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Toughness in Plastics Based on Fracture Surface Appearance

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Ocean Materials Criteria Branch
Ocean Technology Division

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ABSTRACT

Relationships between fracture toughness and fracture surface appearance in plastic materials were studied and reported on a number of years ago. This report recalls such studies in the light of renewed interest in stretched transparent plastics and shows the relationship which exists between fracture toughness and fracture appearance of MIL-P-5425 (Plexiglas II) material.

PROBLEM STATUS

The work upon which this report is based was performed under the sponsorship of the Naval Air Systems Command.

AUTHORIZATION

This research was supported by the Naval Air Systems Command, NRL Problem F01-05, AIRTASK A32-523-072/6521/F020-02-01, Project Order 8-0036. Mr. Charles F. Bersch is the Project Engineer.

Toughness in Plastics Based on Fracture Surface Appearance

PROBLEM ORIGIN

During the early 1950's the Navy lost a number of aircraft and pilots due to explosive decompression of aircraft cockpits when their canopies were pierced by gunfire fragments. The then Bureau of Aeronautics asked the Mechanics Division at the Naval Research Laboratory for assistance in evaluating and improving the fracture toughness of the acrylic material, polymethyl methacrylate, used for the majority of aircraft canopies.

METHOD OF ATTACK

A new method for rating the fracture toughness of a material was in the process of development at NRL at that time. Dr. George Irwin had introduced his first concepts on fracture mechanics modifying the Griffith equation for the energy required to propagate a crack in an infinite plate (References 1,2). The term dw/dA, or work per unit area of fracture surface, was introduced as a measure of the fracture toughness of a material. This term has since been designated as $\mathcal{G}$.

The National Bureau of Standards (Reference 3) had found that hot stretching of polymethyl methacrylate, just above the second order transition temperature, resulted in improved resistance to crazing. It was postulated at NRL that such a treatment would also increase the materials resistance to crack propagation. Such proved to be the case and a program was initiated to explore optimum toughness of polymethyl methacrylate as a function of temperature, rate of stretching, percent of stretch, etc. (References 4,5).

PARAMETERS INVESTIGATED

It was quickly found that stretching must be accomplished within certain boundary conditions if fracture toughness was to be realized. This was brought home with sudden impact when a high level demonstration at one of the aircraft companies failed. Two full scale polymethyl methacrylate canopies, one as-cast and one hot-stretched, were pressurized in a cabin simulating jig and fired at with projectiles. The hot-stretched canopy failed at essentially the same pressure as the as-cast canopy. Examination of the fracture surfaces showed no appreciable increase in toughness due to stretching as was expected. This was soon corrected by research which showed that stretching in itself was not sufficient to guarantee improved fracture toughness unless particular stretching parameters were adhered to. An exhaustive program was begun investigating the influence on toughness of: percent stretch, temperature of stretching, rate of cooling, surface treatment, etc.

COOPERATION

A cooperative program of research in this area was sponsored by the Navy Bureau of Aeronautics under Mr. Phillip Goodwin and by the Air Force Materials

Laboratory at Wright-Patterson Air Force Base. In addition to NRL the cooperative program was carried on at the Rohm and Haas Company, the Goodyear Aircraft Company, Swedlow Plastics, Inc., The Convair Division of General Dynamics and later by several other companies. A military specification was issued in June 1959 detailing requirements for stretched material to be used as aircraft glazing (Reference 6).

RESULTS

NRL studies showed that one could look at the fracture surface of polymethyl methacrylate and estimate the fracture toughness of the material with a fair degree of reliability. A standard reference display of fractured specimens showing dw/dA values versus fracture surface appearances was prepared at NRL for use by those engaged in fracture toughness studies and by those interested in the production and use of acrylic materials. Pictures at a magnification of 1X were made available to interested parties. (Reference 7).

An interest in increasing the fracture toughness of transparent plastics by biaxial stretching has been revived during the past few months partly in connection with materials for use in an ocean environment (Reference 8). It was felt worthwhile to make the NRL reference pictures available at a magnification of 3 to 4X in a memorandum report. The specimens shown in this report are all polymethyl methacrylate, MIL-P-5425 (Plexiglas II), and were tested as center notch tensile specimens. Table I lists the specimen dimensions while Figures 1 through 5 show fracture surfaces and their corresponding dw/dA or critical fracture toughness values in in-lbs/in^2.

