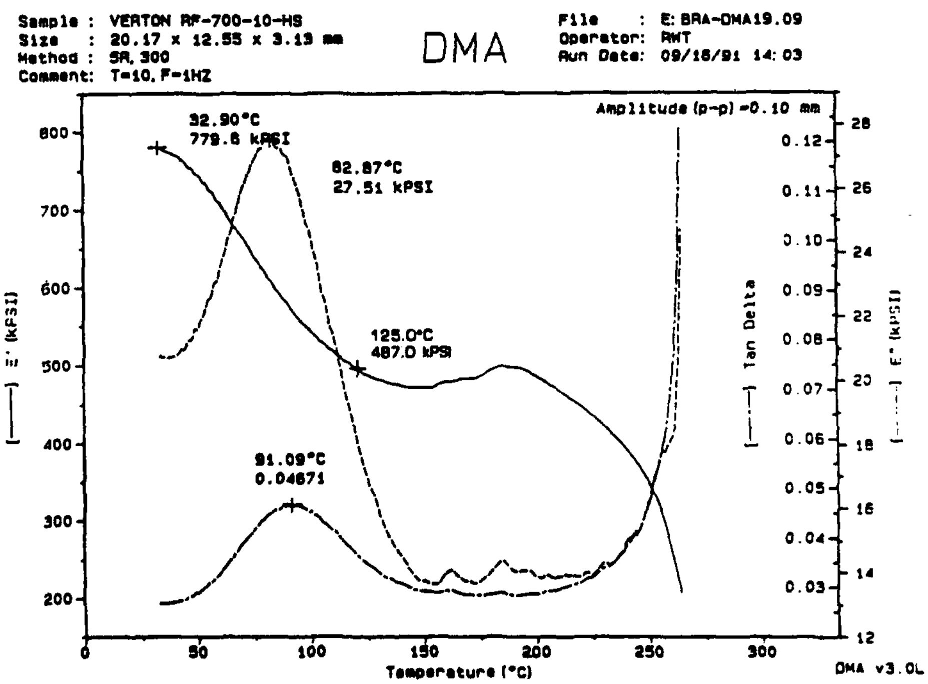


Fig. 37 – DMA plot for Verton 50% long glass

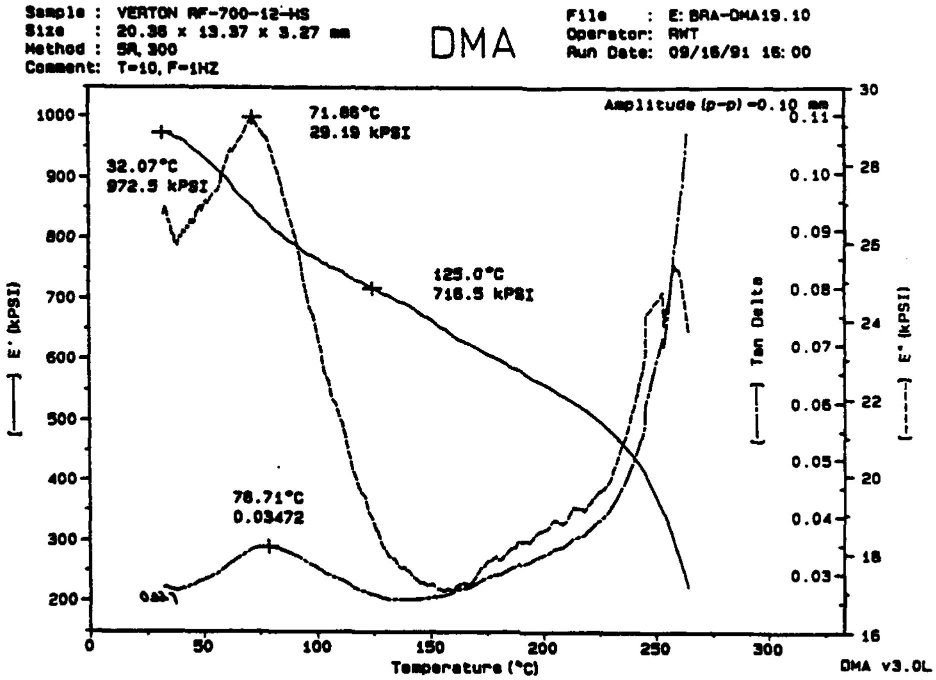


Fig. 38 – DMA plot for Verton 60% long glass

Figure 29 compares the tan delta (ratio of lost to stored energy) values obtained during the DMA analysis. Vectra A-515 produced the highest tan delta of the materials tested. The highly reinforced nylons are grouped together, having the next highest tan deltas, followed by the Isoplast materials and Ultem 2300. The ranking of these materials, with higher tan deltas indicative of lossy properties, corresponds well with the toughness and impact strength findings. In other words, a high impact strength and degree of toughness are predictable from a high tan delta value.

The percent change in flexural modulus as a function of temperature is depicted in Fig. 30. The Isoplast compounds were most affected by elevated temperature, displaying a reduction in modulus above 80% from a range of 25 to 125°C. The nylon materials exhibited a fair degree of temperature resistance under the same conditions with a loss of 25 to 30% in flexural modulus. The relatively temperature-resistant Ultem 2300 had the best performance here with a loss of less than 10%.

Pultruded Rod Tensile Tests

Methods used to fixture the pultruded rod tensile specimens were examined. A sample of 0.318-cm (0.125 in) diam pultruded nylon 12/fiber glass was obtained for tensile testing. Several clamping techniques were attempted with limited success.

In all cases the rod failed within the clamping jaw. Despite these problems, tensile strengths of 483 MPa (70 ksi) were recorded.

FINITE ELEMENT ANALYSIS

The finite element analysis (FEA) has consisted of performing a static weight finite element stress analysis and a preliminary explosive shock analysis on the unmodified TR-317 standard bracket. The TR-317 standard bracket has since been modified for impact resistance and the FEA will be repeated n the modified design.

Unmodified TR-317 Standard Bracket Static Weight Stress Analysis

Figure 39 shows a 3-D view of the unmodified TR-317 standard bracket finite element model. The static weight analysis of the TR-317 bracket used material properties for a representative non-metallic material. The non-metallic material used for this analysis was Ultem 2300 with the following properties:

Modulus Of Elasticity: 11,720 MPa (1.7E+6 psi)
Poisson's Ratio: 0.38
Density: 1662 kg/cu m (0.06 lbm per cu in)

The static forces applied to the bracket are due to the weight of the transducer acting on the bracket at various orientations. It was determined that the worst static weight load is applied with the transducer oriented in the horizontal position. For this reason, only the horizontal load case was executed. Figure 39 shows the orientation of the static forces applied to the finite element model. The transducer mass used for this analysis was 27 kg (60 lbm).

The static weight finite element stress analysis results for the Al-Br and non-metallic material are summarized in Table 4. The non-metallic material shows a significant increase in the X direction deflection and significant increases in stress levels for all Principal Stress directions. Figures 40 through 43 show Principal Stress 1 and deflection contour plots for the Al-Br and non-metallic materials. The contours on the stress and deflection plots are shown as lines identified by capital letters (A, B, C, D). The highest levels of positive (tensile) stress or deflection are shown at the D contours. The corresponding levels of the contours are shown in the key to the right of the plot. DMX refers to the maximum deflection found on the plot. SMN and SMX refer to the minimum and maximum stress values found on the plot. A comparison of the Principal Stress 1 contour plots for Al-Br and non-metallic materials indicate that the highest tensile static weight stresses occur at the point where the bolt shaft joins the bracket shoulder for both the Al-Br and non-metallic materials.

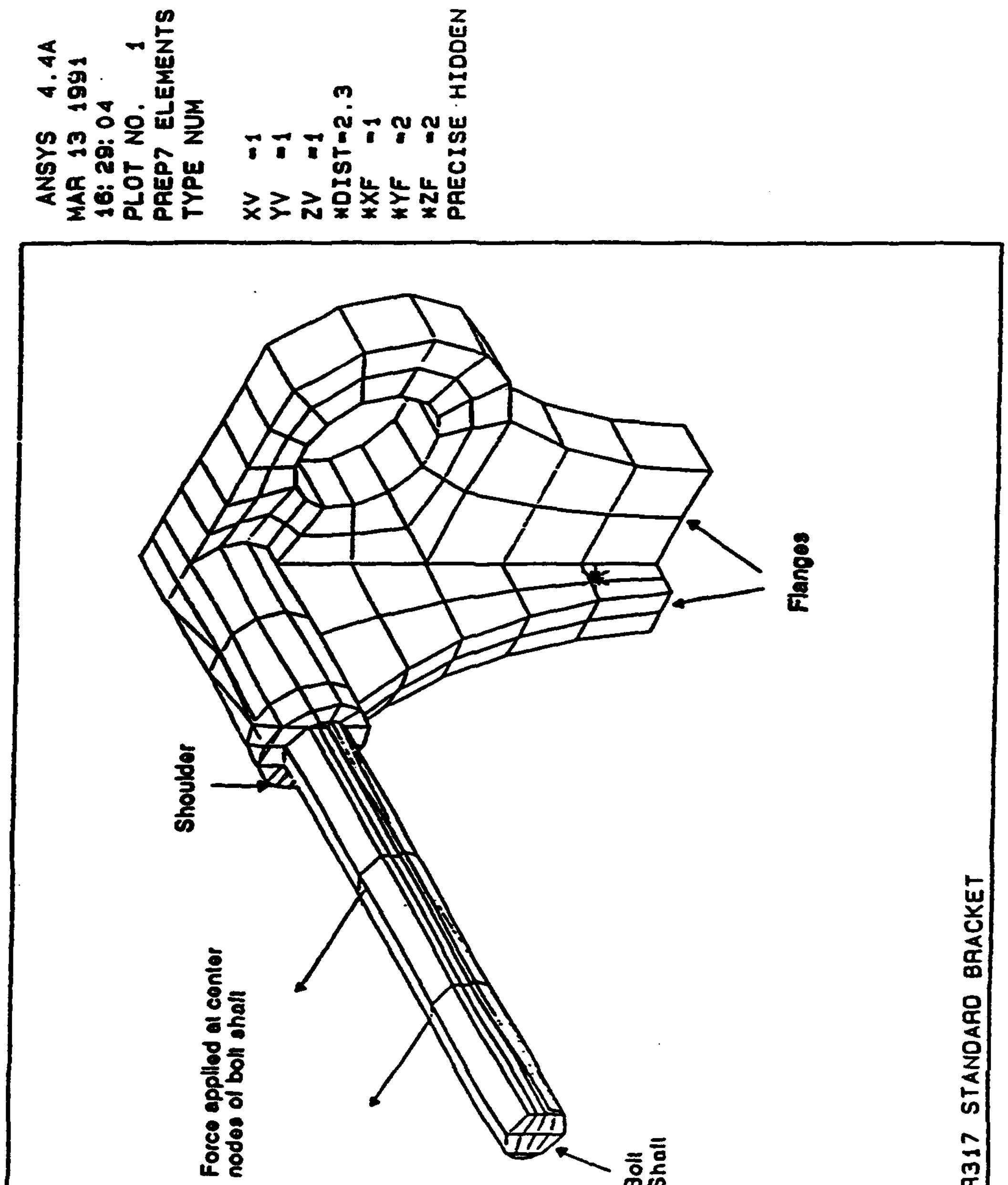


Fig. 39 – One half symmetry finite element model of unmodified TR-317 standard bracket showing static weight load

Table 4 – TR-317 bracket finite element static weight stress analysis summary

Material	Maximum X Direction Deflection (in)	Principle Stress 1 SIG 1 (psi)		Principle Stress 2 SIG 2 (psi)		Principle Stress 3 SIG 3 (psi)	
		Tension	Compression	Tension	Compression	Tension	Compression
AL-BR	0.0012	1,816	-92	750	-183	425	-1,641
Ultem 2300	0.083	5,197	-262	2,505	-630	1,591	-4,793

D153.3.6

Load Case: Static Transducer Mass of 60 lbm. Transducer is Horizontal.

