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DEGRADATION OF THE BIRD IMPACT RESISTANCE OF POLYCARBONATE

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SUMMARY

This report describes a program, comparing the bird impact resistance of new as-extruded polycarbonate with polycarbonate that has undergone natural aging, artificial heat aging, fabrication heat treatments, and fabrication heat treatments with subsequent artificial heat aging.

The two pound bird impacts were carried out on flat 24 inch by 24 inch monolithic specimens, mounted 45° to the horizontal. A rigid test frame incorporating a "clamped" specimen edge design was utilized.

Bird impacts on the modified material resulted in a significant decrease of penetration velocity, with a corresponding change from a ductile to a brittle type failure mode.

1.0 INTRODUCTION

Recent published information on the design and development of aircraft transparencies reveals that the majority of new generation transparencies are fabricated with polycarbonate as the main structural material. Because of its high ductility, and hence exceptional bird impact resistance, polycarbonate has become the transparency designer's first choice when a birdproof, light-weight part is required for a high performance military aircraft. Laminated polycarbonate transparencies are now capable of withstanding, without penetration or major transparency damage, a four pound bird impact at speeds in excess of 500 knots. These results are obtainable mainly because of the energy absorbed through transparency deflections during impact.

The sensitivity of polycarbonate to solvent and stress crazing, heat aging, fabrication heat treatments, and natural and artificial weathering has been well documented (Ref. 1). All of the work has been carried out utilizing standard type (ASTM) test procedures. Very little work, if any, has taken place in which actual bird impacts were used to investigate the change in impact resistance of polycarbonate due to natural aging or other factors.

By a fortunate combination of circumstances, the Flight Impact Simulator Group of NAE/NRCC, found itself in a position to investigate the effect of natural aging on the bird impact resistance of polycarbonate. A number of monolithic panels which had been in storage for up to seven years were available. These panels were left over from a previous research project (Ref. 2), during which they had been subjected to bird impacts. The velocities, however, were sufficiently low, that visible damage, if any, was limited to localized deformation or tearing around the bolt holes. Storage conditions would be expected to produce natural aging, as opposed to weathering, with degradation due to ultra-violet exposure minimized.

As work progressed on the naturally aged material, the program was expanded to include artificially heat aged material. This was carried out to establish a relationship between the bird impact resistance of the artificially aged and naturally aged material.

Published data (Ref.3) indicated that the bird impact resistance of polycarbonate that undergoes normal fabrication heat treatments, including drying, press-polishing and forming cycles, was lower than that of the as-extruded material. Verification of these results as well as the artificial aging of the processed material before bird impacting was also carried out.

The impact tests resulted in substantially lower penetration velocities of the modified material compared to the new as-extruded material. The ductility normally associated with polycarbonate was almost non-existent with the modified material. Based on these results, it was decided to carry out Izod impact tests on samples taken from the penetrated panels.

2.0 PROGRAM

The objective of the test program was to obtain meaningful bird impact data on polycarbonate material whose impact properties might have been altered through natural aging, artificial aging, and fabrication heat treatments. The program was carried out in two parts. The first part was the actual bird impacting of selected polycarbonate panels having a documented history. The second part of the program was a study to ascertain a correlation between the bird impact data from part one and the Izod impact property of the material

3.0 BIRD IMPACT TESTS

The bird impacts were carried out at the NRCC/NAE Flight Impact Simulator Facility, as detailed in Ref. 4., utilizing the 10 inch bore compressed air powered cannon to propel packaged real bird carcasses to the test specimens. The birds had been killed and immediately frozen for storage some weeks prior to use. The carcasses were allowed to thaw at room temperature for at least 24 hours before being packaged, weighed and placed into the gun breech. The carcasses were selected so the total package weight, including bag packaging, was two pounds ± two ounces.

The velocity of the package was timed, just prior to impact, with two independently operating optoelectronic timing systems. The accuracy of each of the systems is considered to be within 0.5%. The mean velocity of the two systems was recorded as the velocity of the package.