While this report shows only MIL-P-5425 material, fracture surfaces in other plastic materials show a similar change from smooth flat surfaces to rough hackle surfaces as fracture toughness increases. Fracture surface appearance remains as a good guide to the level of fracture toughness present. Most plastic materials which are not appreciably cross linked are capable of fracture toughness improvement through biaxial stretching.

A majority of all military and commercial aircraft are now using stretched acrylic material as the load bearing member in their canopies or cabin windows. Many more potential uses exist for tough transparent plastics.

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(6) "Plastic, Sheets, and Parts, Modified Acrylic Base, Monolithic, Crack Propagation Resistant," Military Specification, MIL-P-25690, 26 June 1959.

(7) Irvin Wolock, "Fracture Phenomena in Polymers", Proceedings of the Conference on Fracture, Swampscott, Massachusetts, 12-14 April 1959.

(8) "Study of Hot Stretching of Transparent Plastics", July 1967, Prepared for U. S. Army Natick Laboratories by the Lowell Technological Institute Research Foundation on Contract No. DA19-129-AMC-844(N).

TABLE I

Polymethyl Methacrylate
MIL-P-5425 (Plexiglas II)

Specimen No.	Ave. % Stretch	Width (inches)	Thickness (inches)	Load (lbs)	Crack Length (inches)	dw/dA (in-lbs/in²)
9-299	0%	6.0	0.256	1380	1.15	4.1
9-641	20%	6.1	0.324	2200	1.12	6.0
9-649	40%	6.1	0.279	2575	0.82	8.0
9-736	40%	6.15	0.260	2050	1.38	10.0
9-651	60%	6.05	0.181	1570	1.32	12.0
9-719	40%	6.1	0.230	2300	1.20	14.1
9-622	73%	5.9	0.218	2320	1.12	16.0
9-617	74%	5.9	0.219	2400	1.20	18.1
9-666	73%	6.1	0.184	2160	1.24	20.1
9-794	101%	6.1	0.209	3330	0.75	22.0
9-179	75%	6.0	0.194	3000	0.84	24.1
9-589	73%	6.1	0.208	3560	0.78	26.1
9-821	100%	6.1	0.214	3550	0.88	28.0
9-120	75%	6.0	0.202	4080	0.67	30.0
9-553	73%	6.05	0.219	3735	0.92	31.9
9-137	72%	6.0	0.215	4370	0.69	34.1
9-810	101%	6.1	0.218	4385	0.78	36.2
9-867	100%	5.95	0.227	3260	1.45	38.1
9-534	75%	6.0	0.200	4025	0.83	40.1
9-604	74%	6.04	0.215	4535	0.81	41.9