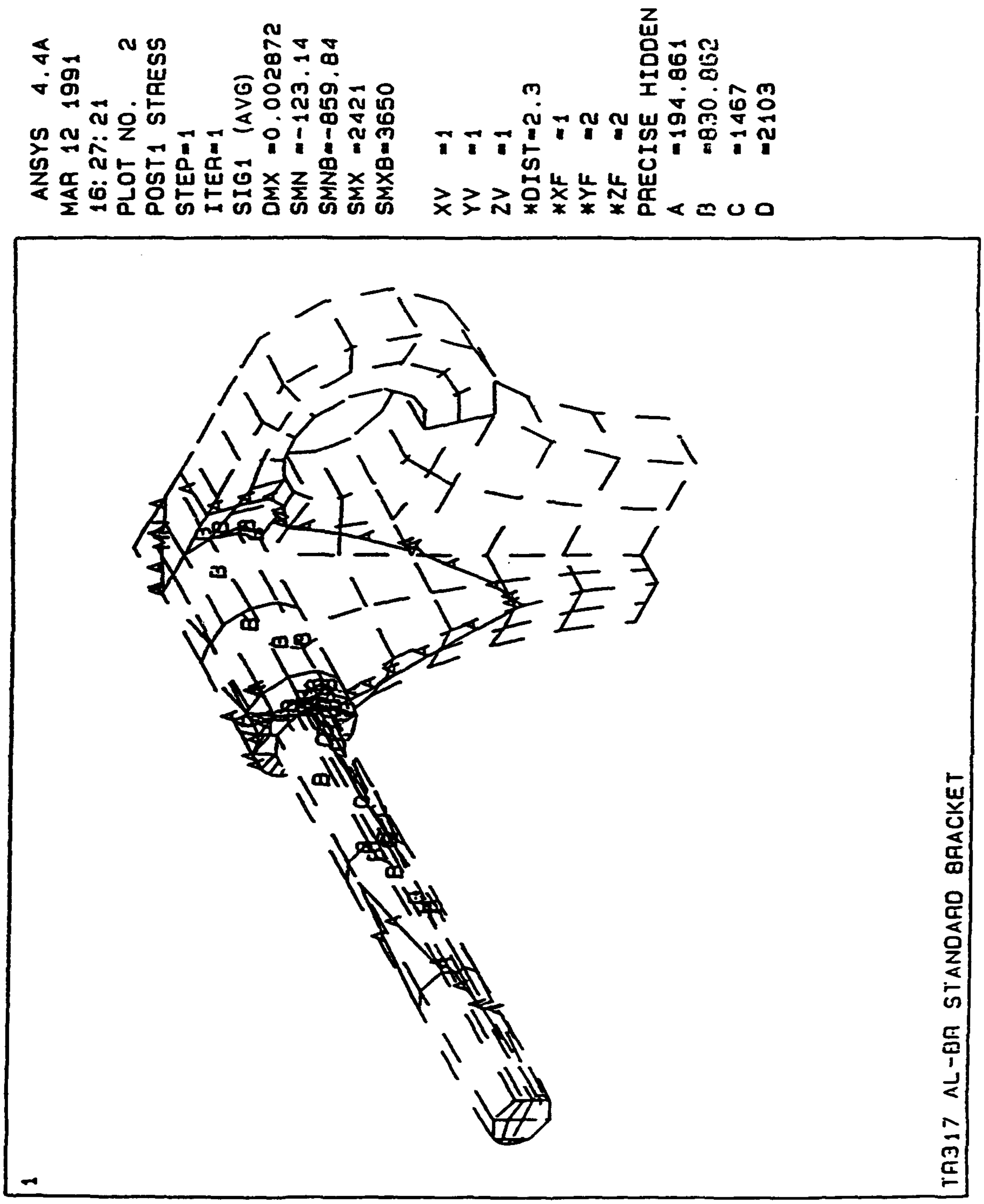


Fig. 40 – Principal stress 1 (Sig 1) contour plot

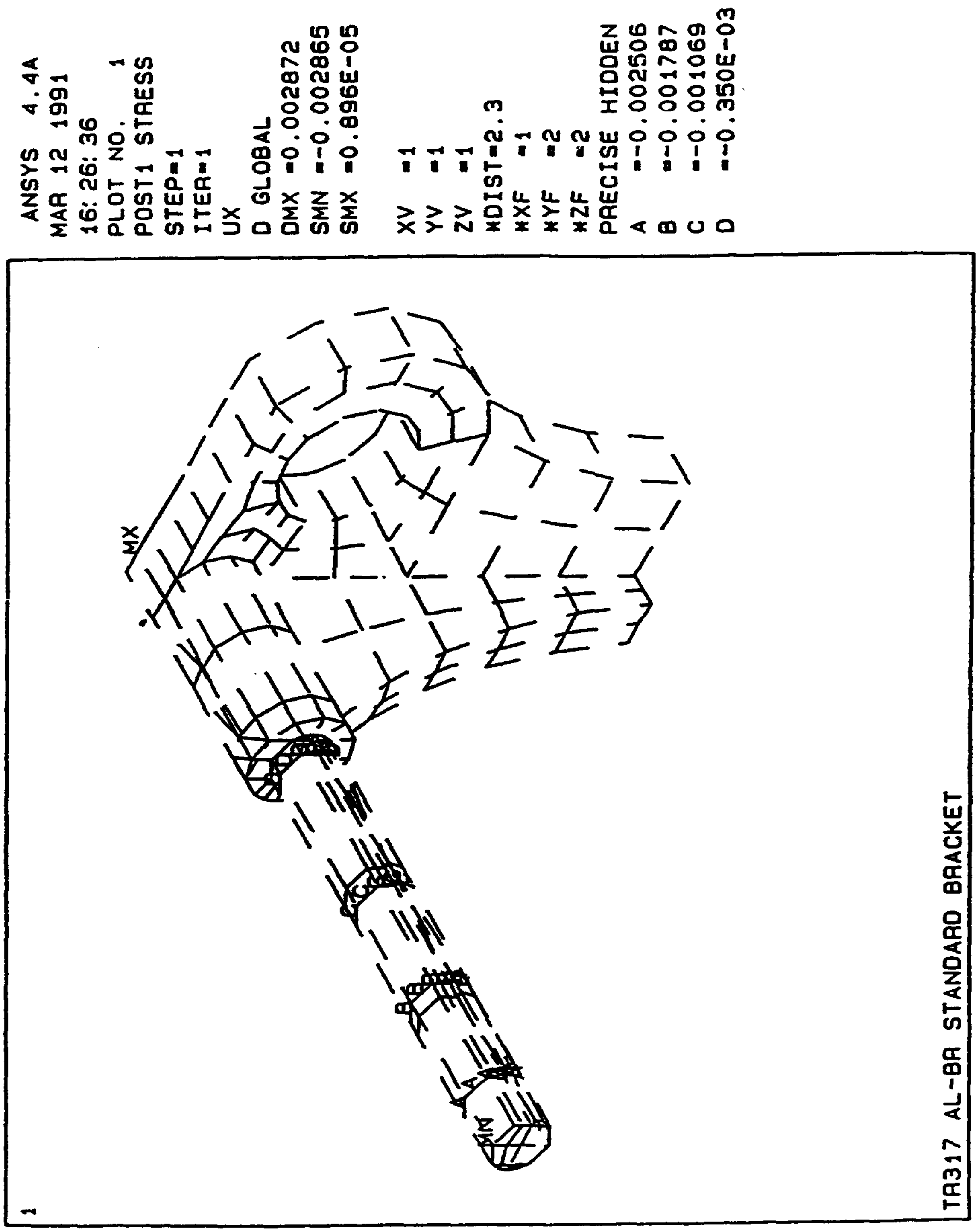


Fig. 41 – Deflection plot in X direction

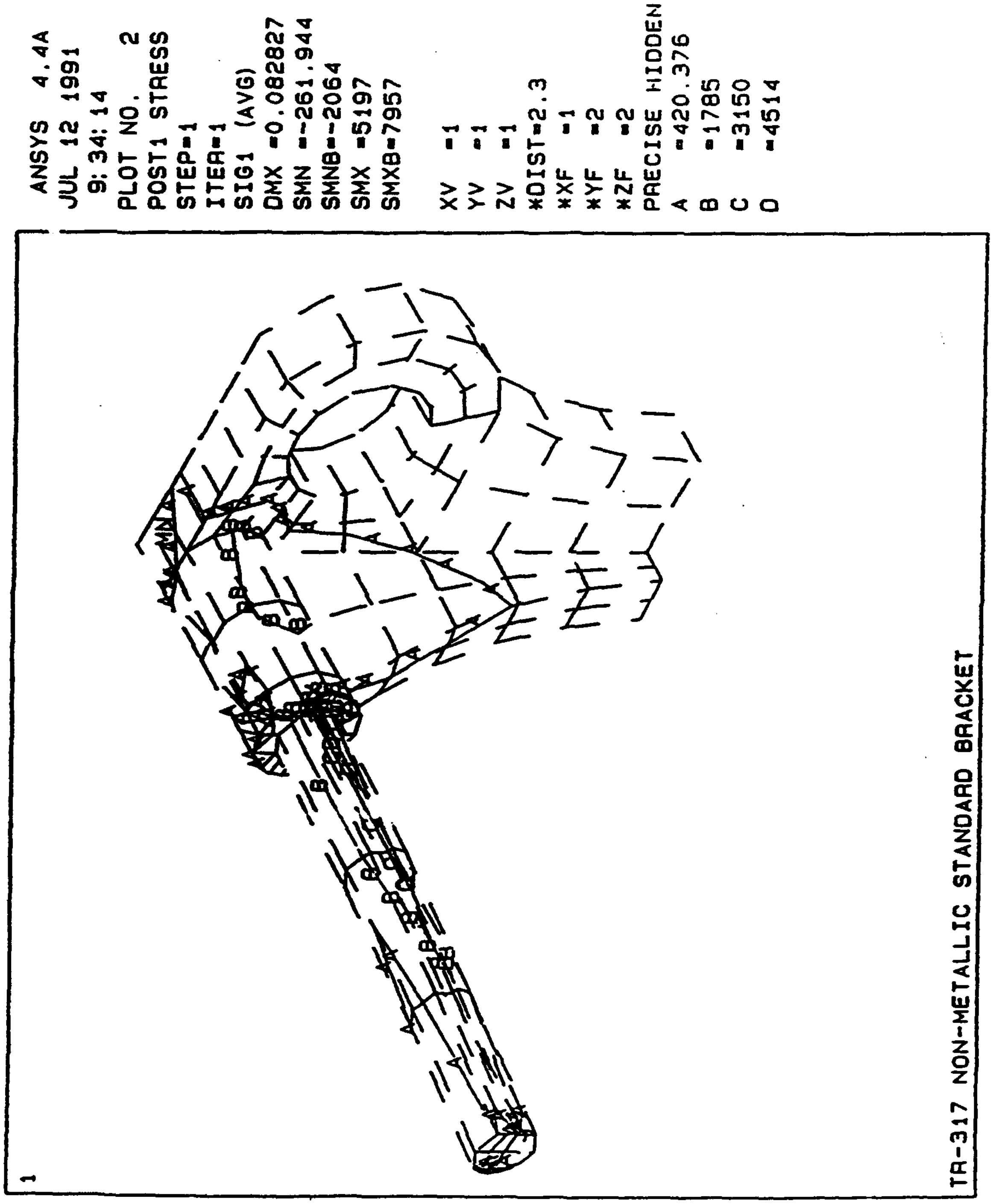


Fig. 42 – Principal stress 1 (Sig 1) contour plot

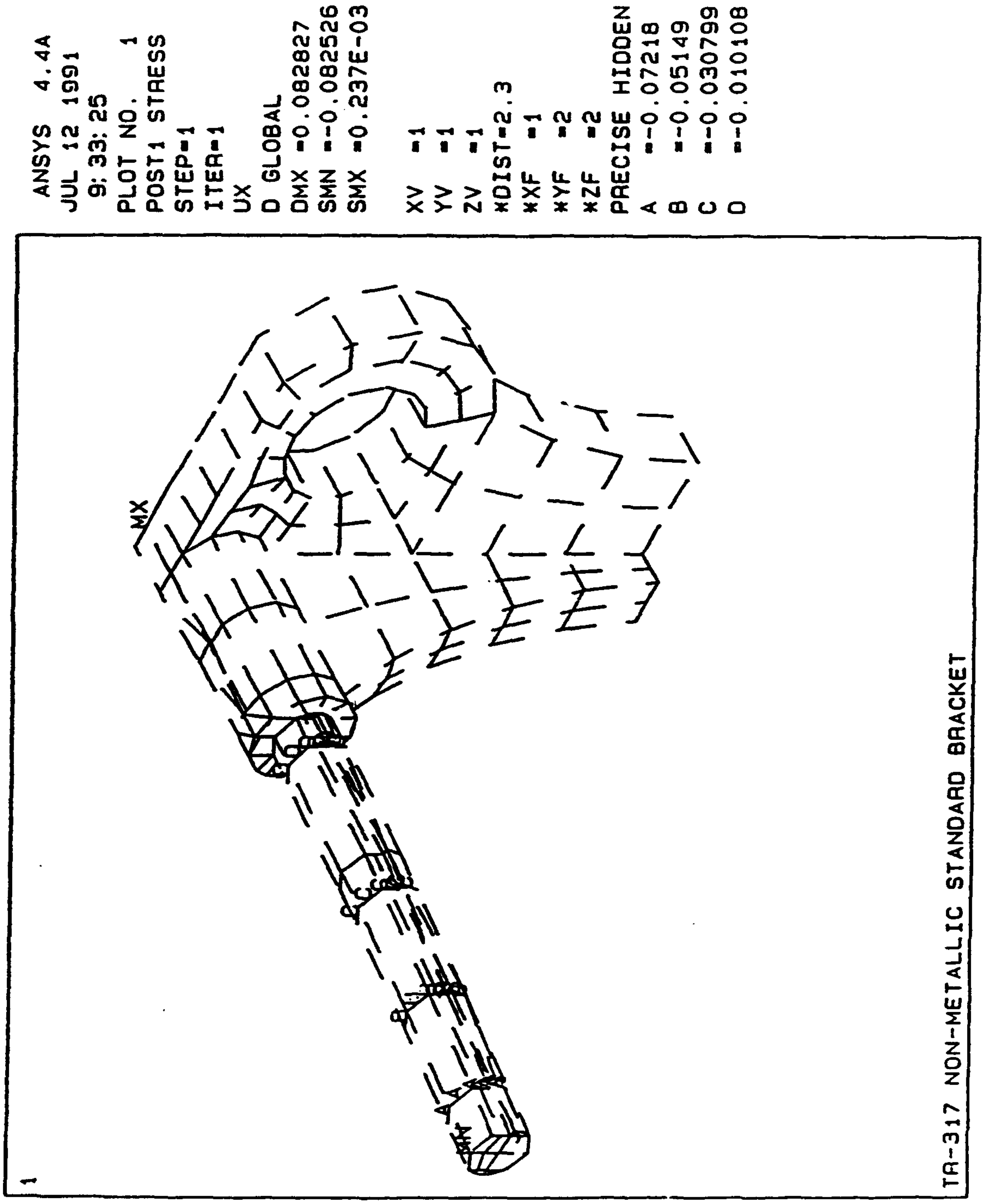


Fig. 43 – Deflection plot in X direction

Although the stress levels for the non-metallic material bracket show a large increase (maximum tensile stress of 35.9 MPa (5.2 ksi)) over the Al-Br material, it should be emphasized that they are still well below the minimum ultimate tensile strength 168.9 MPa (24.5 ksi) of the non-metallic materials. The static analysis results indicate that both the Al-Br and the non-metallic materials perform well under static weight loading. The Al-Br material experiences a maximum tensile stress of 12.4 MPa (1.8 ksi) and has an ultimate tensile strength of 510 MPa (74 ksi) which results in a ultimate factor of safety of approximately 41. The non-metallic material experiences a maximum tensile stress of 35.9 MPa (5.2 ksi) and has an ultimate tensile strength of 168.9 MPa (24.5 ksi) which results in an ultimate factor of safety of 4.7. The increase in the amount of deflection under static load that the non-metallic material exhibits may be of some concern however. The non-metallic material exhibits a maximum deflection of 2 mm (0.08 in) vs 0.025 mm (0.001 in) for Al-Br material.

Unmodified TR-317 Standard Bracket Preliminary Explosive Shock Analysis

The preliminary explosive shock analysis consisted of a modal analysis to determine the natural frequencies of the bracket and a quasistatic stress analysis using "best guess" estimates of dynamic material properties. It was felt that a quasistatic stress analysis would provide adequate comparison data given the "best guess" estimates used for this analysis.

The static model of the TR-317 bracket described above was modified for the preliminary modal analysis by distributing mass elements along the bolt shaft to represent the transducer mass attached to the bracket. The bracket post was allowed to vibrate freely and no attempt was made to model the transducer constraints on the bolt shaft for this preliminary analysis. The model was executed with a fixed mount for both the Al-Br and non-metallic materials. The fixed mount was represented by constraining the nodes around the i.d. of the flange hole from movement in all three directions. The model was then executed with a shock isolation mount for both the Al-Br and non-metallic materials. The shock isolation mount was represented by placing spring elements from a fixed nr at the center of the flange hole to the nodes around the i.d. of the flange hole.

Table 5 presents the results from the preliminary modal analysis. The natural frequencies for the first three modes of vibration are shown for the fixed mount and shock isolation mount for both materials. A comparison of the Al-Br material to the non-metallic material shows that the Al-Br bracket has higher natural frequencies than the non-metallic bracket. This is expected since the Al-Br material has a much higher modulus which results in a higher stiffness. Also as expected, the use of the rubber shock isolation washers drastically reduces the natural frequencies of the bracket.

Table 5 – Unmodified TR-317 standard bracket preliminary modal analysis results (symmetrical boundary conditions)

Natural Frequency (Hz)	Fixed Mount	
	Non-metallic Material	Al-Br Material
f_1	15.3	48.1
f_2	23.7	75.1
f_3	78.1	246.0
Natural Frequency (Hz)	**Shock Isolation Mount**	
	Non-metallic Material	**Al-Br Material**
f_1	5.1×10^{-5}	1.5×10^{-4}
f_2	9.36	9.40
f_3	18.81	40.15

D.153.3.5

Note: Bracket post is allowed to move freely with a distributed mass of 15 lbm.

Unmodified TR-317 Standard Bracket Preliminary Explosive Shock Stress Analysis

The TR-317 static stress model was used to perform a preliminary quasistatic explosive shock stress analysis. Figure 44 shows a plot of pressure vs time measured by a pressure gauge located on the test platform at the Hi-Test explosive shock test facility in Arvonia, VA. This plot is actual data generated during Shot #1 of the MIL-S-901-D explosive shock test series. The peak overpressure is approximately 22.1 MPa (3.2 ksi). This instantaneous explosive shock peak overpressure was applied to the static bracket model as a static force acting on the bolt shaft through the nut. This equivalent force was determined by multiplying the overpressure by the area of the face of the transducer headmass and dividing by the number of bracket posts (4). Figure 45 shows that this applied force is distributed around the circumference of the shaft and acts in the positive Z direction. The force acts to try and pull the transducer and nut off of the bracket post. Since this was a static analysis the bracket was assumed to have a fixed mount at the flange mounting hole. This model was executed using both Al-Br and non-metallic material properties.

Table 6 presents a summary of the preliminary quasistatic explosive shock stress analysis results. Extremely high instantaneous stress and deflection values are found for both material cases. These stress and deflection values have no absolute meaning since they cannot be compared to material yield or ultimate strengths. However, these values can be used as a relative comparison of the two materials. Both materials experience about the same level of stresses in each direction, but, as in the static weight analysis case, the non-metallic material experiences substantially more deflection than the Al-Br material. The quasistatic analysis results also provide insight into where the highest stresses occur on the bracket due to explosive shock loading. Figure 46 is the stress contour plot in the X direction and Fig. 47 is the deflection plot in the Z direction for the Al-Br material. Figures 48 and 49 present the same results for the non-metallic material. The maximum X direction tensile stresses occur on the back surface of the flange at the mounting hole (D contour lines) for both materials. A comparison of the deflection plots for each material indicates that they deform in a similar manner except that the non-metallic material experiences an order of magnitude increase in deflection over the Al-Br material.

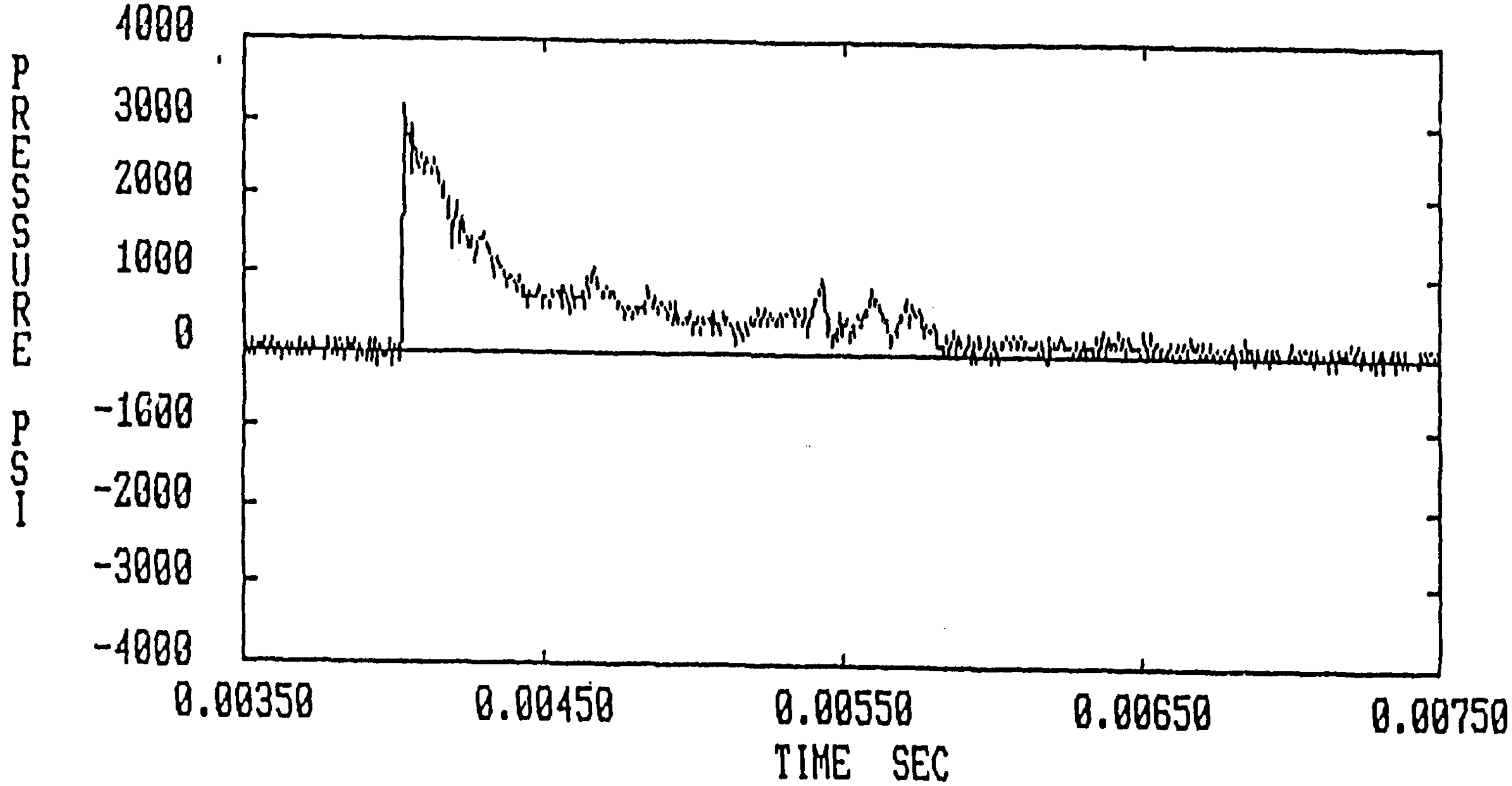


Fig. 44 – HI-Test explosive shock pressure gauge PE-1 time history for shot #1

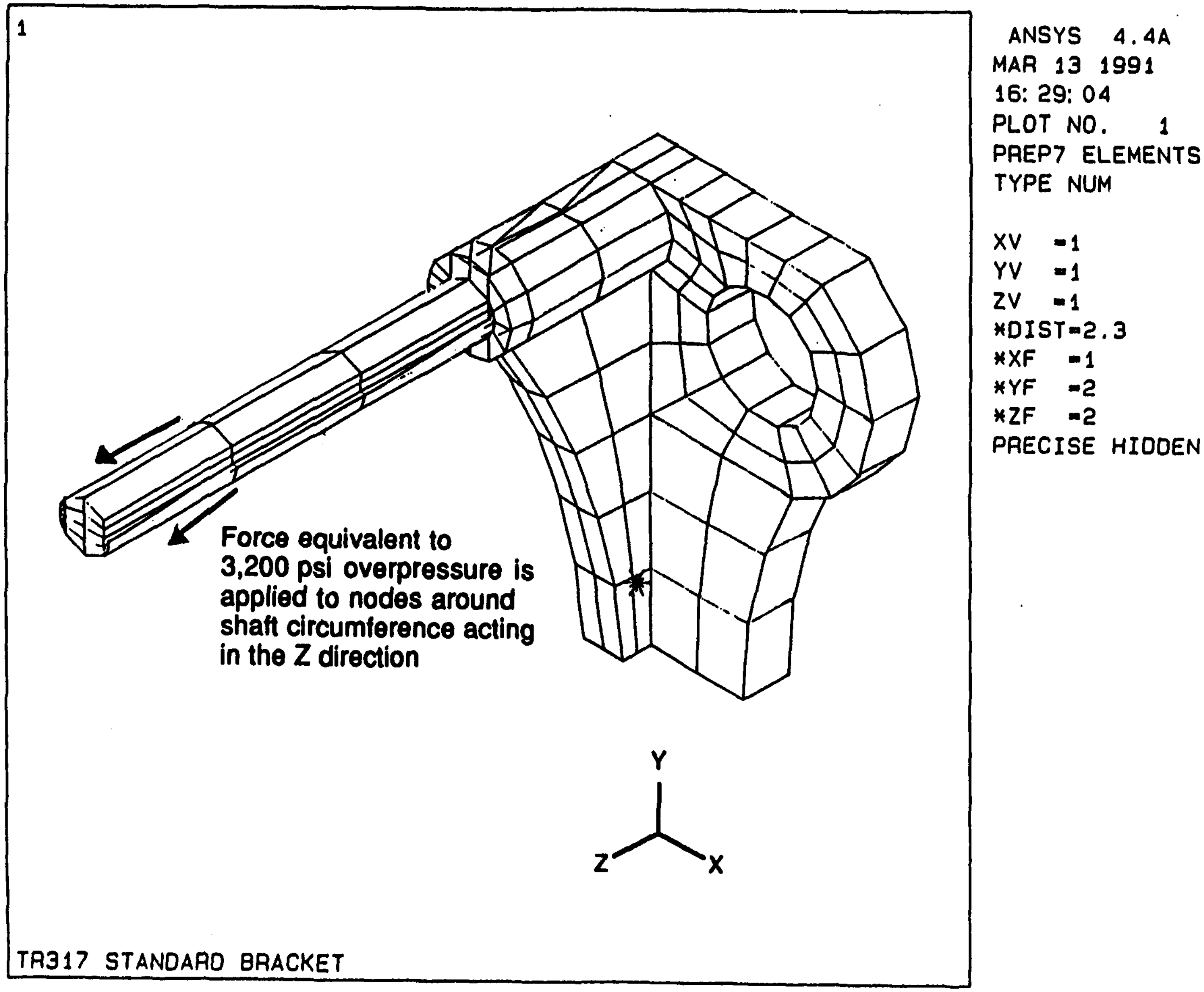


Fig. 45 – One half symmetry finite element model of unmodified TR-317 standard bracket showing quasistatic explosive shock load

Table 6 – Unmodified TR-317 standard bracket preliminary finite element explosive shock stress analysis summary

Material	Maximum Z Direction Deflection (in)	Maximum X Direction Stress SX (Ksi)		Maximum Y Direction Stress SY (Ksi)		Maximum Z Direction Stress SZ (Ksi)	
		Tension	Compression	Tension	Compression	Tension	Compression
Aluminum-Bronze	0.11	537	-478	241	-196	611	-195
Non-metallic	1.04	534	-470	255	-207	609	-191

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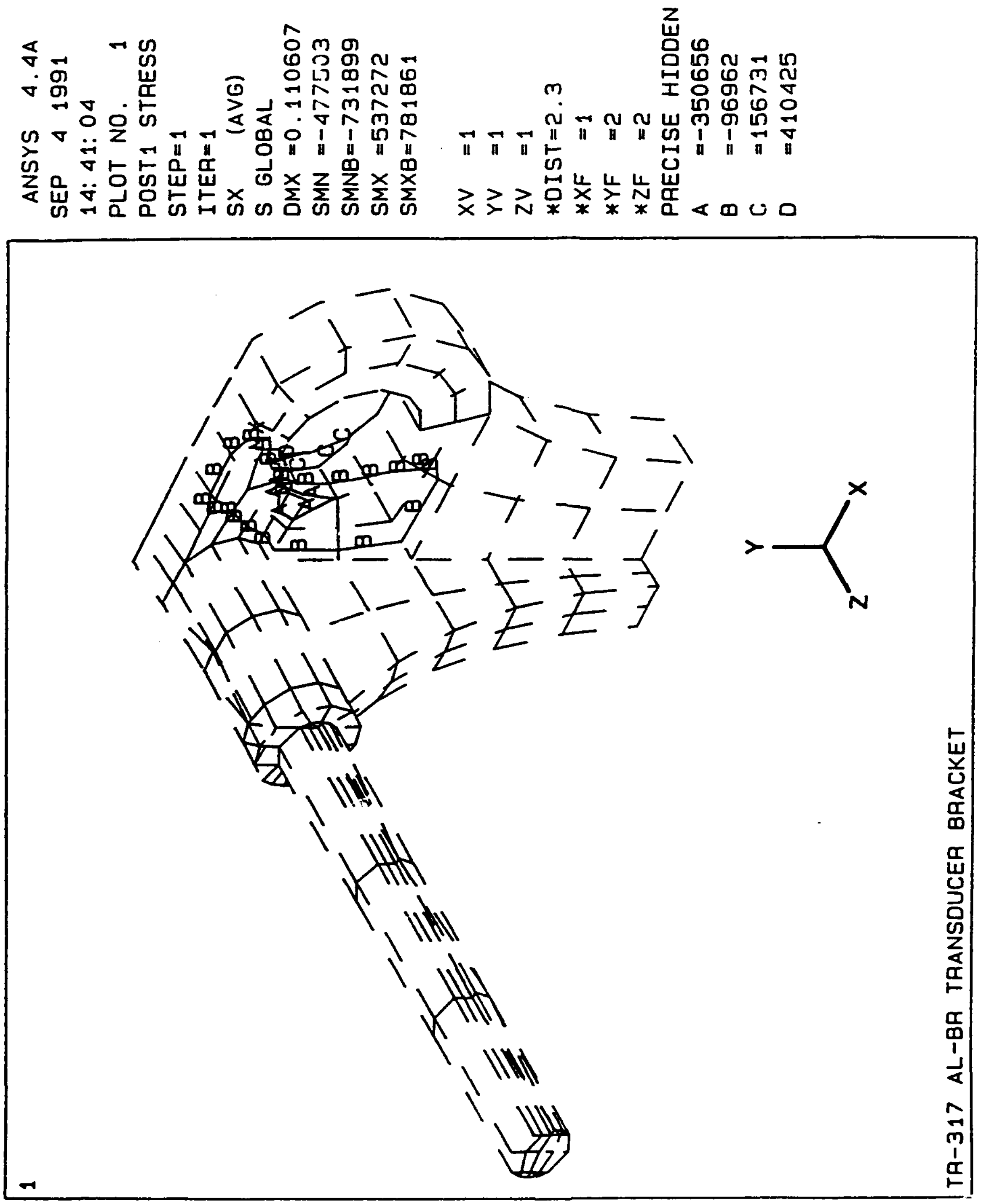