To position the test article for an impact, a surveyor's transit was first aligned to the gun barrel axis and then the test article was positioned so that the impact point (geometric centre of the test specimen) coincided with the transit line. The transit line was also used to set the longitudinal axis of the test article parallel to the gun barrel axis. The aligned test article was then secured to the tie-down plates on the target site floor. The test article is shown in Fig. 1.

3.2 Test Specimen Set-up

The polycarbonate test specimen, 24 inches by 24 inches, was "clamped" to a one inch thick aluminum mounting plate at 45° to the horizontal. The mounting plate had outside dimensions of 28 inches by 30 inches with inside dimensions of 19 inches by 19 inches. The inside edges were radiused to prevent shearing of the specimen during impact. The mounting plate was bolted to two, four inch by four inch box beams, which were then clamped to the support structure. The test specimen set-up is shown in Fig. 2.

The method for clamping polycarbonate specimens was developed in earlier work (Ref 2) and under bird impact loading prevented failures from originating at the bolt holes or specimen edges. Fig. 3 details the clamping method.

All impacts were carried out under ambient room temperature and humidity conditions.

3.3 Polycarbonate Test Specimens

3.3.1 New Material As-Extruded

The new as-extruded polycarbonate was commercial grade "Lexan"

(General Electric), purchased locally. The material was assumed to have an age of less than 6 months based on information from the supplier.

3.3.2. Naturally Aged Material

The naturally aged panels consisted of 0.125 inch and 0.250 inch thick panels that had been tested in 1973 and subsequently stored in a closed cabinet. Impact damage to the panels was limited and consisted of yielding about the original bolt holes. The edge of the panel with the most damage was always installed at the bottom of the mounting plate. No panel with any permanent deformation near the impact point was utilized in these tests.

During storage, the panels could have been subjected to temperature extremes of $40^{o}F$ to $100^{o}F$, and humidity would have ranged from a high of 100% to a low of 10%.

Some material that had been in inventory at the suppliers for a minimum of 18 months was also obtained. It was assumed that temperature and humidity conditions during storage would have been less severe than with the older material.

3.3.3 Artificially (Heat) Aged Material

New as-extruded (see 3.3.1) material was first cut into 24 inch by 24 inch panels and then aged at $260 \pm 5^{o}F$ for 100 hours in an air circulating oven. A copper-constantan thermocouple connected to a digital indicator and a strip chart recorder monitored the temperature of the oven during aging. Some of the panels that were used in the as-extruded series and in the heat aged series were selected from the same parent sheet. Impacting of the as-extruded material verified that the parent sheet material behaved in a normal ductile manner under bird impact loading.

3.3.4 As-Extruded New Material, Dried, Polish and Forming Heat Treatments.

The conditioning of this material was carried out in the same manner as in 3.3.3 except for the following temperatures and times, which are typical of fabrication heat treatments for formed transparencies.

Drying	:	18 hours at $265 \pm 5^{o}F$
Polish Heat	:	2 hours at $305 \pm 5^{o}F$
Forming Heat	:	2 hours at $305 \pm 5^{o}F$

During the polish and forming heat cycles the panels were clamped between two ¼ inch thick aluminum plates to prevent warping. Between each heat cycle the panel was allowed to cool to room temperature.

3.3.5 As-Extruded New Material, Dried, Polish and Forming Heat Treatments and Artificial (Heat) Aging.

The conditioning of this material was the same as in 3.3.4 with an additional heat aging cycle as in 3.3.3 (100 hours at 260 $\pm 5^{o}$F).

4.0 MECHANICAL PROPERTIES

Because the amount of material available for mechanical testing was limited and the published literature (Ref. 1) indicated that there was no significant change in tensile properties of aged polycarbonate, it was decided to only carry out Izod impact tests on the material. Since polycarbonate is known to be extremely notch-sensitive during impact, an attempt was made to carry out the Izod impact tests utilizing un-notched specimens.