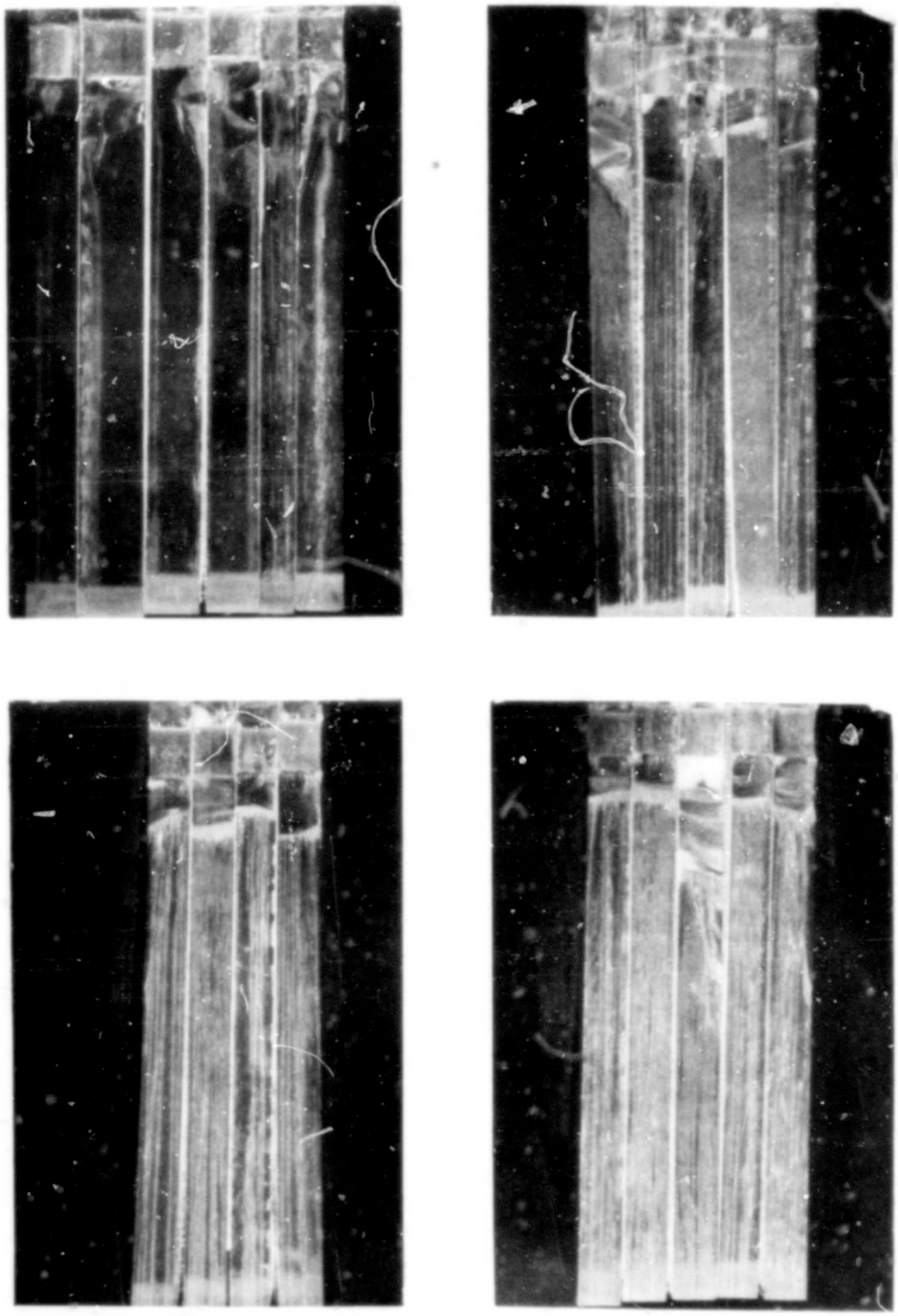
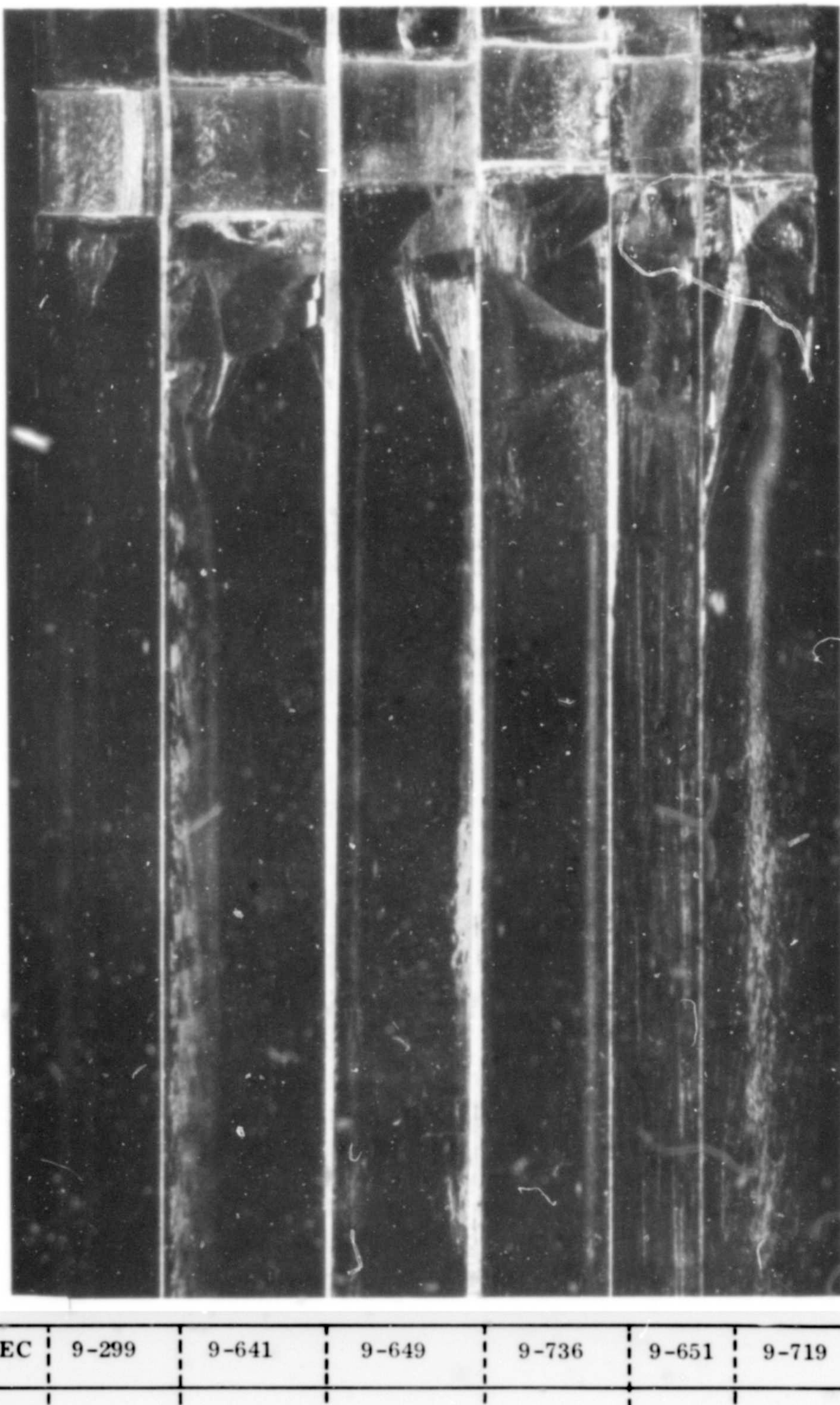