Fig. 46 – Al-Br TR-317 standard bracket X direction (SX) stress contour plot

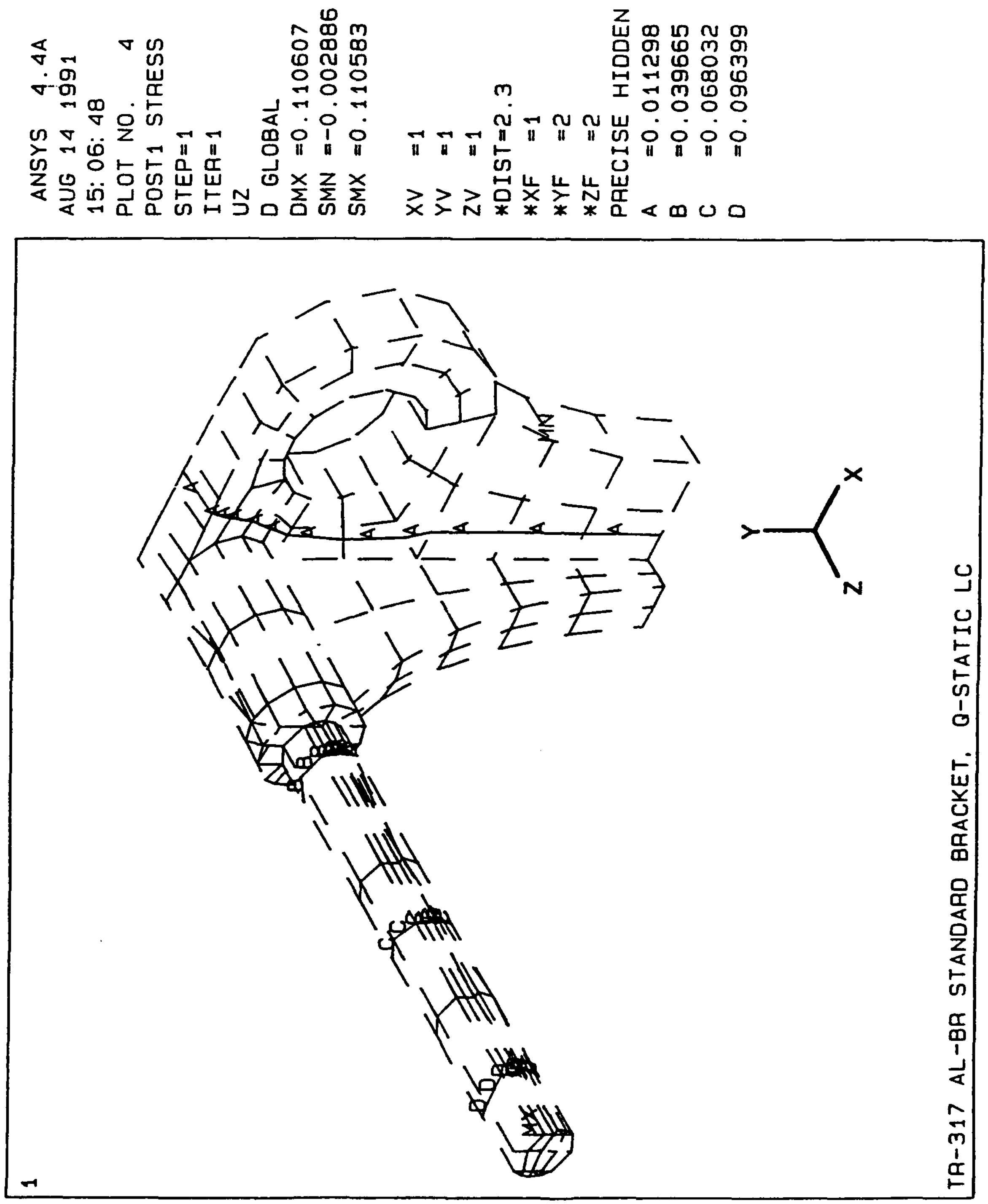


Fig. 47 – Al-Br TR-317 standard bracket deflection plot in Z direction

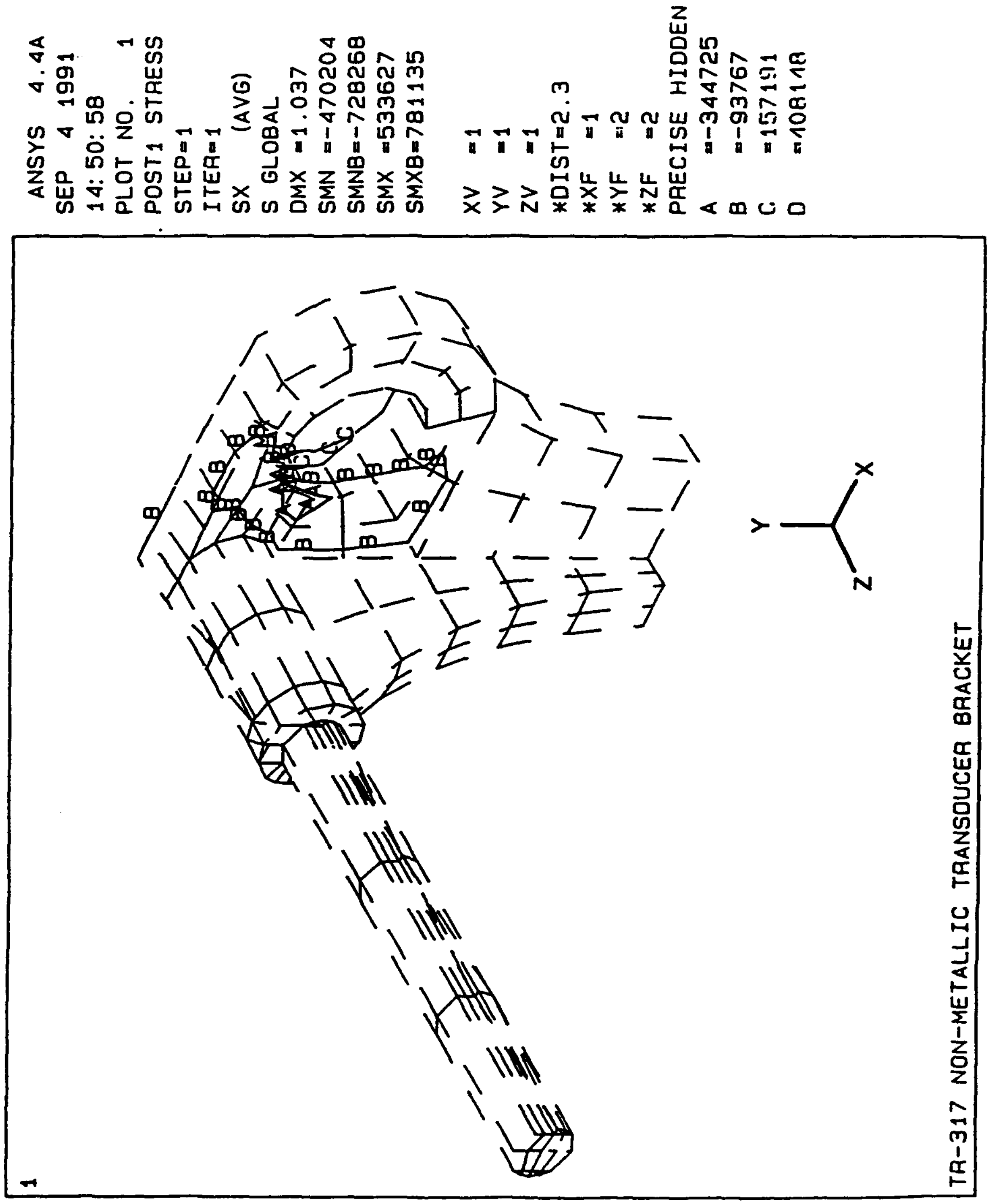


Fig. 48 – Non-metallic TR-317 standard bracket X direction (SX) stress contour plot

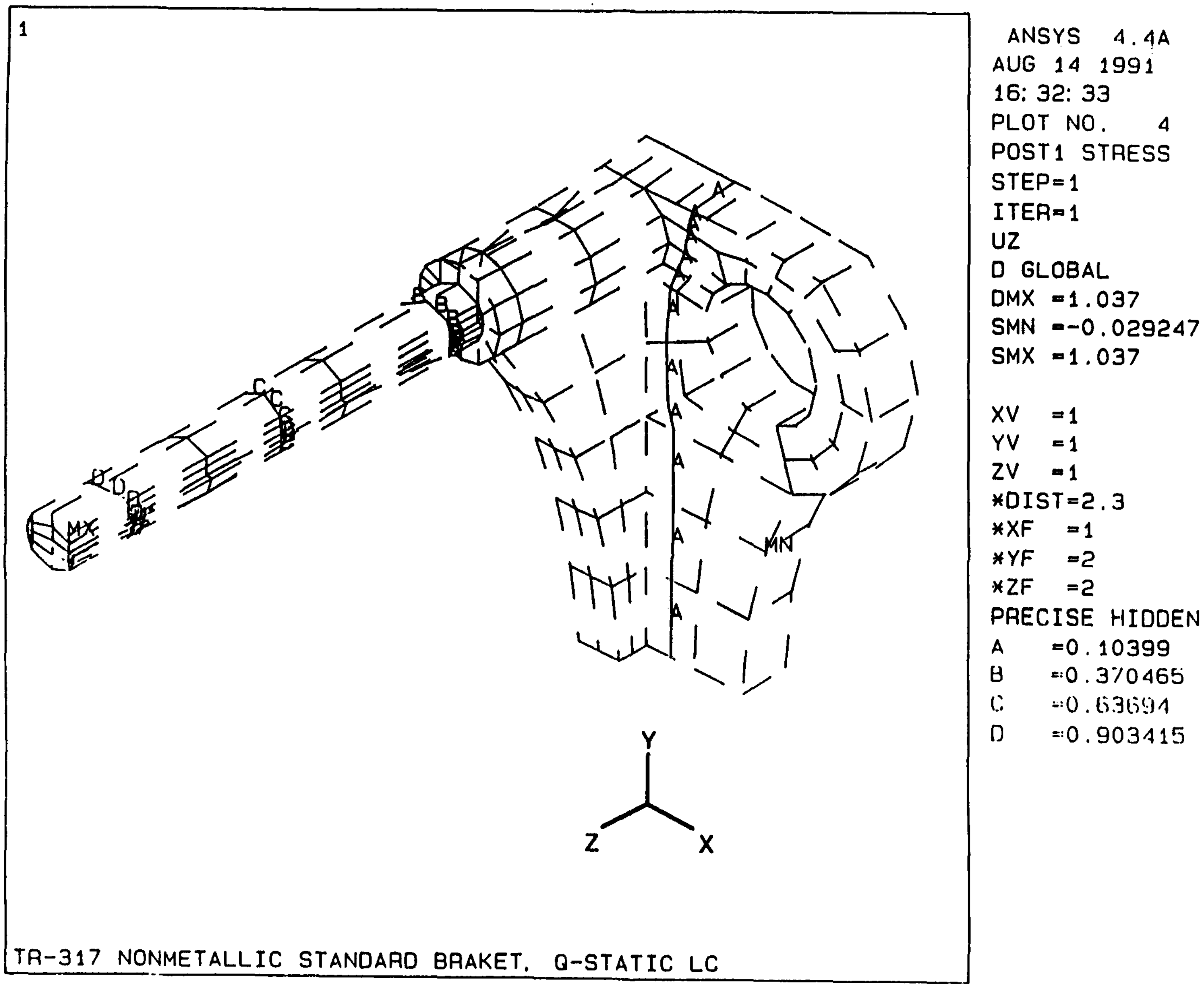


Fig. 49 – Non-metallic TR-317 standard bracket deflection plot in Z direction

BRACKET MOLD DESIGN

Figure 50 is a part drawing of the unmodified TR-317 standard nonmetallic bracket. The unmodified TR-317 standard bracket injection-molded, shown in Fig. 51, was designed from the part drawing with the following features:

- Conversion of thread dimensions from 24 tpi fine, used in the aluminum-bronze bracket, to 16 tpi allowing for more compatibility with commonly available composite nuts.
- Incorporation of convertible thread insert cavities permitting changes in thread dimensions necessary for various materials.
- An altered bolt-shoulder buildup eliminating the fiberglass washer used on the aluminum-bronze bracket.
- Incorporation of a 2.4 mm (0.095 in) injection gate for minimization of long-fiber degradation.
- Attachment slots for placement of pultruded rods.

Figures 52 and 53 are photographs of the unmodified TR-317 standard bracket mold.

A mold flow analysis was performed by constructing a model of the TR-317 non-metallic bracket using the MOLDFLOW Analysis Program. The mold flow model is based on the mold drawing shown in Fig. 51. Figure 54 is a contour plot showing the mold fill time. The progression of contours represent the material front as it moves through the mold as a function of time. This plot indicates that the fan gate will provide adequate gating and allow for good flow through the mold. Figure 55 shows the orientation of the mold flow angles at the instant of fill providing an indication of the fiber orientation in the part. If the glass fibers do indeed orient themselves as indicated, then the post should gain added strength in the axial direction. Figure 56 shows the part temperature during molding. The rise in temperature from the center of the post to the end of the post is attributed to frictional heating as the material "shoots" down the post.

Molding Results

Fifty unmodified TR-317 standard brackets have been molded with the following materials: Ultem 2300, Vectra A-515, Isoplast 101 40% long glass, and Isoplast 101 60% long glass. Surface appearance of the molded parts is excellent. In addition, one bracket was produced using Ultem 2300 with a carbon fiber pultruded rod in order to determine flow characteristics of the resin around the rod. The results indicate good flow properties with no voids observed. Figure 57 shows a view of the unmodified molded brackets produced and an Al-Br bracket. Figure 58 shows a view of the Ultem 2300 bracket with pultruded rod next to an Al-Br bracket. Figures 59 and 60 allow a direct comparison between an unmodified molded bracket (Isoplast 60% long glass) and an Al-Br bracket. Note the bolt shoulder build up and the coarse threads used on the molded bracket.