4.1 Impact Tests

The un-notched impact tests were carried out on an Avery-Denison 6709 Charpy and Izod Impact Testing Machine.

Preliminary Izod impact testing was carried out with specimens obtained from new as-extruded, artificially heat aged, and naturally aged (seven years) material.

5.0 RESULTS

5.1 Bird Impact Tests

The results of the bird impacts are contained in Tables 1 to 6.

It should be noted that after two impacts on the 7 year old 0.125 inch thick material, (Table 3), there was no sign of material degradation due to loss of ductility (see Fig. 4). This result was not unexpected since other investigators have found that the material undergoes a ductile to brittle transition at a thickness between 0.140 and 0.180 inch (Ref. 5). Consequently further testing of 0.125 inch thick material was discontinued.

The results of the impacts of the 0.250 inch thick panels are summarized in Table 7. The effect of natural aging and various heat cycles are shown in Figs. 5 and 6. Typical impact results are shown in Figs. 7 to 13.

The radical change in failure mode with aging should be noted. New material exhibits high ductility, large deformations and a limited amount of fracture as shown in Fig. 7. In contrast, most of the aged material shatters on impact into a large number of fragments with little or no evidence of ductility as shown in Figs. 8 and 9.

5.2 Un-notched Izod Impact Tests

Only a limited number of tests were carried out as it was observed that even specimens from the seven year naturally aged material showed no signs of brittle failure as a result of the Izod impact test. Since the material used for the Izod impact test (naturally aged) was obtained from fragments of a panel that had failed in a brittle manner during bird impact, one surmises that the material is extremely rate sensitive. This result would render standard material properties tests of polycarbonate questionable when bird impact is considered.

6.0 CONCLUSIONS

6.1 Bird Impact Resistance

6.1.1 Naturally Aged Polycarbonate

The results show that the bird impact resistance of 0.250 inch thick monolithic polycarbonate is 10% lower than new as-extruded material after only two years of storage under ambient room conditions. Polycarbonate transparencies stored under these conditions should be suspect if they were initially designed to be bird impact resistant.

6.1.2 Heat Treated Polycarbonate

The bird impact resistance of 0.250 inch thick monolithic polycarbona that undergoes the normal fabrication heat treatments (drying, polishing and forming) is reduced by as much as 11% as compared to the new as-extruded materi Obviously, if these fabrication heat treatments can be minimized the exceptiona bird impact resistance of polycarbonate can be retained.

6.1.3 New Material, Artificially Heat Aged

The results from these bird impacts indicate that artificial heat aging of the polycarbonate at 260°F for 100 hours is equivalent to natural aging (i.e. storage) of somewhere between five and six years. These results should be of interest to studies of the relationship between natural and artificial aging.

It is worth noting, that if the results from material conditioned under 3.3.4 and 3.3.5 were plotted on Fig. 6 at the 0 year point and the $5\frac{1}{2}$ year point respectively and the points were joined by a curve, the resulting curve indicates that the impact resistance of 4 year old material with normal fabrication heat treatments would be 25% less than new as-extruded material.

6.2 Mechanical Properties

Most published information on the mechanical properties of aged polycarbonate does not indicate a dramatic change in the material properties. The published (Ref. 1) un-notched Izod impact results are inconsistent to say the least. The failure to initiate brittle type failures in the aged polycarbonate samples by the Izod impact method indicates that the material is impact rate sensitive.

A method should be developed by which Izod type tests can be carried out at impact velocities approaching 1000 ft/sec.

The relationship between meaningful mechanical properties and bird impact resistance is still an area that merits further study.

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5. Environmental Data and Machining Techniques of Polycarbonates G.E. Husman and R.J. Kuhbander, Conference on Transparent Aircraft Enclosures, Las Vegas, February 1973, sponsored by Air Force Materials Laboratory, Air Force Systems Command, Wright-Patterson Air Force Base.