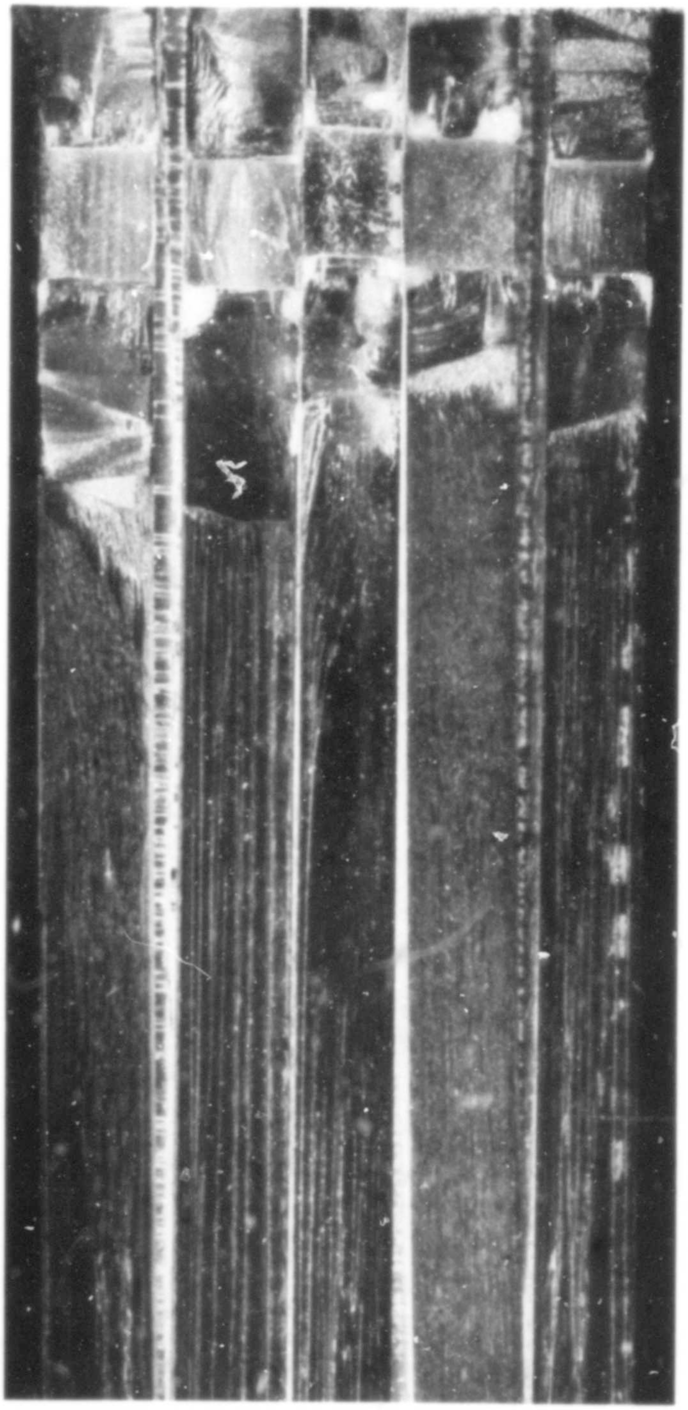