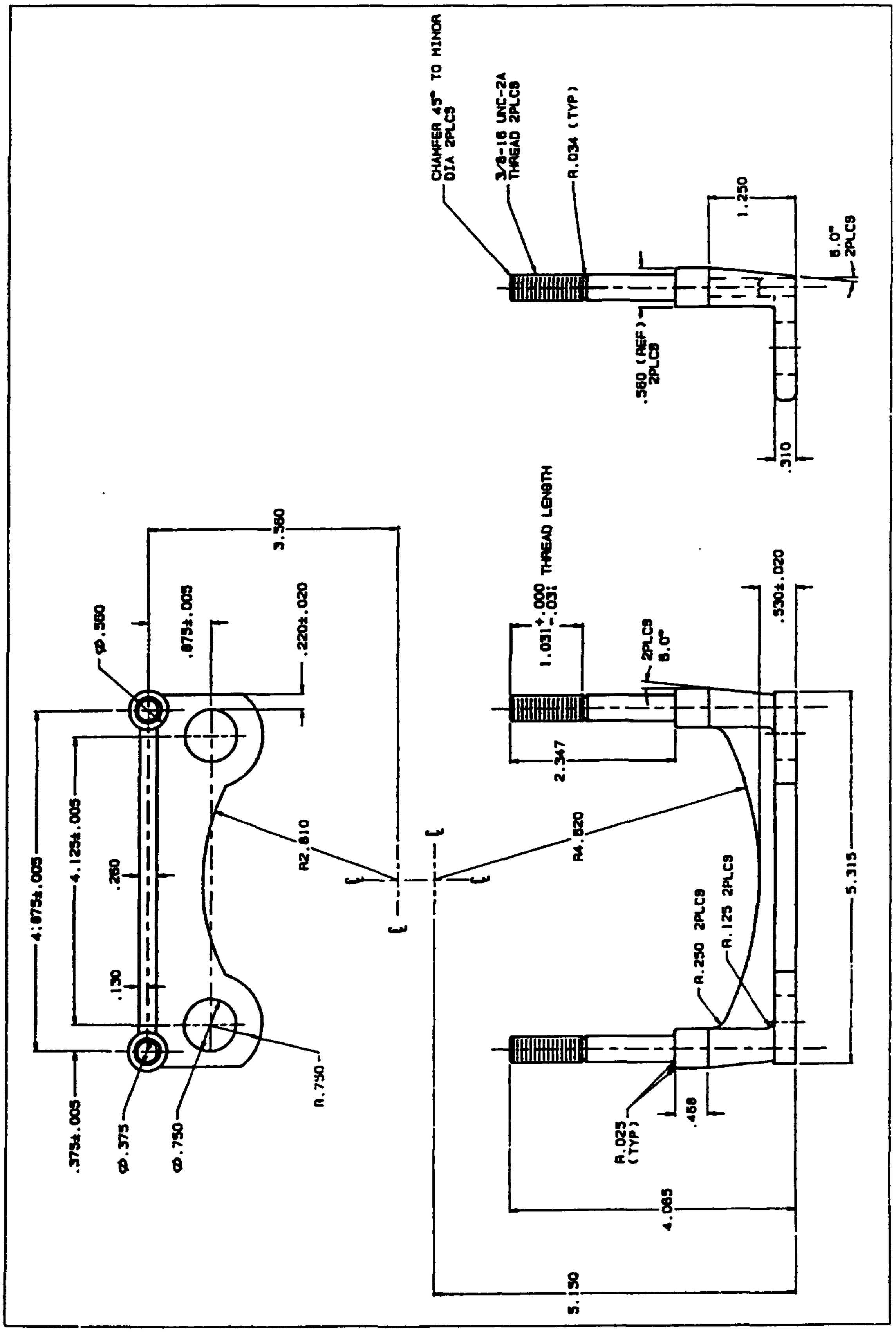


Fig. 50 – Unmodified TR-317 standard bracket design drawing

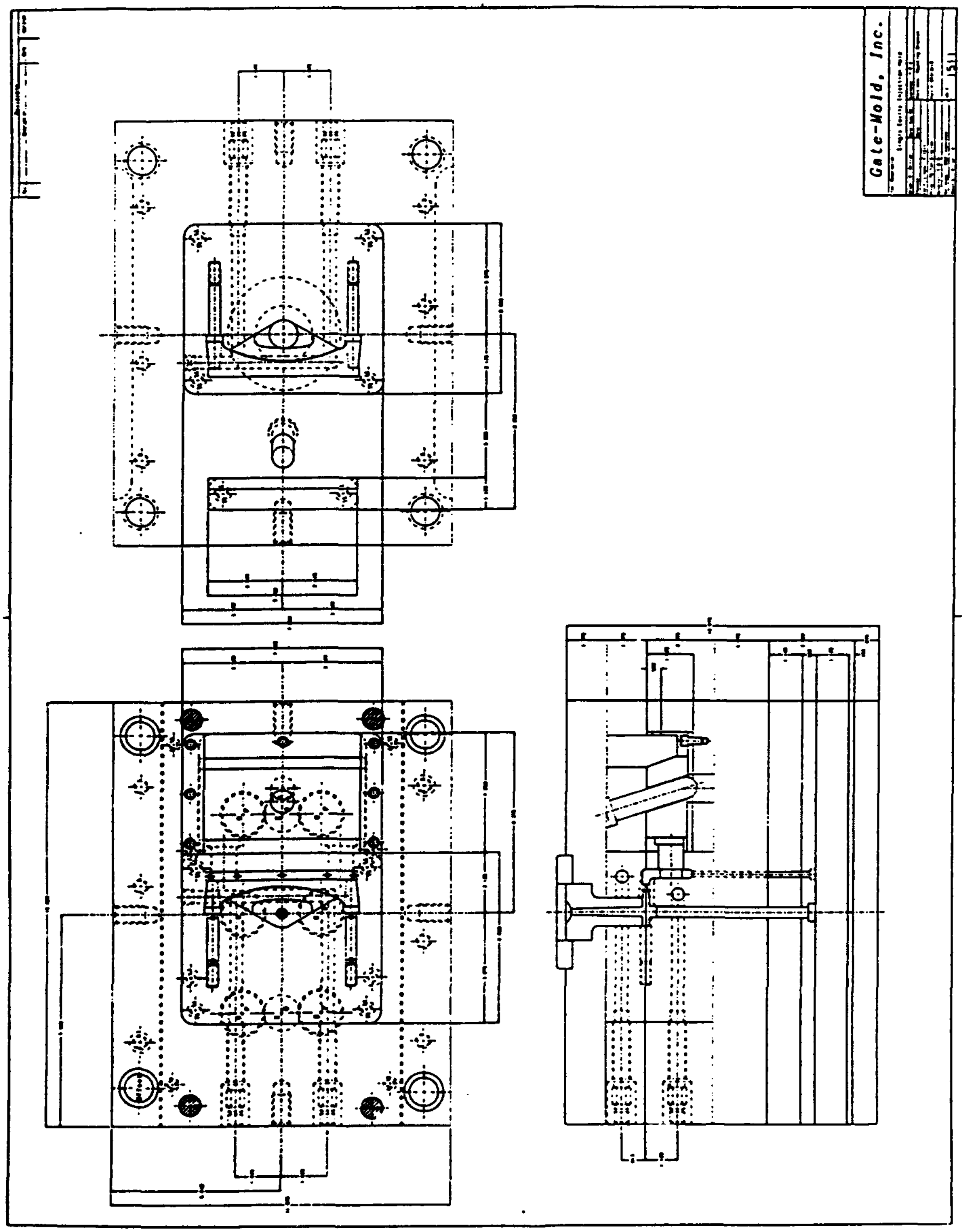


Fig. 51 – Unmodified TR-317 bracket mold design drawing

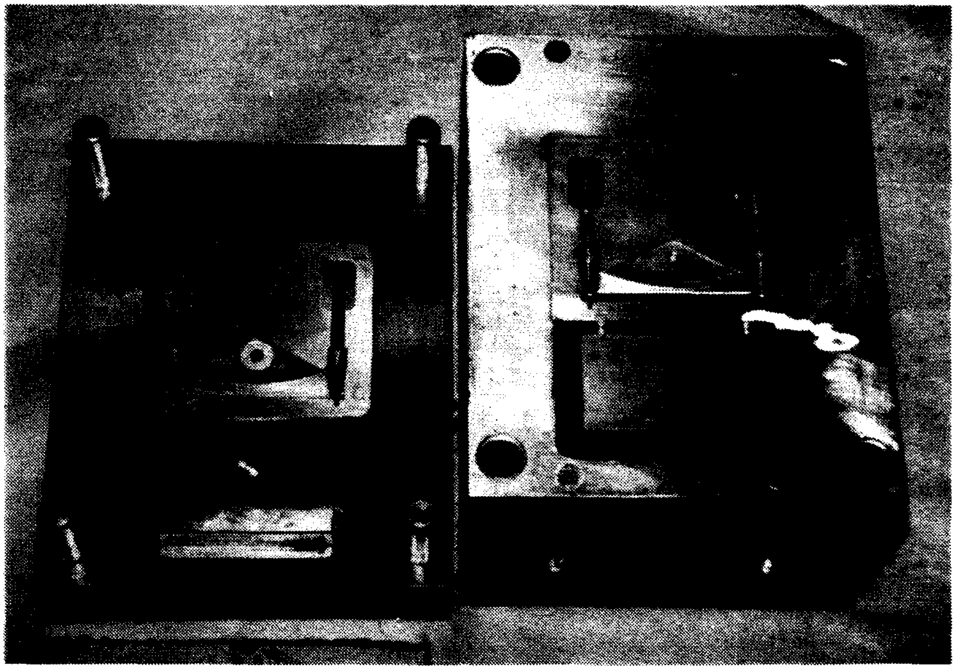


Fig. 52 – Top and bottom sections of TR-317 bracket injection mold

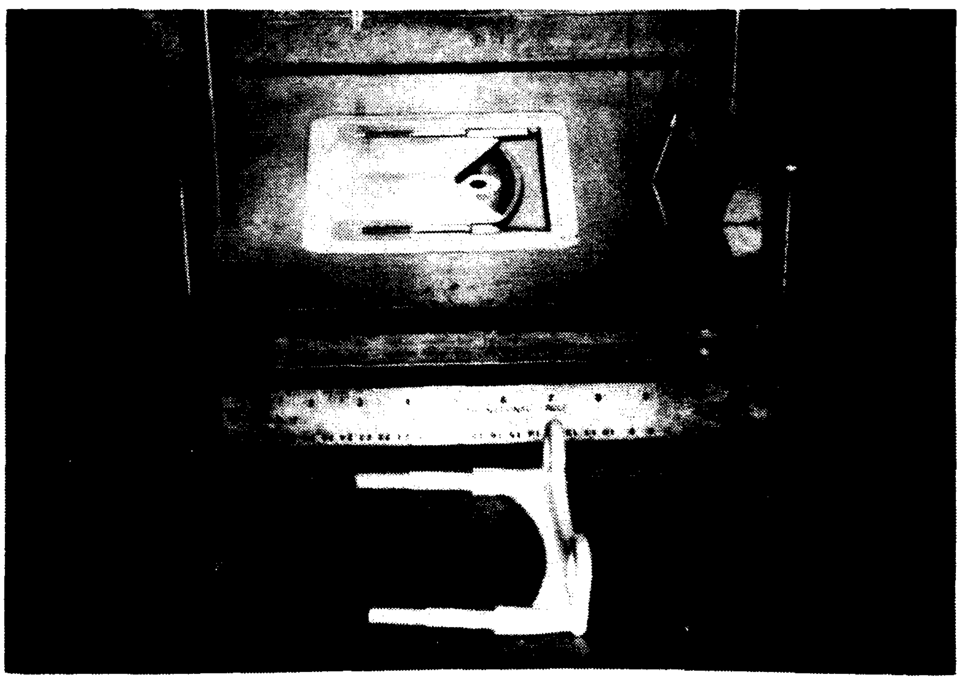


Fig. 53 – Close up of TR-317 bracket injection mold

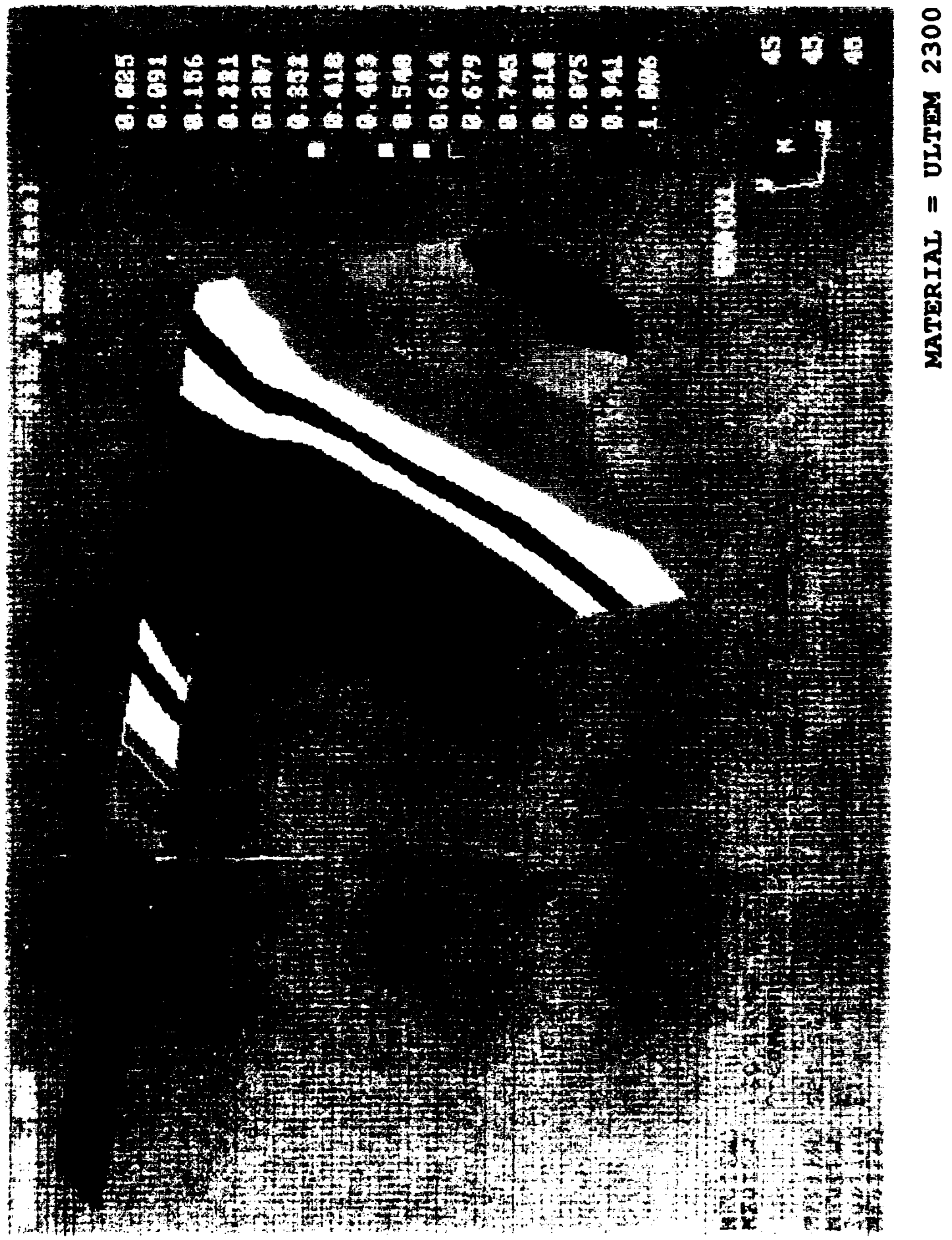
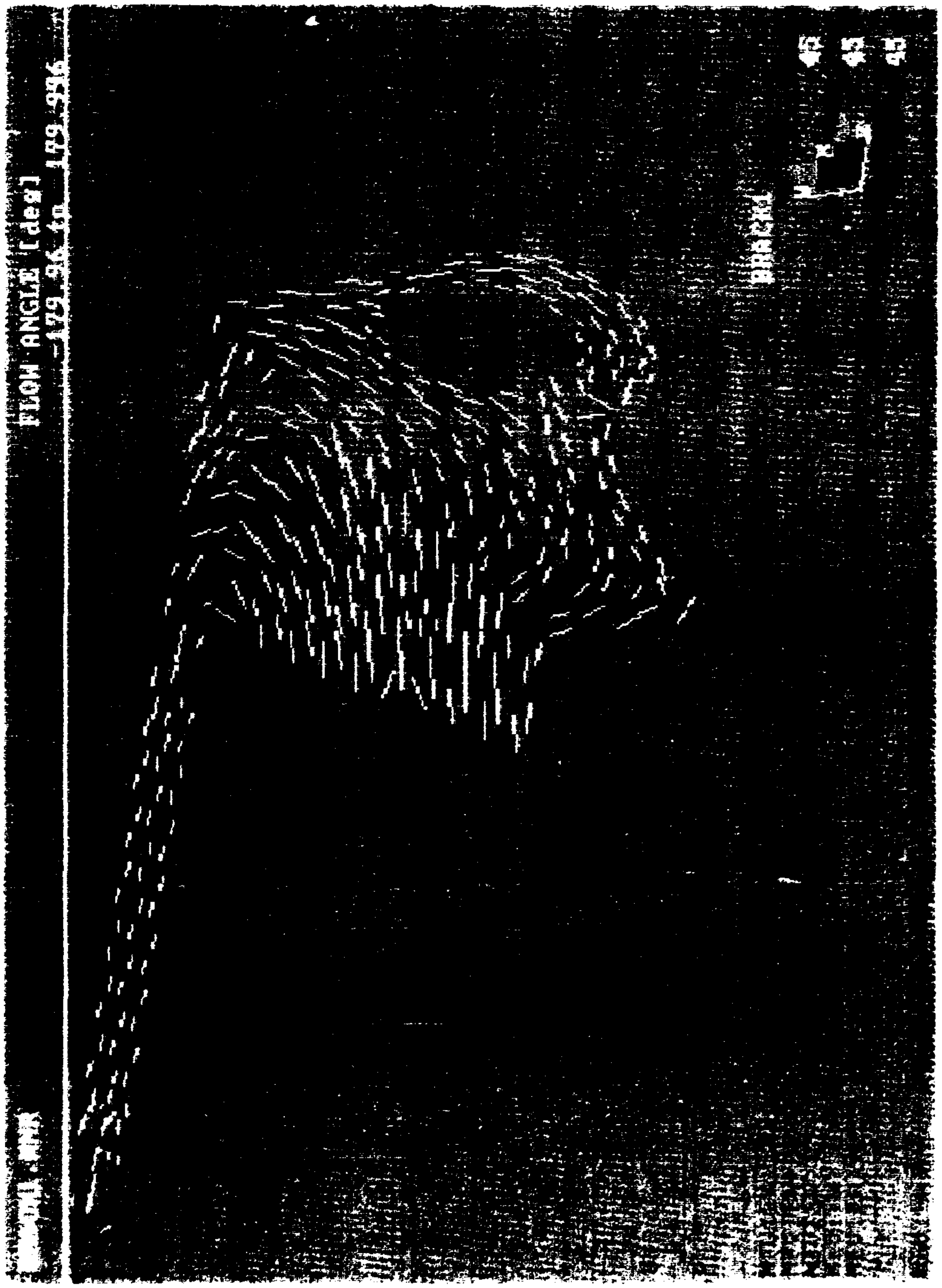
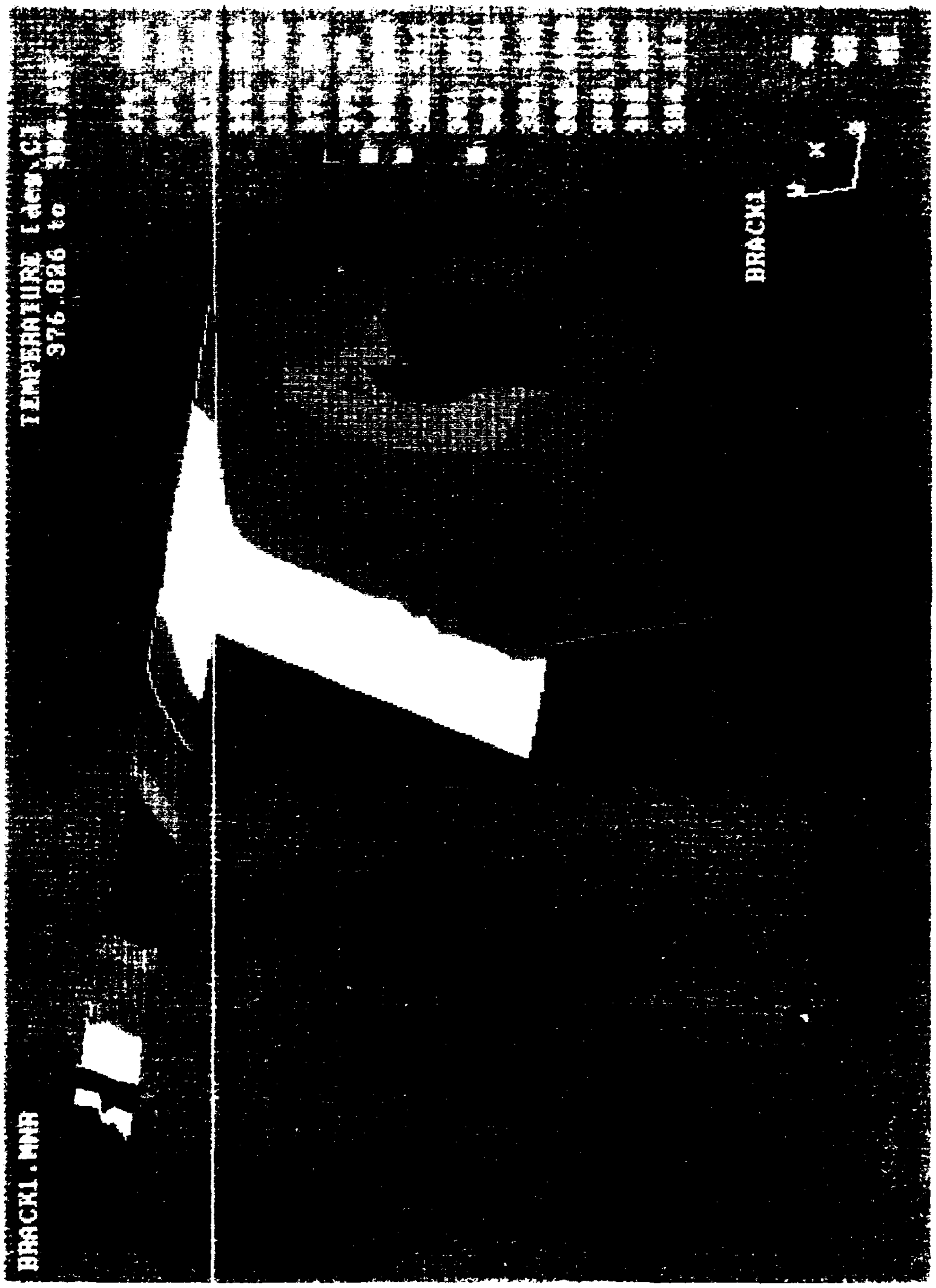


Fig. 54 – Mold fill time (sec)



MATERIAL = ULTEM 2300

Fig. 55 – Mold flow angles at instant of fill



MATERIAL = ULTEM 2300

Fig. 56 – Part temperature during molding (initial mold temperature of 400°)

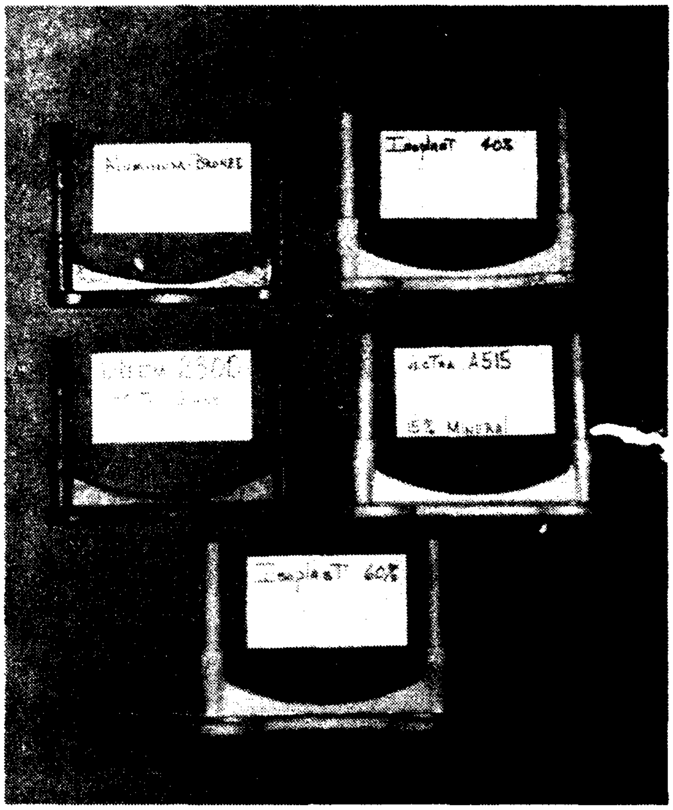


Fig. 57 – View of Al-Br bracket and unmodified injection-molded brackets

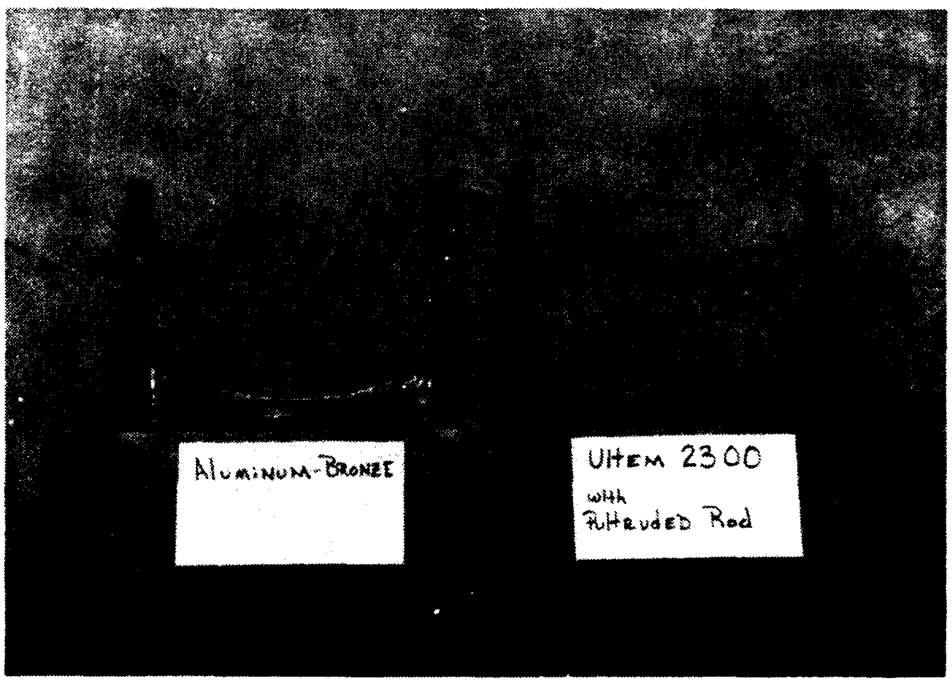


Fig. 58 – Close up view of Al-Br bracket and Ultem 2300 bracket with pultruded rod inserts

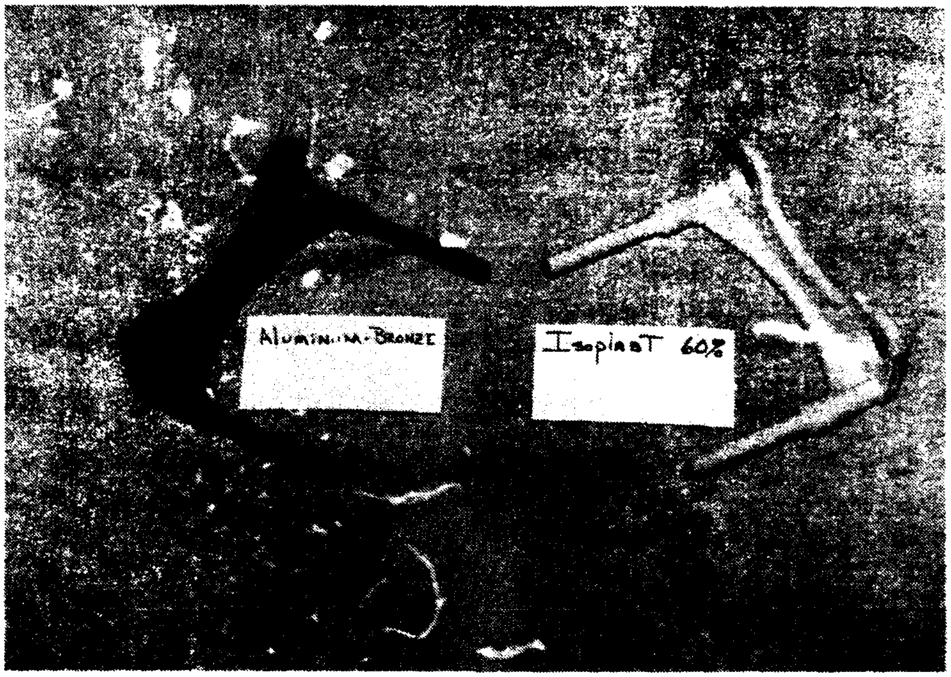


Fig. 59 – View of Al-Br bracket and Isoplast 60% long glass molded bracket

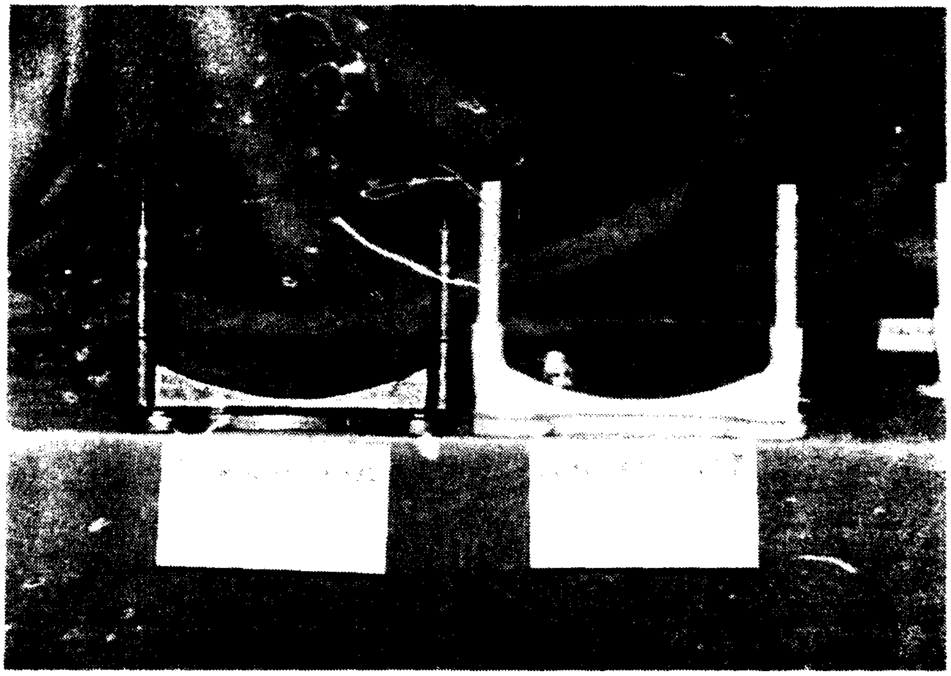


Fig. 60 – Close up view of Al-Br bracket and Isoplast molded bracket (note additional shoulder material and coarse threads on Isoplast bracket)

Processing parameters to mold the TR-317 standard brackets are summarized in Table 7.

Table 7 – Injection Molding Process Parameters

Processing Parameters	Ultem 2300	Isoplast 101	Vectra A-515
Barrel Temperature	343-382°C	232-260°C	271-188°C
Mold Set Temperature	104°C	79°C	82°C
Pressures			
Boost	1,500 psi	1,250 psi	1,100 psi
Hold	1,200 psi	1,200 psi	1,000 psi
Cycle Time	68.5 sec	64 sec	67 sec

TR-317 Standard Bracket Design Modified For Impact Resistance

First-article impact tests were run on the molded TR-317 standard non-metallic brackets. Results from these impact tests revealed a possible weakness in the bracket design. (See the ITM test section.) The non-metallic TR-317 standard bracket design was modified for increased impact resistance by strengthening the flange area of the bracket. This strengthening was achieved by adding material to the area where the two flanges are attached. Figure 61 shows a part drawing of the impact modified non-metallic TR-317 standard bracket. These design changes were incorporated into the TR-317 injection-mold. Figure 62 shows the impact modified mold design drawing. Impact modified brackets were molded using Isoplast and Vectra materials for use in the explosive shock test. Figure 63 and Fig. 64 provide comparison views of the unmodified and impact modified TR-317 standard brackets.

FIRST-ARTICLE TESTING

First-article testing of the prototype non-metallic brackets consists of four types of tests: Impact Test Machine (ITM) testing, explosive shock testing, creep testing, and accelerated life testing (ALT). To date, ITM testing has been performed on the unmodified non-metallic and Al-Br TR-317 standard brackets and explosive shock testing has been performed on the impact modified non-metallic and Al-Br TR-317 standard brackets. The results of these tests are discussed below. Long-term creep tests and ALT have not started yet. ITM tests showed that three

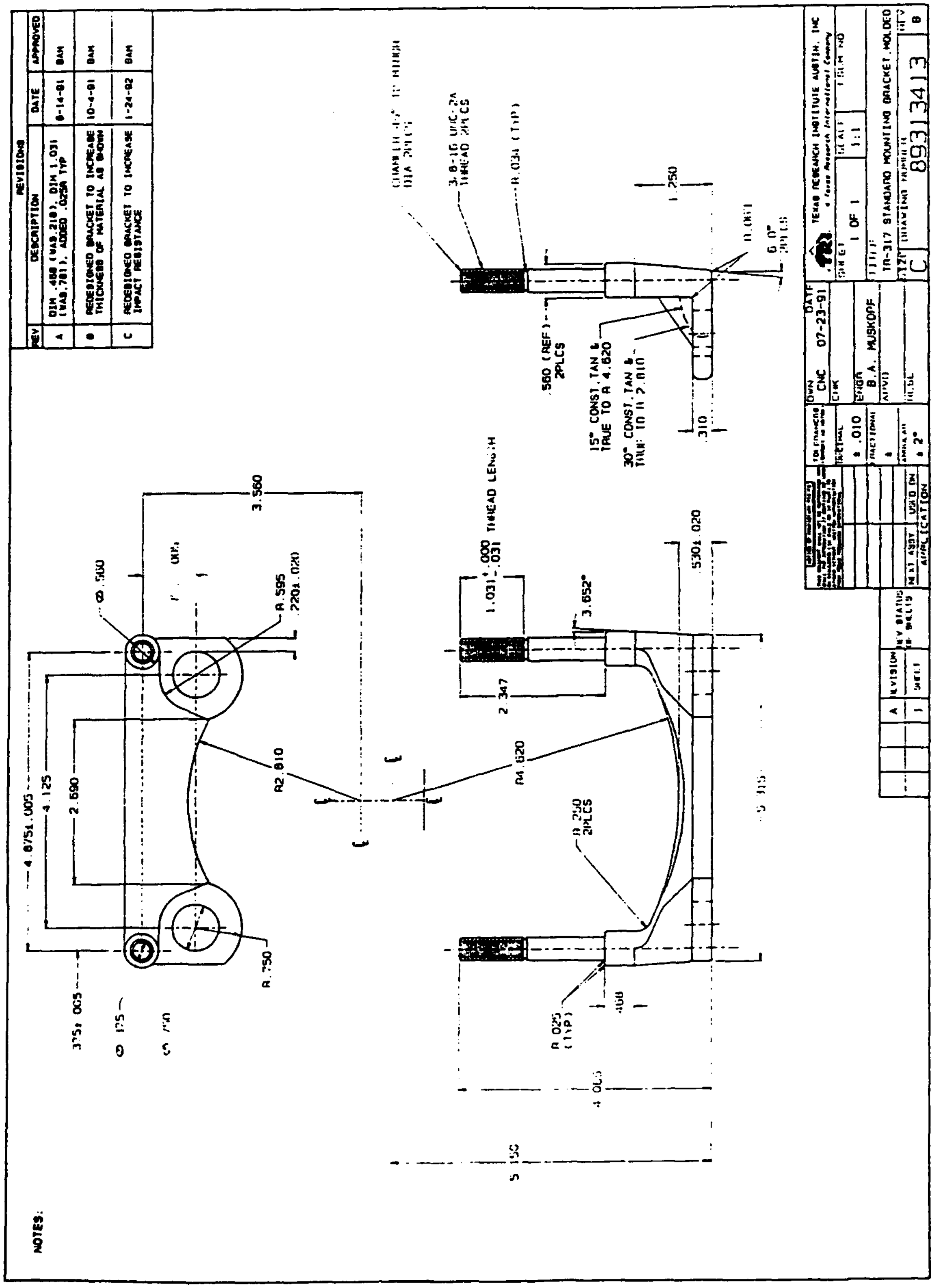


Fig. 61 – Impact modified TR-317 standard bracket design drawing

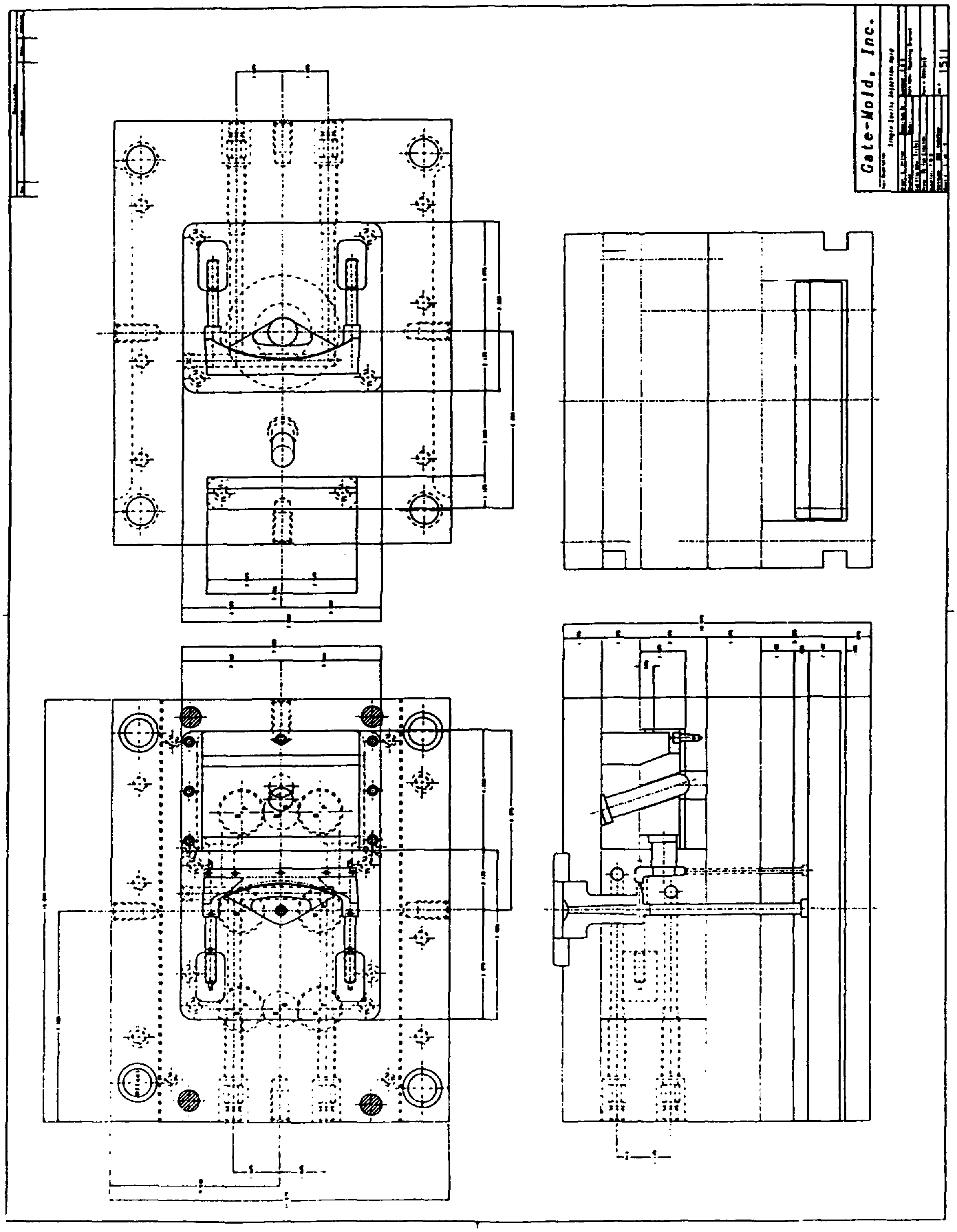


Fig. 62 – Impact modified TR-317 standard bracket mold design drawing

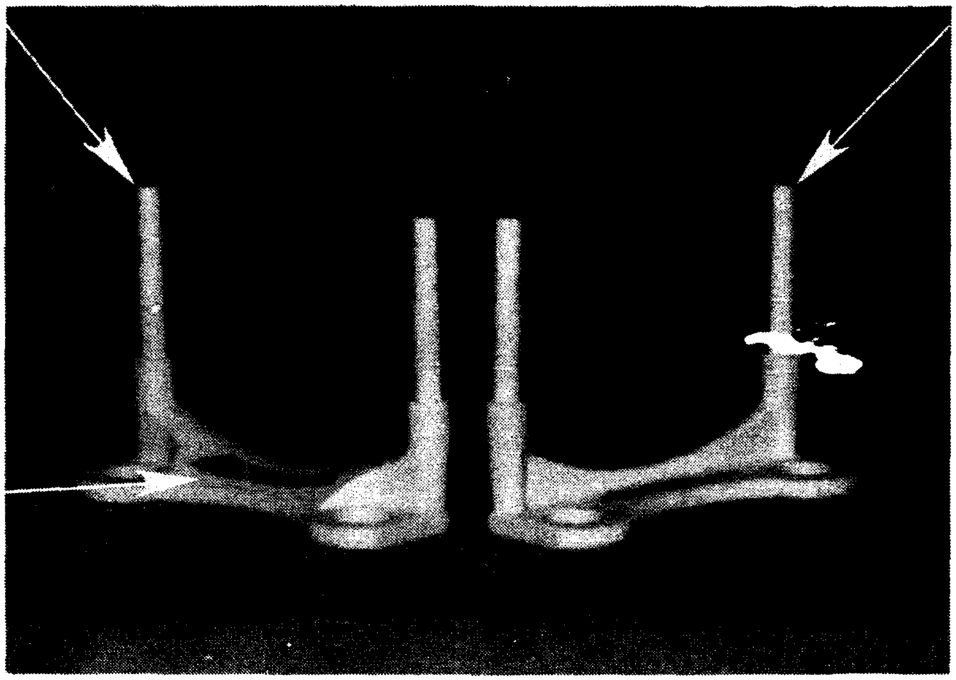


Fig. 63 – *Side view of unmodified and impact modified TR-317 standard brackets*

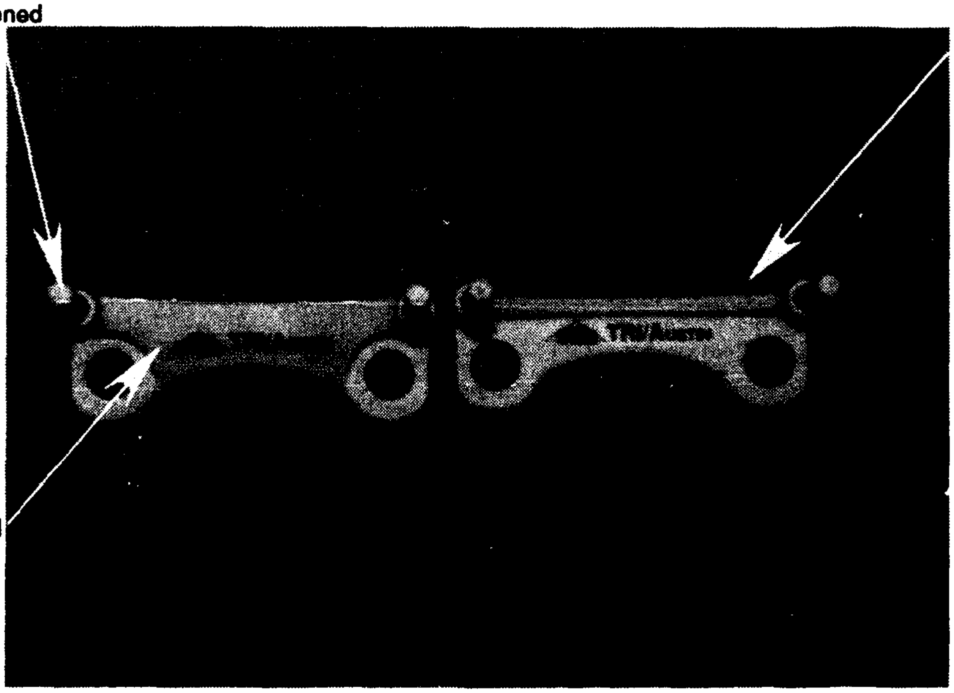


Fig. 64 – Top view of unmodified and impact modified TR-317 standard brackets

resin-filler material systems, Isoplast 40% long glass, Isoplast 60% long glass, and Vectra with 15% mineral filler, were the most impact resistant. The explosive shock test confirmed the high impact strenth of each of these materials since all survived the test with little or no visible damage.

Impact Test Machine (ITM) Testing

Figure 65 is a schematic drawing of the impact testing machine developed to determine gross resistance to impact forces and to provide estimates of damping factors as inputs for the finite element modeling. The ITM uses a 22.7 kg (50 lbm) mass suspended on a 1.7 m (5.54 ft), 9.6 kg (21.2 lbm), swing arm to achieve impact velocities ranging from 2.3 m/s (7.5 ft/s) to 5.6 m/s (18.5 ft/s). This range of impact velocities is sufficient to damage the current Al-Br TR-317 bracket, with damage initiation occurring at 3.6 m/s (11.7 ft/s), and severe damage accumulation at 3.8 m/s (12.5 ft/s). The ITM is patterned after the MIL-901C test machine with adaptation for the transducer application. The transducer and bracket are installed in a floor mount fixture which is, in turn, bolted to the foundation. The hammer is allowed to strike the face of the transducer headmass from a predetermined height through the use of a height adjustment bar. The ITM data acquisition system consists of two shock accelerometers, two signal couplers, and a high-speed A/D board installed in a 386 computer. The Labtech Notebook data acquisition software package is used to collect accelerometer data at high speed and perform an FFT on the collected data. The accelerometers are installed on the back of the hammer mass and on the top bracket.

Figure 66 is a photograph of the test machine in operation, and Fig. 67 is a photograph of the pendulum arm just prior to impact. Figures 68 and 69 show the shock signature of an ITM run with the Al-Br bracket at an impact velocity of 3 m/s (9.9 ft/s). Peak hammer accelerations from the bracket saw approximately 340 g's. Figures 70 and 71 show an example of the Vectra A-515 bracket material impact signatures at position 6 which attains an impact velocity of 3.6 m/s (11.7 ft/s).

It is tempting to compare the explosive shock test conditions to those of the ITM. Strictly speaking, this comparison can only be approximate because an actual explosive shock test includes the dual effects of the pressure shock wave and the inertial motion caused by the expanding gas bubble. The ITM can only emulate the inertial effect which is a major function in an explosive shock test. As a bench mark the Al-Br brackets of the current design are heavily damaged at an impact velocity of roughly 3.9 m/s (12.7 ft/s), but these brackets survive explosive shock testing essentially unscathed. The inertial motion vertical kickoff velocity of the barge at the Hunter's Point Facility was 3.3 m/s (10.7 ft/s), while the equivalent measure for the ITM impact velocity ranges form 2.3 m/s (7.5 ft/s) to 5.6 m/s (18.5 ft/s).