Figure 1



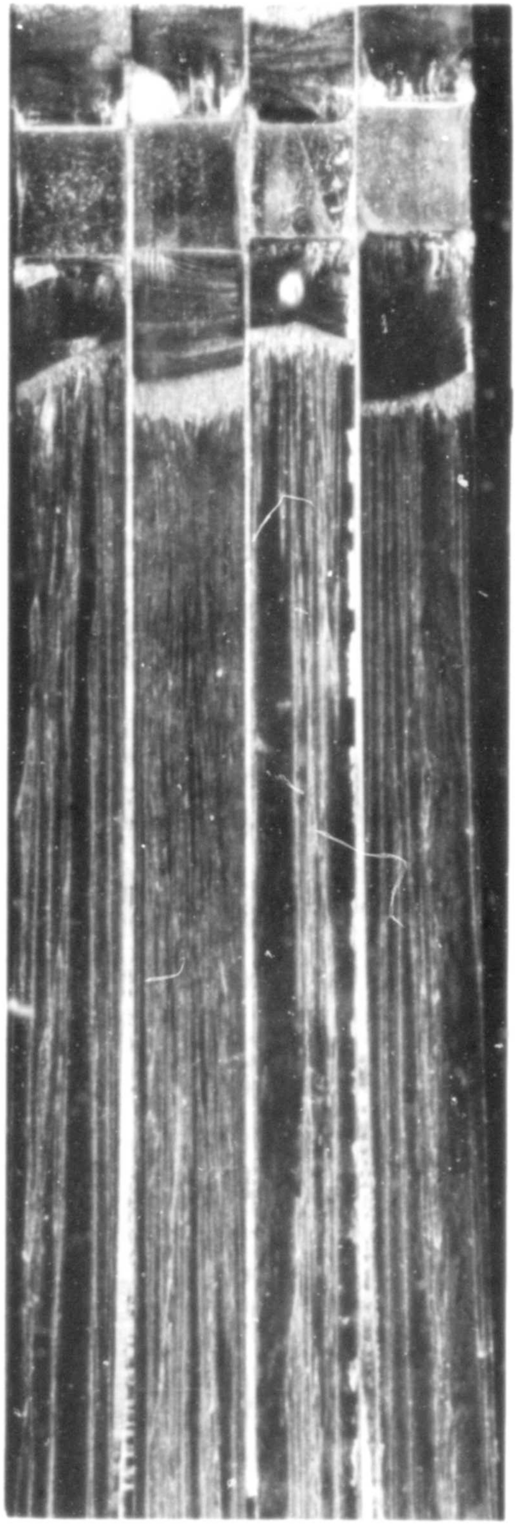
SPEC	9-299	9-641	9-649	9-736	9-651	9-719
dW/dA	4	6	8	10	12	14

Figure 2



SPEC	9-622	9-617	9-666	9-794	9-179
dW/dA	16	18	20	22	24

Figure 3



SPEC	9-589	9-821	9-120	9-553
dW/dA	26	28	30	32

Figure 4

SPEC	9-137	9-810	9-867	9-534	9-604
dW/dA	34	36	38	40	42

Figure 5

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