The ITM has proven to be an excellent initial screening device to determine the most impact-resistant materials for explosive shock testing. Cumulative impact damage assessment tests were performed on Al-Br and unmodified non-metallic

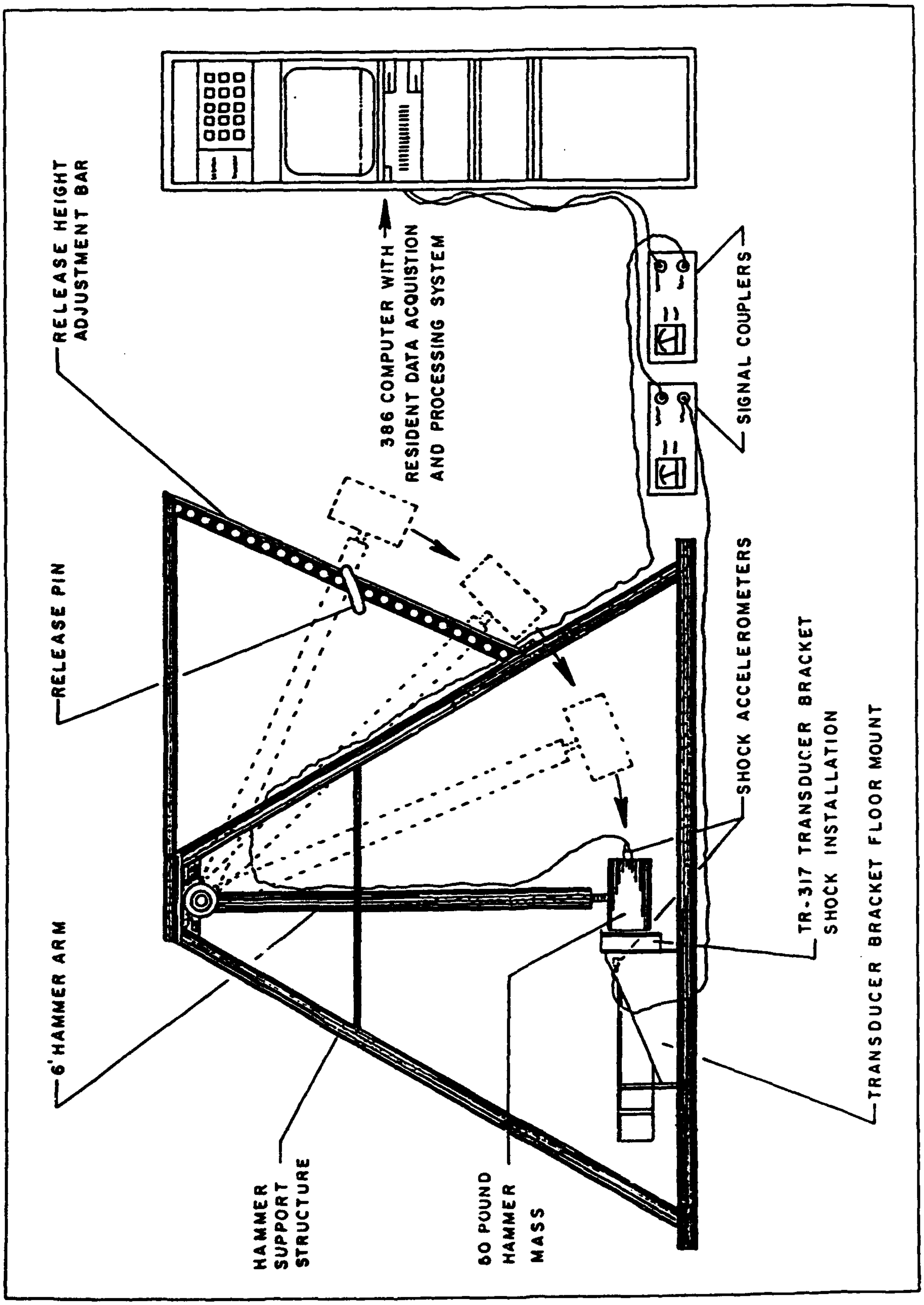


Fig. 65 – Illustration of impact testing machine and data acquisition system

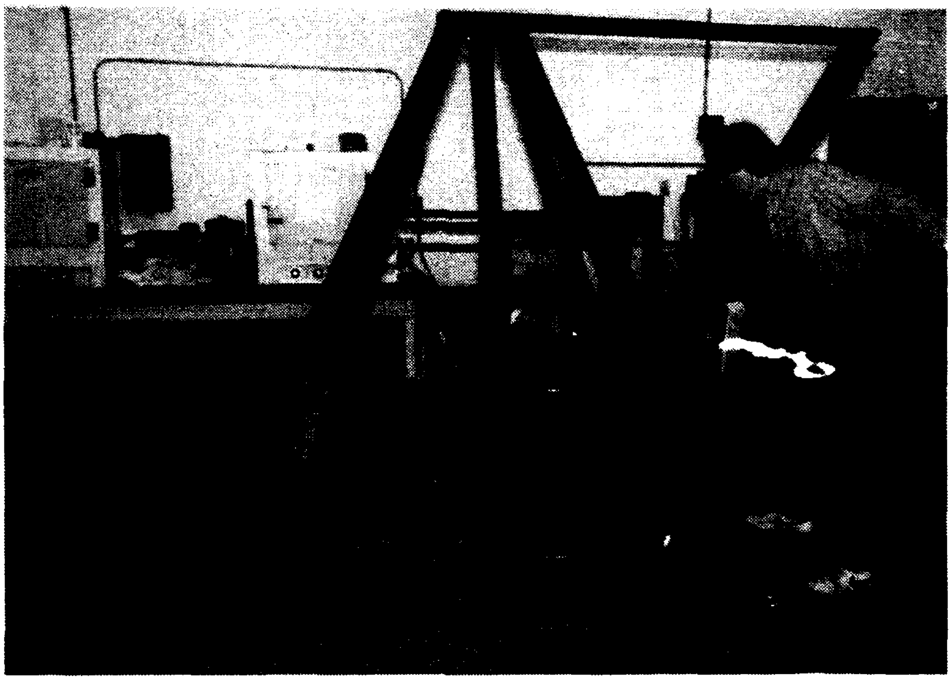


Fig. 66 – ITM in operation

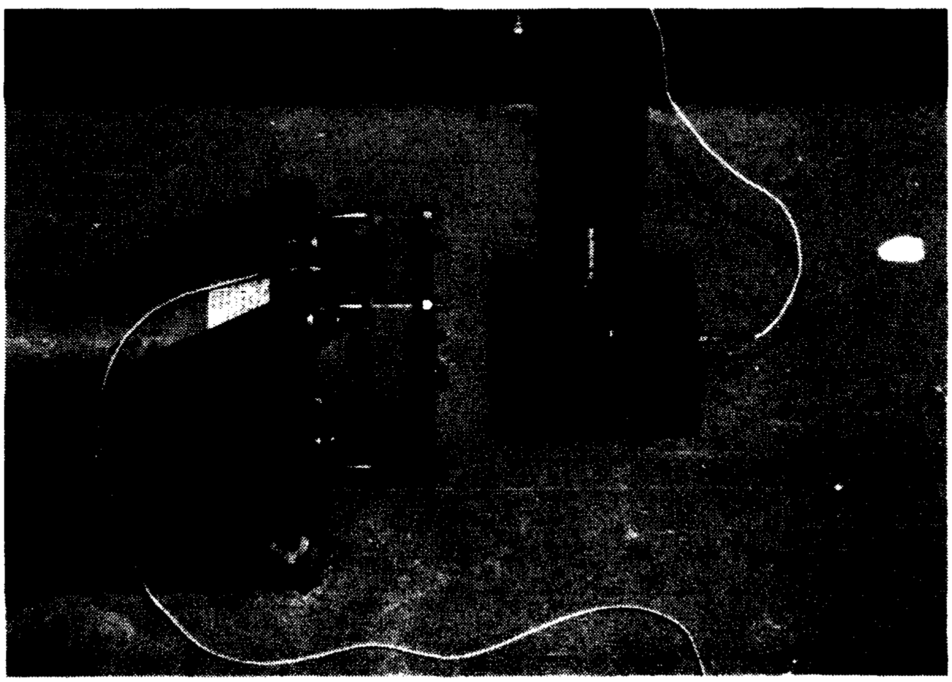


Fig. 67 – ITM hammer just prior to impact.
Note accelerometer leads on hammer of bracket.

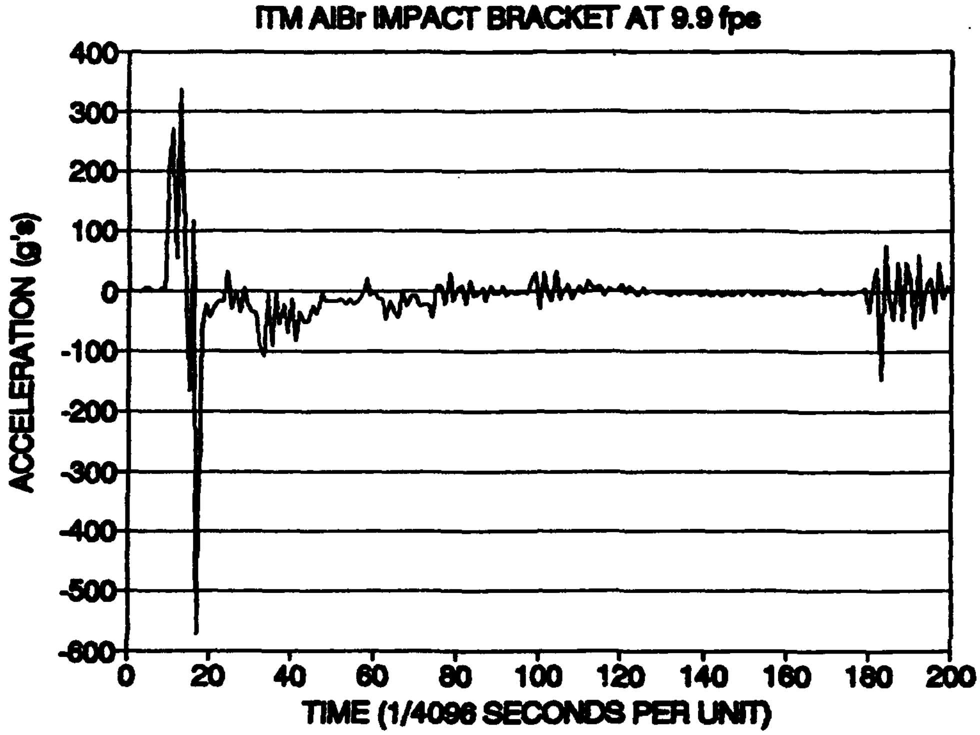


Fig. 68 – Shock signature for Al-Br bracket at impact velocity of 9.9 ft/s

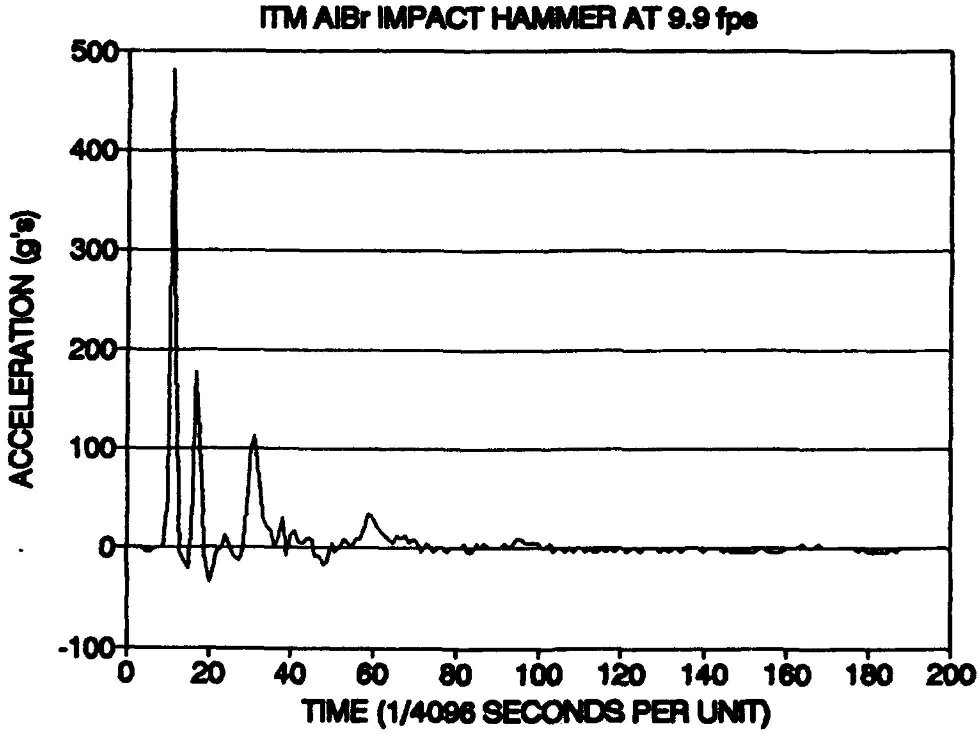


Fig. 69 – Shock signature for the hammer in the Al-Br bracket test at 9.9 ft/s

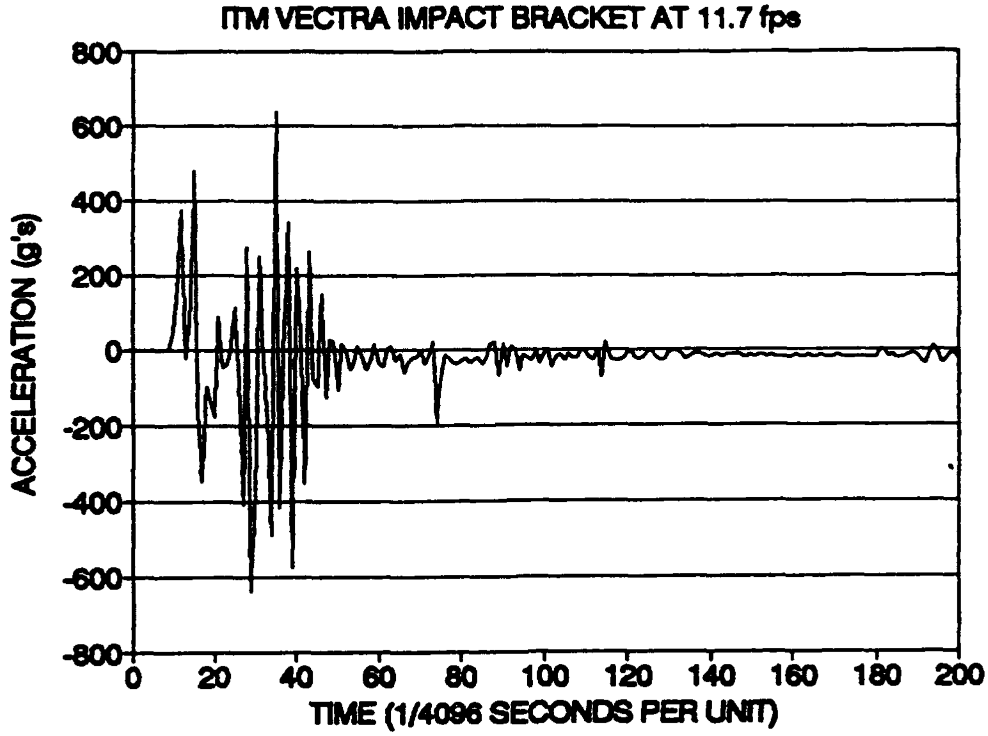


Fig. 70 – Shock signature for Vectra A-515 bracket at impact velocity of 11.7 ft/s

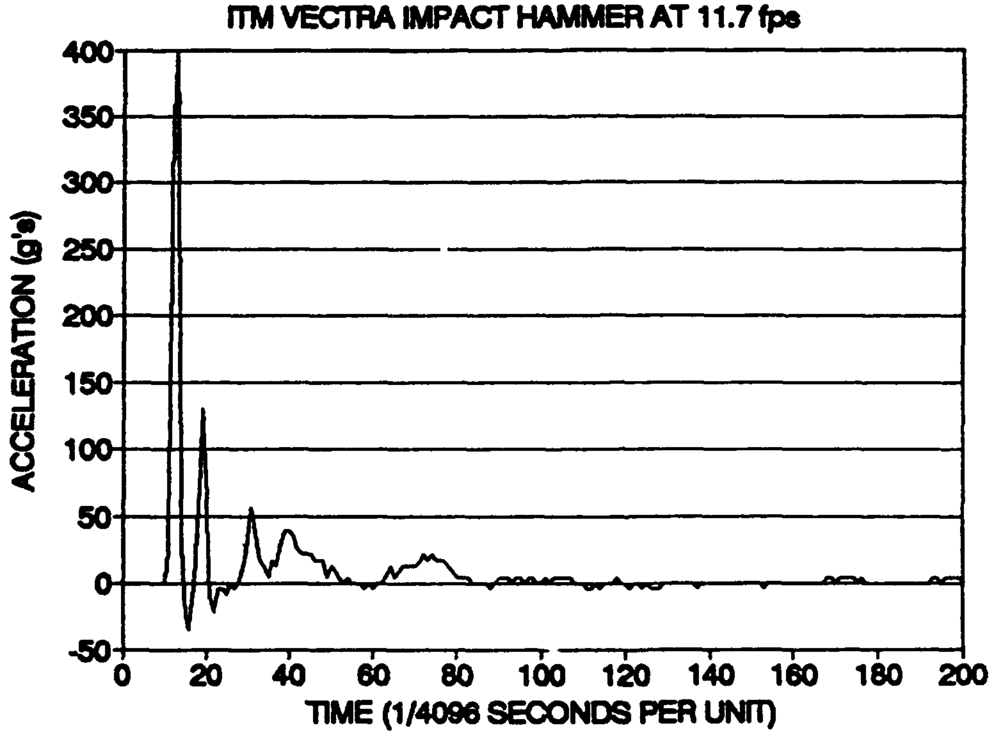


Fig. 71 – Shock signature for the hammer in the Vectra A-515 bracket test at 11.7 ft/s

TR-317 standard brackets. The cumulative impact tests are performed by releasing the ITM hammer from increasingly higher height positions until failure of the bracket or the maximum height position on the ITM is reached. Table 8 presents the results of the cumulative impact tests on the TR-317 standard brackets with the impact occurring on the transducer headmass. This impact orientation represents the explosive shock experienced by the brackets in an actual submarine sonar dome installation. Table 9 shows the same results with the impact occurring on the tail assembly of the transducer. This impact orientation represents the explosive shock experienced by the brackets during a MIL-S-901-D explosive shock test. The results from these tests show that the Isoplast and Vectra materials are the most impact resistant and were chosen for explosive shock testing. Note that the MIL-S-901-D explosive shock test orientation (impact on transducer tail assembly) is a more severe impact test of the TR-317 brackets than installation in a submarine sonar dome. Figures 72 and 73 show cumulative impact damage sustained by the Isoplast material with 40% glass. Figures 74 and 75 show impact damage sustained by the 60% glass Isoplast. Figures 76 and 77 document the impact damage sustained by the Vectra material. Figure 78 shows a comparison of the cumulative impact damage on the Al-Br brackets with an untested bracket. Note the bending of the bracket posts on the damaged bracket.

The ITM was developed to compare composite bracket shock resistance with Al-Br bracket designs, to provide fully installed damping ratio estimates for finite element model inputs, and to act as a platform for design verification and improvement. A number of time domain data runs for the nonmetallic and Al-Br brackets were obtained. Figures 79 to 82 are power spectra of both the Al-Br and the Vectra A-515 bracket shock signatures at 3.6 m/s (11.7 ft/s) impact velocity. Note that, in general, the resonant frequencies for shock excitation in the Al-Br bracket are lower than those for the Vectra A-515, an expected result considering the 5:1 mass difference between the Al-Br and the Vectra A-515.

Table 8 – ITM cumulative impact damage assessment for unmodified TR-317 standard bracket installation (impact on transducer head mass)

Material	Position Number						
	2	4	6	8	10	12	14
Al-Br	N	N	S	S	M	V	V
Celstran 60%	N	N	S	F	—	—	—
Isoplast 40%	N	N	S	M	M	M	M
Isoplast 60%	N	S	S	M	M	M	M
Ultem 2300	N	F	—	—	—	—	—
Vectra A-515	N	S	S	M	V	V	V
Verton 50%	N	N	S	M	V	F	—
Verton 60%	N	S	S	M	V	V	F

N = No visible damage
S = Slight damage - surface cracking
M = Medium damage - subsurface cracking
V = Severe damage - deep subsurface cracking
F = Failure

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Table 9 – ITM cumulative impact damage assessment for unmodified TR-317 standard bracket installation (impact on transducer tail mass)

Material	Position Number						
	2	4	6	8	10	12	14
AL-BR	N	S	M	M	M	V	V
Celstran 60% glass	N	F	—	—	—	—	—
Isoplast 40% glass	N	S	S	F	—	—	—
Isoplast 60% glass	N	N	S	F	—	—	—
Ultem 2300	F	—	—	—	—	—	—
Vectra A-515	S	F	—	—	—	—	—
Verton 50% glass	M	F	—	—	—	—	—
Verton 60% glass	S	F	—	—	—	—	—

N = No visible damage
S = Slight damage-surface cracking
M = Medium damage-subsurface cracking
V = Severe damage - deep subsurface cracking
F = Failure

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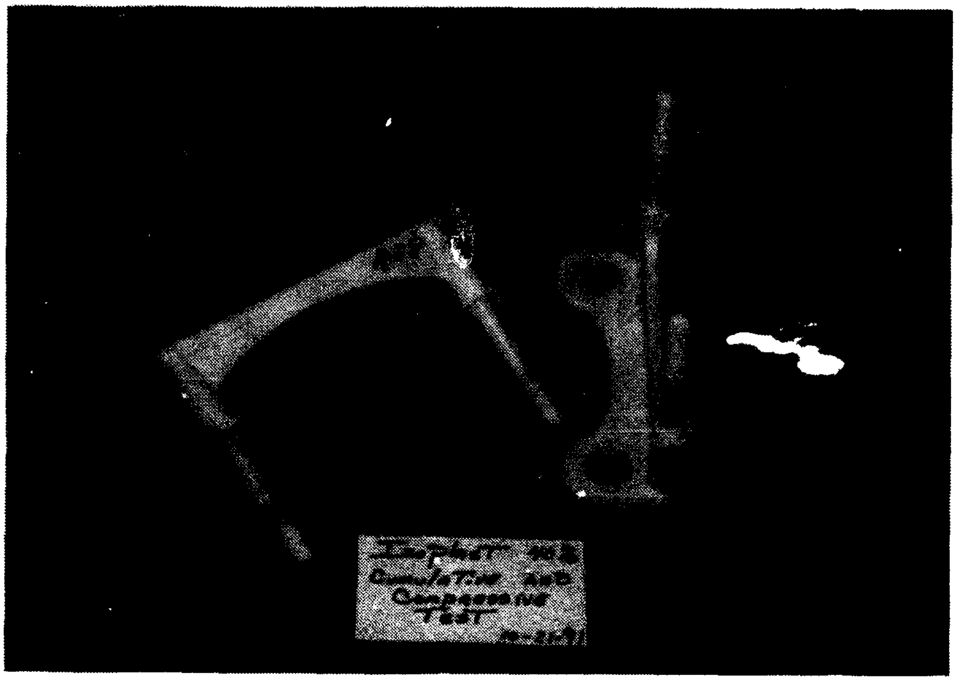


Fig. 72 – Cumulative impact damage on Isoplast 40% glass unmodified TR-317 brackets (impact on transducer headmass)

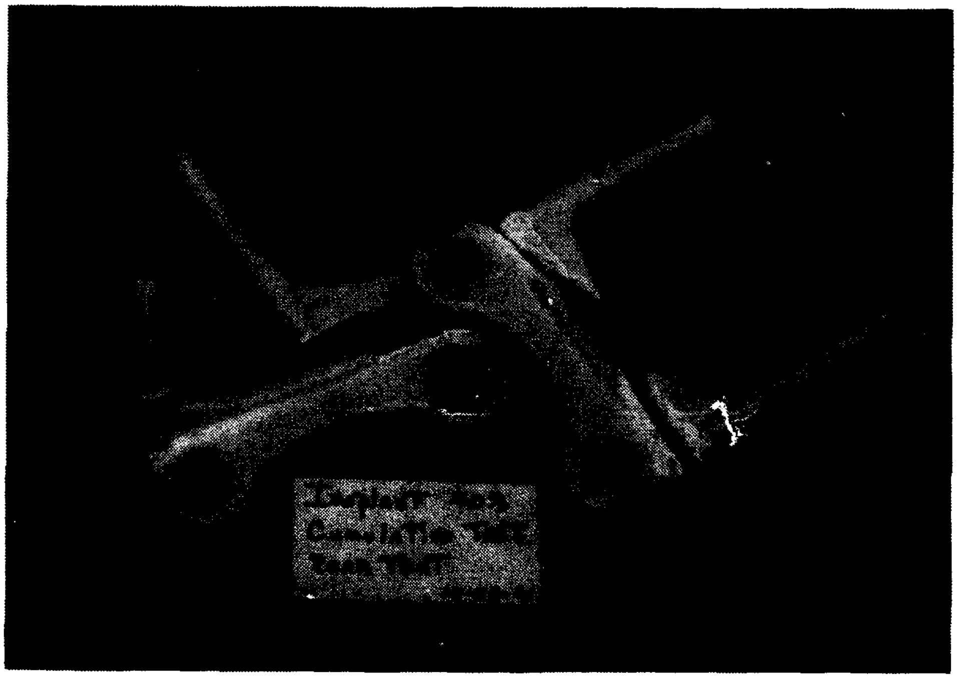


Fig. 73 – Cumulative impact damage on Isoplast 40% glass unmodified TR-317 brackets (impact on transducer tail assembly)

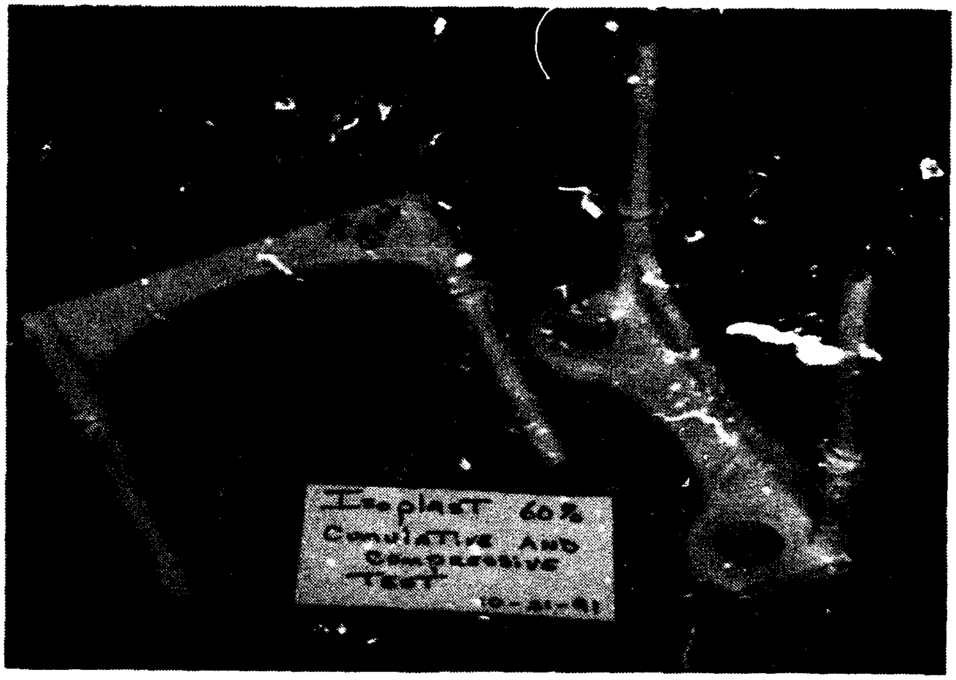


Fig. 74 – Cumulative impact damage on Isoplast 60% glass unmodified TR-317 brackets (impact on transducer headmass)

Fig. 75 – Cumulative impact damage on Isoplast 60% glass unmodified TR-317 brackets (impact on transducer tail assembly)

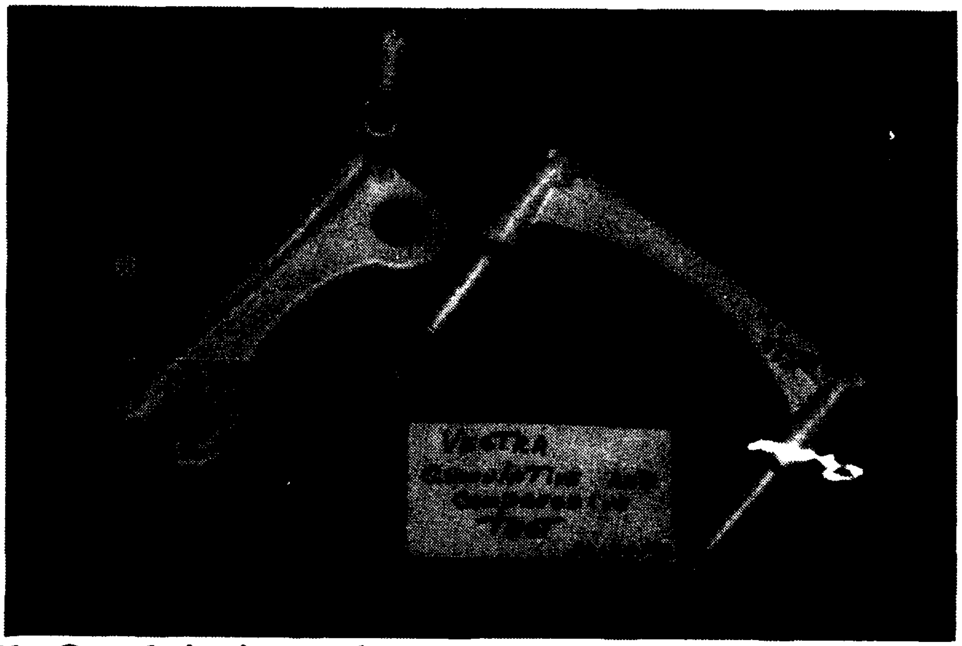


Fig. 76 – Cumulative impact damage on Vectra 40% glass unmodified TR-317 brackets (impact on transducer headmass)

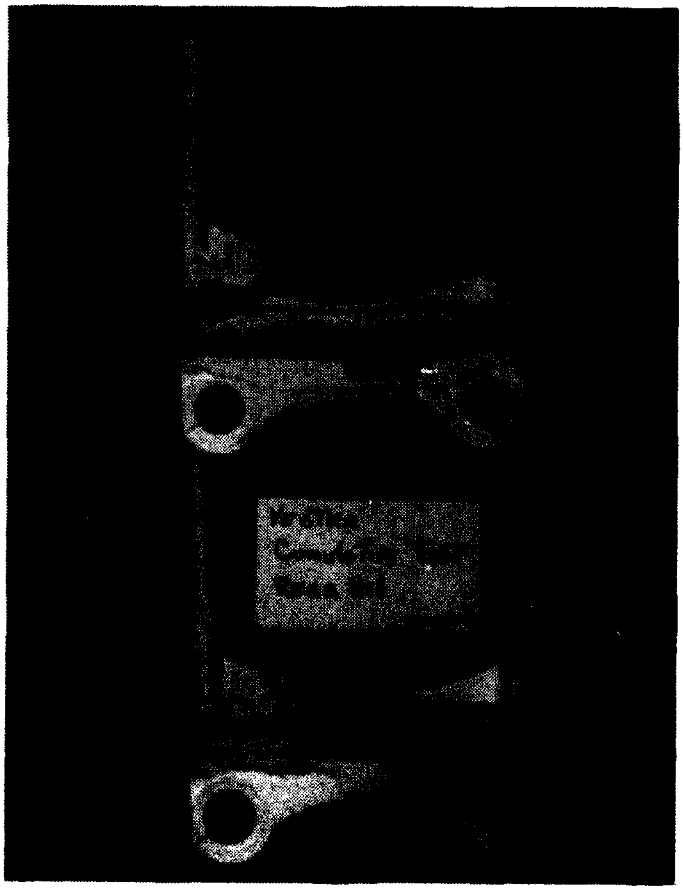


Fig. 77 – Cumulative impact damage on Vectra 40% glass unmodified TR-317 brackets (impact on transducer tail assembly)

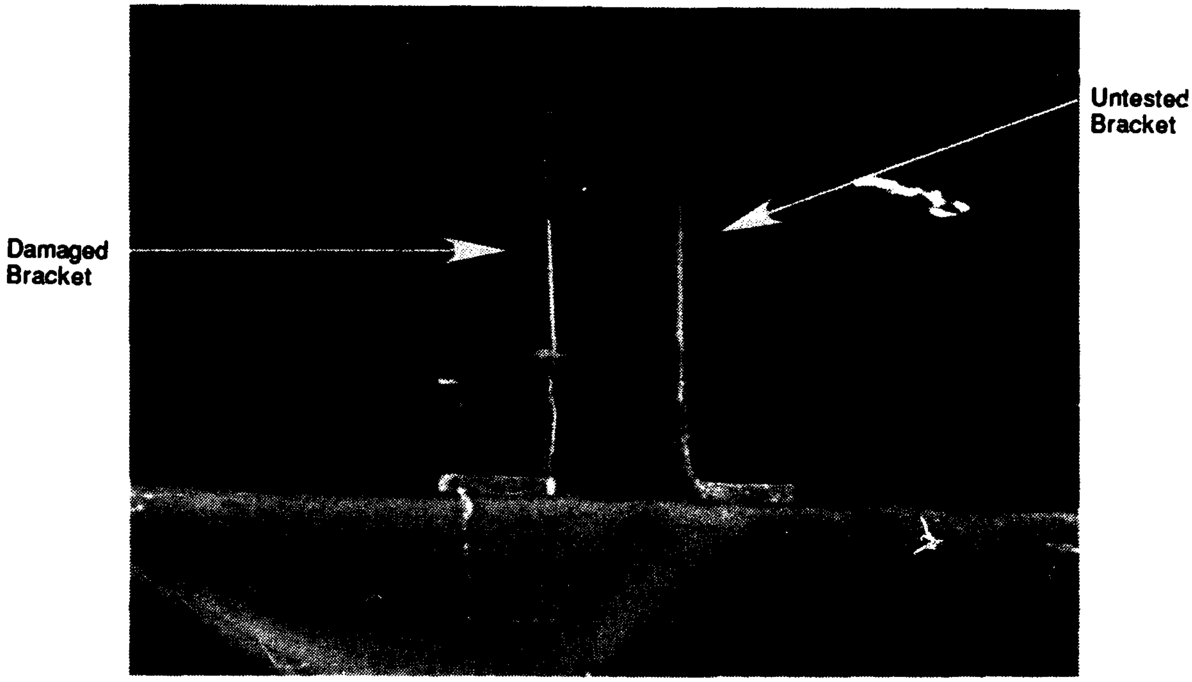


Fig. 78 – Comparison of cumulative impact damage on Al-Br TR-317 bracket to untested bracket

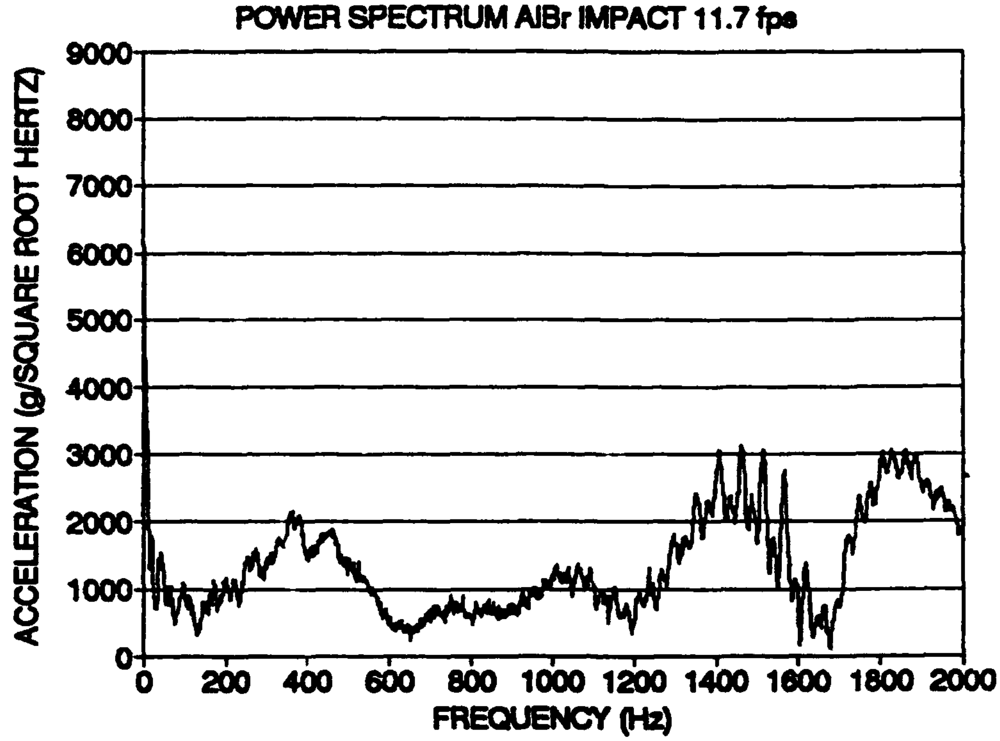


Fig. 79 – Power spectrum to 2000 Hz of Al-Br bracket at 11.7 ft/s impact velocity

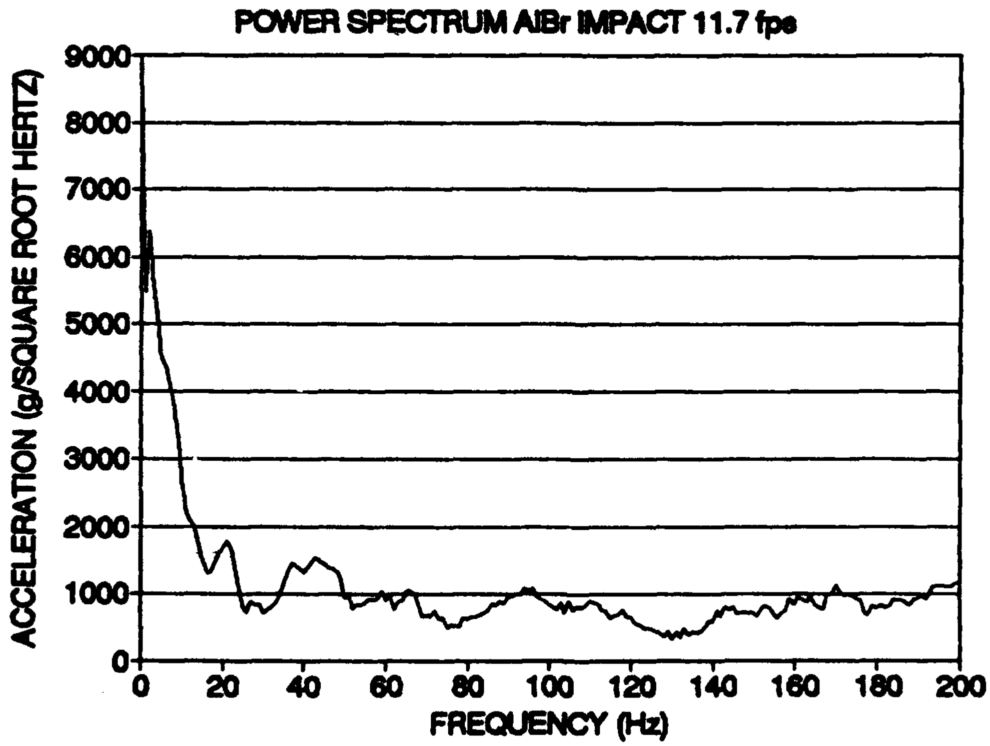


Fig. 80 – Power spectrum to 200 Hz of Al-Br bracket at 11.7 ft/s impact velocity

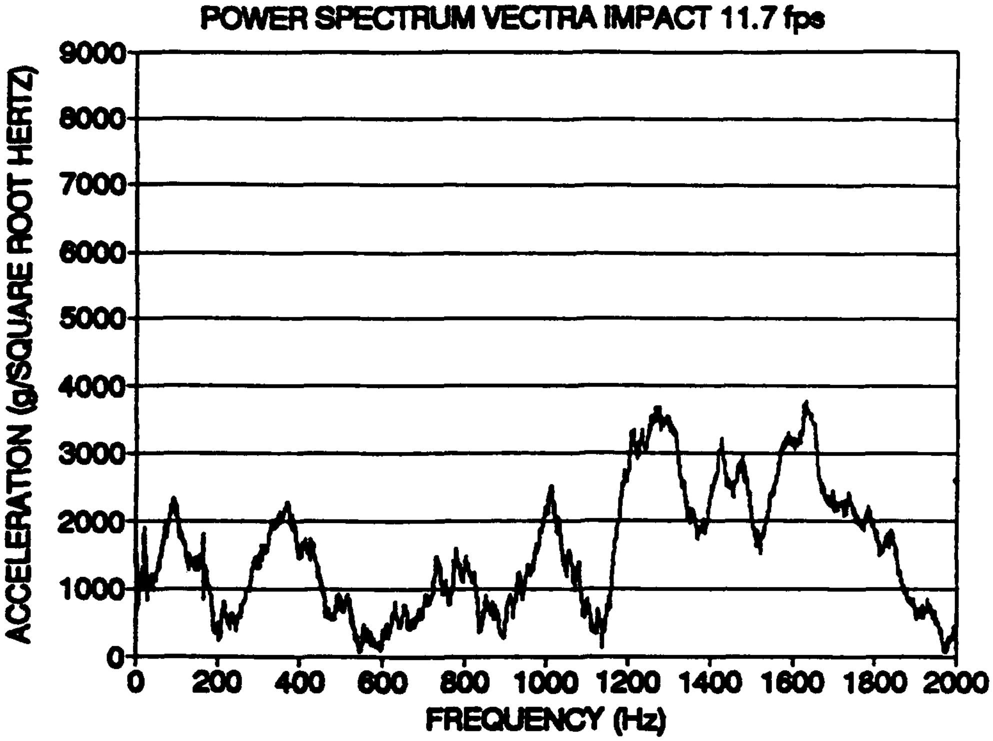


Fig. 81 – Power spectrum to 2000 Hz of Vectra A-515 bracket at 11.7 ft/s impact velocity

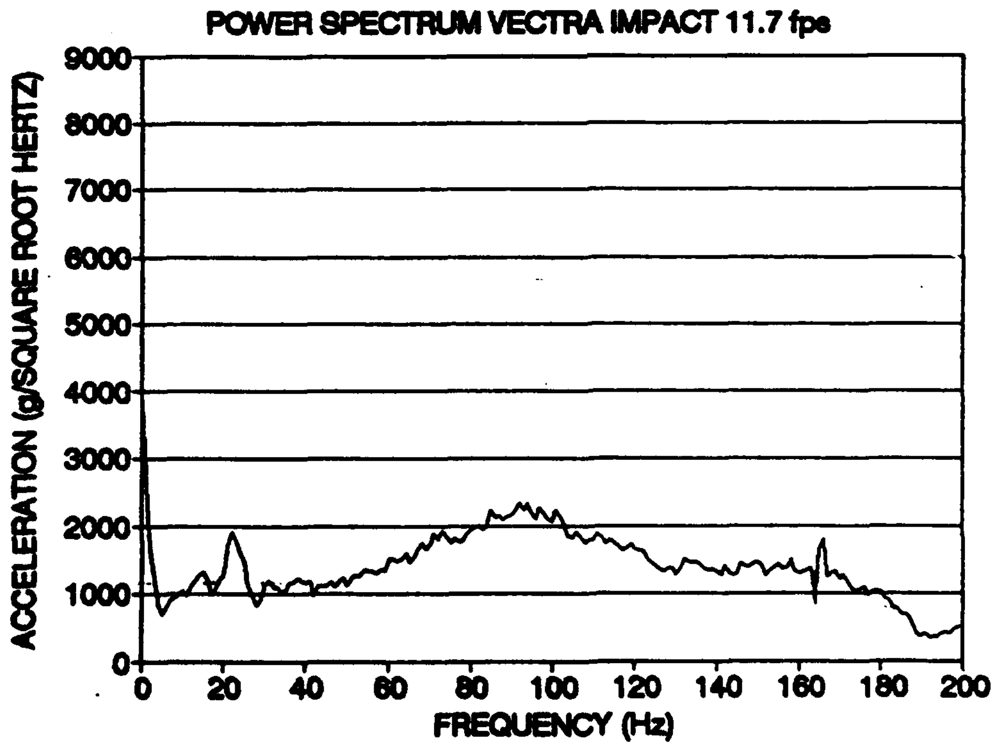


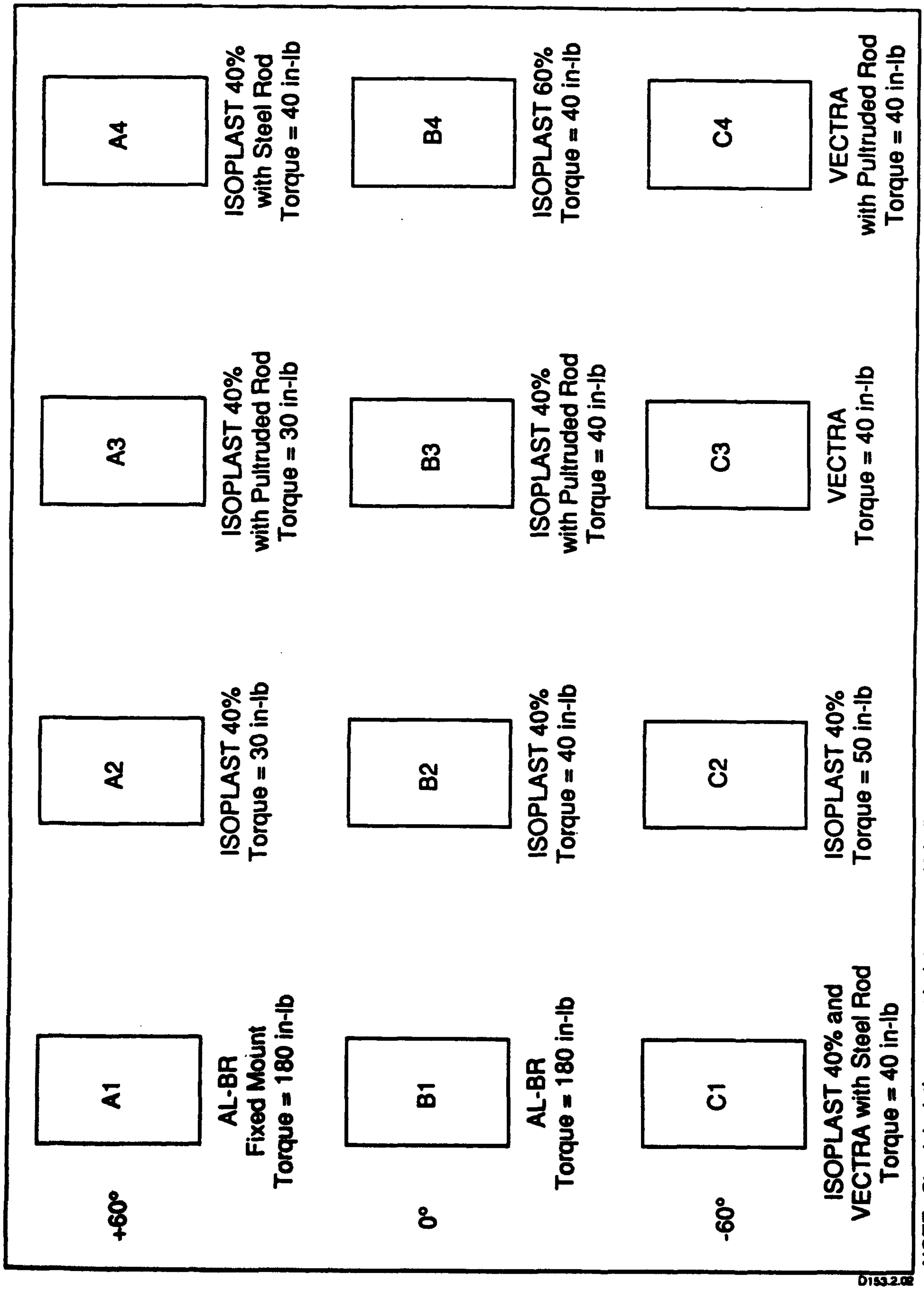
Fig. 82 – Power spectrum to 200 Hz of Vectra A-515 bracket at 11.7 ft/s impact velocity

Explosive Shock Test

The molded non-metallic standard TR-317 brackets modified for impact resistance were subjected to underwater explosive shock testing per MIL-S-901-D at the HI-Test explosive shock test facility. Figure 83 presents the explosive shock test matrix used during this test. Three resin-filler material systems were chosen for the test based on prior laboratory ITM impact testing; Isoplast with 40% long glass fibers, Isoplast with 60% long glass fibers, and Vectra with 15% mineral filler. In addition, some of the brackets were reinforced with pultruded glass-filled PEEK rod and with steel rod. All of the non-metallic brackets were installed on the test fixture using standard rubber shock isolation mounts torqued to 4.5 N-m (40 in-lbs). A pair of Al-Br brackets was installed with rubber shock isolation mounts and another pair was installed with a fixed mount, both torqued to 4.5 N-m (40 in-lbs). TR-317 transducers were installed on the brackets and the nuts were torqued to the specified values provided in the test matrix. The non-metallic brackets used commercially available Isoplast nuts with 30% glass fibers and the Br brackets used Monel nuts. Figure 84 shows the TR-317 test fixture mounted to the bottom of the barge. Figure 85 presents a close-up view of the TR-317 bracket installation on the test barge.

Figures 86 and 87 illustrate the explosive shock test progression for shot #4 at the HI-Test explosive shock test facility. After each shot the barge was lifted out of the water and a visual inspection was made of the test fixture. All of the non-metallic brackets survived the test series. Initial visual examination after shot #4 showed no visible surface damage to any of the non-metallic brackets. A more extensive visual examination was made at TRI/Austin. Figure 88 shows the brackets after testing, laid out in the test matrix configuration. The only visible damage to the non-metallic brackets was a surface crack on the Vectra brackets located on the molding knit line formed at the holes in the bracket flange. See Fig. 89. A portion of the rubber shock isolation grommet was pinched in the crack indicating that the crack was opened up allowing the rubber to be pushed into the crack and then closed rapidly trapping the rubber material. These surface cracks appear to be present only in the hard liquid crystal polymer skin that forms during the molding of the Vectra material. Since the cracks formed only at the knit line it seems likely the cracking is due to a molding problem with the Vectra material. The presence of these surface cracks are minor in nature and did not result in a part failure.

Results from the explosive shock test indicate that the modified non-metallic standard TR-317 brackets have passed the MIL-S-901-D explosive shock test. Furthermore, the test results indicate that reinforcement of the TR-317 brackets with pultruded or steel rod will not be necessary.



NOTE: Shock isolation mount bolt torque = 40 in-lb

Fig. 83 – Explosive shock test matrix

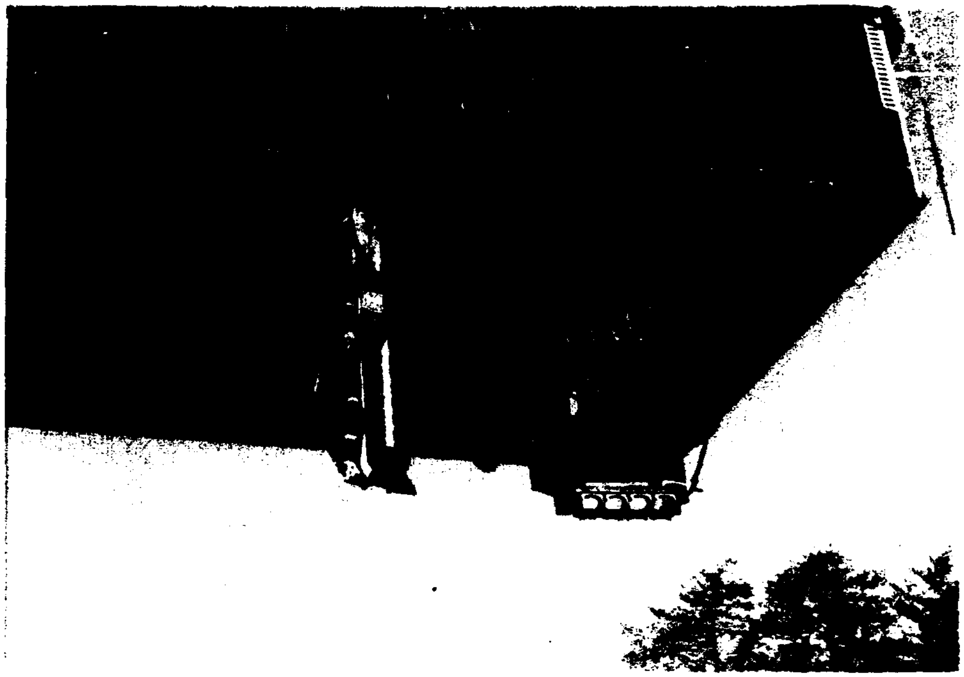


Fig. 84 – TR-317 bracket test fixture mounted to bottom of test barge

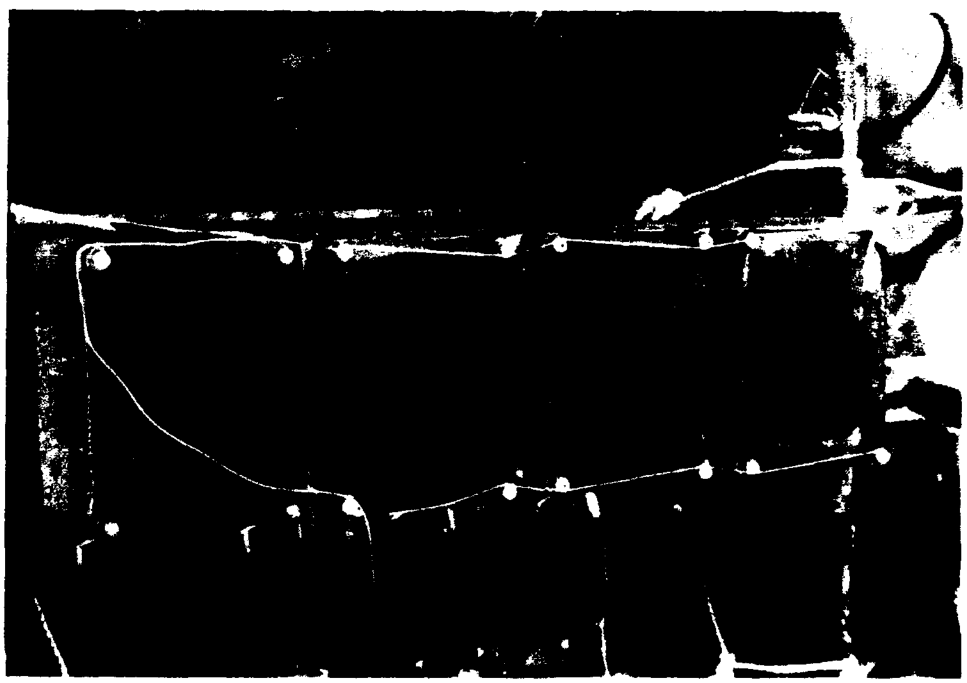


Fig. 85 – Close-up view of TR-317 bracket installation on test barge

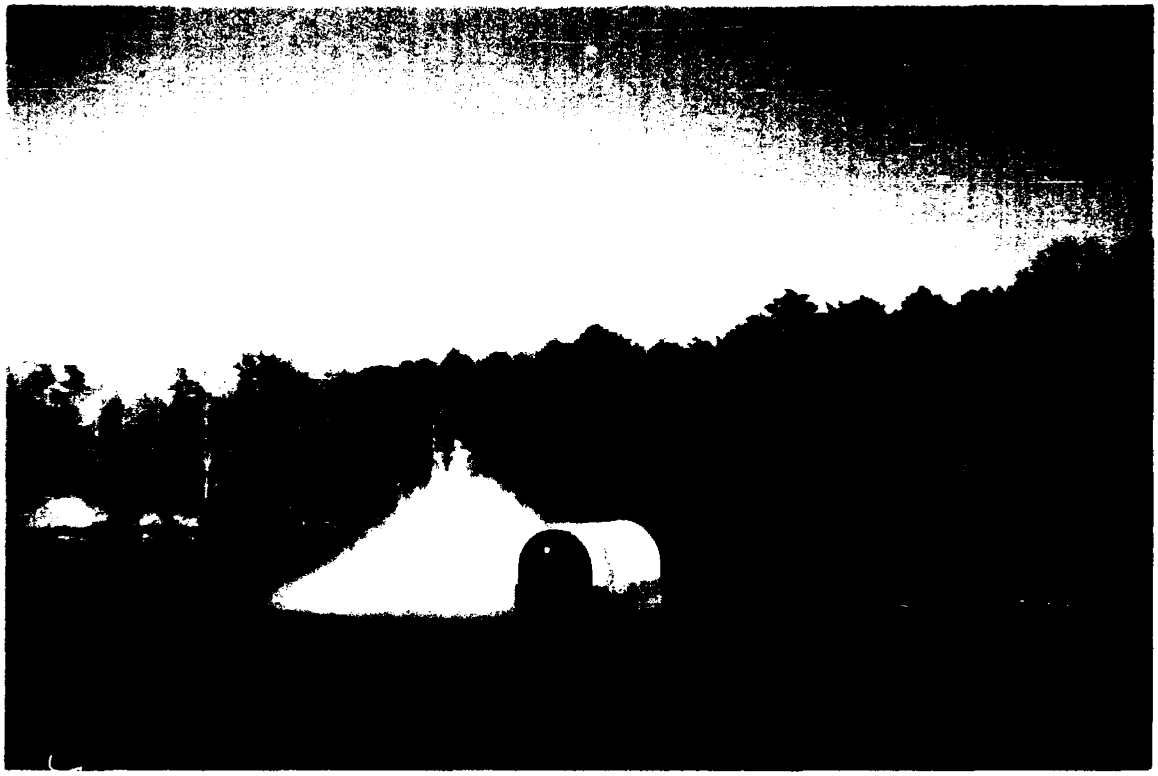


Fig. 86 – Start of explosive shock test shot #4 at the HI-Test shock test facility

Fig. 87 – End of explosive shock test shot #4 at the HI-Test shock test facility

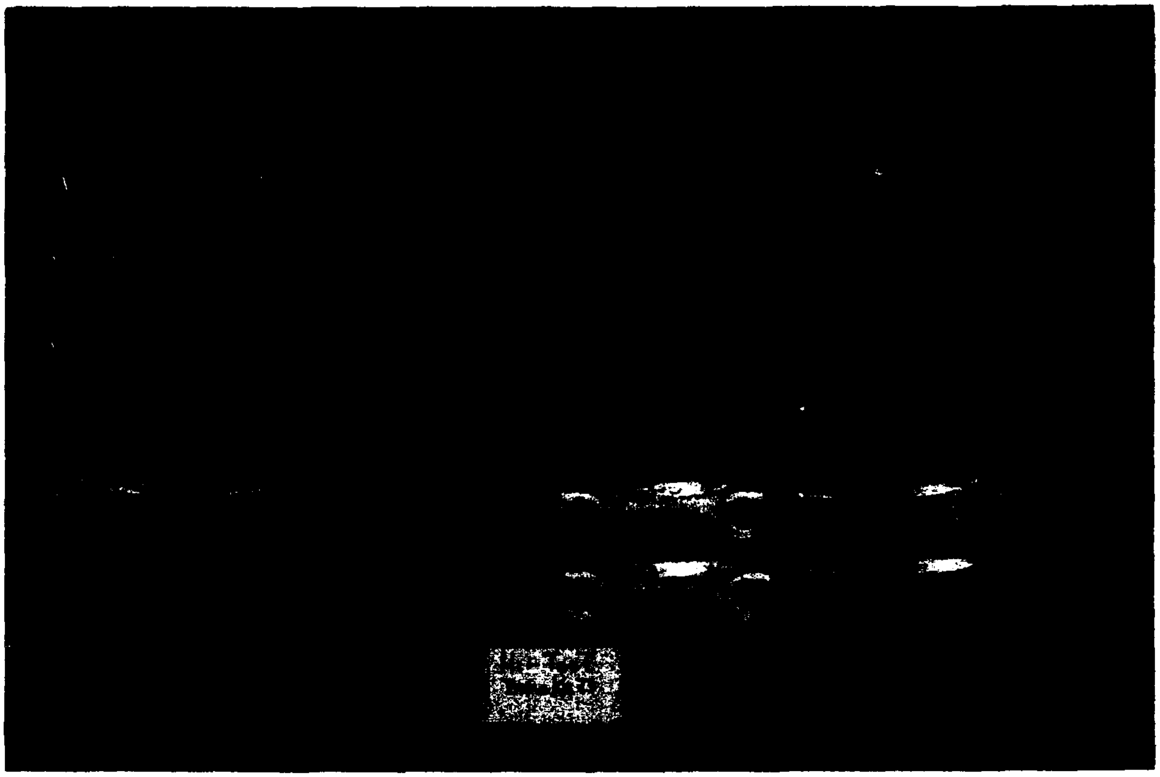


Fig. 88 – TR-317 brackets after explosive shock testing at the HI-Test explosive shock test facility

Surface crack located at mold knit line around hole

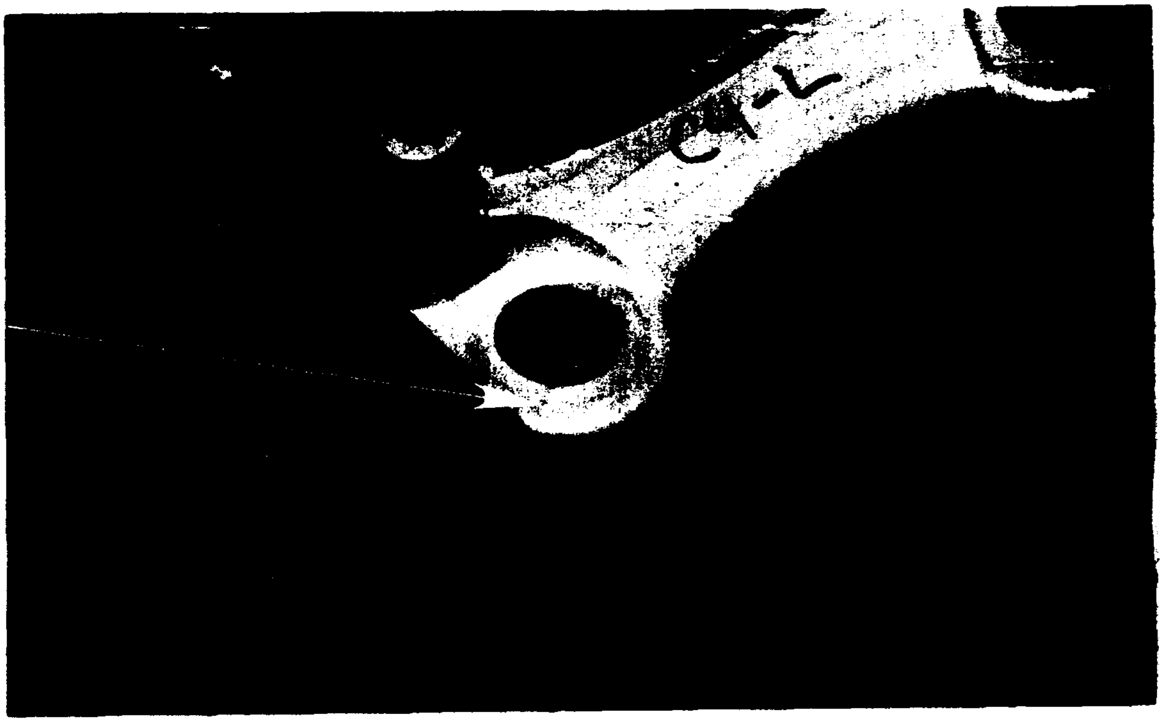


Fig. 89 – Example surface crack found on Vectra brackets after explosive shock testing

SUMMARY

Initial results indicate that all the objectives of the non-metallic bracket tasks will be met. The non-metallic sonar transducer mounting bracket engineering improvement program began in January 1991 and significant progress has been made toward the program goals as summarized below:

- Seven commercially available candidate materials were selected for evaluation by performing a material selection analysis.
- Tensile testing of the candidate materials has been completed for the four test conditions: dry/room ambient temperature, dry-hot, wet-room ambient temperature, and wet-hot.
- Izod impact testing, ultimate toughness calculations, moisture absorption, and TMA and DMA material testing of the candidate materials has been completed.
- Finite element models have been constructed of the unmodified TR-317 standard bracket to verify the ability of the non-metallic materials to withstand operational and explosive shock loads. All static weight load cases for the TR-317 bracket have been completed. Preliminary explosive shock load cases have been executed for the unmodified TR-317 bracket. Finite element analyses indicate that all of the candidate non-metallic materials molded as TR-317 brackets possess the necessary strength to support static weight loads.
- A prototype injection-mold has been designed and built to produce molded non-metallic TR-317 standard brackets for first article testing. Approximately 250 test brackets have been molded to date.
- An Impact Testing Machine has been designed and constructed to apply impact loads to a complete TR-317 transducer and bracket installation. This machine is capable of collecting accelerometer data to determine damping properties for the finite element modeling and as a pass/fail test for candidate non-metallic materials. Initial results from the impact testing indicated that the most impact resistant non-metallic materials would survive the Hi-Test explosive shock test.
- Pultruded composite rod has been investigated and proven to be a viable molded bracket reinforcement method.
- Impact modified TR-317 standard brackets molded from Isoplast and Vectra resin materials survived the MIL-S-901-D explosive shock test without damage.

Results from preliminary tests on the molded non-metallic TR-317 standard brackets indicate that the non-metallic brackets are a viable low cost replacement for the current Al-Br brackets. The Al-Br brackets cost approximately $19 per standard bracket and $30 per special bracket. Excluding development costs, the non-metallic material bracket cost is approximately $10 per molded TR-317 standard bracket. This cost is based on low volume production (100 parts per molding run). Low volume material costs are approximately $600 per 100 parts, and molding and final machining costs are approximately $400 per 100 parts. High volume production runs should reduce the TR-317 standard bracket cost to well below $10 per part, perhaps as low as $6 or $7.

The non-metallic brackets will also provide a substantial weight savings over the current Al-Br brackets. The TR-317 standard Al-Br bracket weighs 450 g (1 lbm). The non-metallic bracket weighs approximately 136 g (0.3 lbm). Assuming that 2,400 TR-317 brackets (1,200 transducers) are installed on a boat, that translates into a weight savings of 871 kg (1,920 lbm) or almost 1 ton per boat. Additional weight savings will be realized with the replacement of the current metallic nut with a non-metallic fastener and by the elimination of four epoxy washers used in the current Al-Br bracket installation.

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REFERENCES

1. S.L. Arnett, C.J. Corley, and A.V. Bray, "Accelerated Life Testing of Candidate Design for the Extended Life Portsmouth Connectors," NRL Memorandum Report No. 6758, Feb 1991.

2. S.L. Arnett, "Accelerated Life Test of Six MIL-C-24217 Alternate Design Glass Reinforced Epoxy Connectors," Texas Research Institute Austin Report, 89313-605, Austin, TX, Jun 1990.

3. A.V. Bray and S.L Arnett, "Accelerated Life Test Results for 7, 14 and 24 Pin MIL-C-24231/GRE Connector," Texas Research Institute Austin Report, A1089313-605-13.1.3, Austin, TX, May 1990.

4. Fleet Support Department, NWSC-Crane Report 7052-88-011, May 1989.

5. S.L. Arnett, M.A. Danna, and C.J. Corley, "Accelerated Life Testing of MIL-C-22539/GRE Connectors for Use with TR-338 and TR-217B Transducers," Texas Research Institute Austin Report, 86190-504, Austin, TX, Mar 1989.

6. R.W. Timme and S.L. Arnett, "Development of the Extended Life Portsmouth Connector," NRL-USRD Letter Report No. 9464 to NAVSEA, 25 Apr 1988.

7. J.S. Thornton, R.E. Montgomery, and J.F. Cartier, "Failure Rate Model for Cathodic Delamination of Protective Coatings," NRL Memorandum Report No. 5584, May 1985.