TABLE 1: POLYCARBONATE NEW MATERIAL

TEST	PANEL THICK-NESS IN	MATERIAL HISTORY: ESTIMATED AGE	HEAT TREATMENT (HOURS): DRY CYCLE @ 265°F	POLISH CYCLE @ 305°F	FORMING CYCLE @ 305°F	AGING CYCLE @ 265°F	IMPACT VELOCITY FT/SEC	RESULTS
8	.250	NEW MATERIAL	--	--	--	--	779	PENETRATION; NORMAL YIELDING BEFORE FAILURE ALONG TOP BOLT HOLES.
9	.250	NEW MATERIAL	--	--	--	--	735	PENETRATION; MATERIAL FAILURE. NORMAL YIELDING BEFORE FAILURE.
10	.250	NEW MATERIAL	—	—	—	—	692	NO PENETRATION; LARGE PANEL DEFORMATION NORMAL YIELDING 3 5/8in. DEEP POCKET ABOVE IMPACT POINT.

TABLE 2 POLYCARBONATE 7 YEAR OLD MATERIAL

TEST NO	PANEL THICK-NESS IN	PREVIOUS PANEL HISTORY, PANEL ANGLE 45°, AMBIENT, EDGE DESIGN Fig. 3(a)					PRESENT TEST CONDITIONS, 2lb BIRD, 45° PANEL ANGLE, AMBIENT, EDGE DESIGN Fig. 3(b)		
		DATE OF TEST	PACK WT (lbs)	PENETR-ATION VELOCITY ft/sec (Ref. 2)	IMPACT VELOCITY ft/sec	RESULTS	PENETRATION VELOCITY AS-EXTRUDED MATERIAL ft/sec	IMPACT VELOCITY ft/sec	RESULTS
1	.250	5-73	4	434	420	NO PANEL DEFORMATION SLIGHT PULLING IN UPPER BOLT HOLES	714	575	PENETRATION; 80% OF PANEL DESTROYED, LIMITED SIGNS OF YIELDING BEFORE BRITTLE TYPE FAILURE
2	.250	6-73	2	523	503	AS IN TEST 1	714	401	NO PENETRATION; SLIGHT YIELDING ALONG TOP EDGE, SMALL DEFORMATION ABOVE IMPACT POINT, 1/8 IN. DEEP POCKET
3	SAME	PANEL	AS	TEST	2		714	451	NO PENETRATION; DEFORMATION ABOVE IMPACT POINT 1/4 IN. DEEP POCKET
4	SAME AND 3	PANEL PANEL ROTATED	AS	IN 180° (TOP	TESTS 2 TO BOTTOM)		714	483	NO PENETRATION; DEFORMATION ABOVE IMPACT POINT 1-1/4 IN. DEEP POCKET, SOME PULLING IN TOP BOLT HOLES
5	.250	5-73	4	434	447	PANEL PENETR-ATED ALONG TOP BOLT HOLES	714	542	PENETRATION; 25% OF PANEL DESTROYED, NO SIGNS OF YIELDING BEFORE BRITTLE TYPE FAILURE, FRACTURE DOES NOT INITIATE FROM PREVIOUS DAMAGED AREA

cont'd.

TABLE 2 CONT'D

TEST NO	PANEL THICK-NESS IN	PREVIOUS PANEL HISTORY, PANEL ANGLE 45°, AMBIENT EDGE DESIGN Fig. 3(a)					PRESENT TEST CONDITIONS, 21b BIRD, 45° PANEL ANGLE, AMBIENT, EDGE DESIGN Fig. 3(b)		
		DATE OF TEST	PACK WT (lbs)	PENETR-ATION VELOCITY ft/sec (Ref. 2)	IMPACT VELOCITY ft/sec	RESULTS	PENETRATION VELOCITY AS-EXTRUDED MATERIAL ft/sec	IMPACT VELOCITY ft/sec	RESULTS
6	.250	6-73	2	523	464	NO PANEL DEFORMATION SLIGHT PULL-ING IN BOLT HOLES	714	509	NO PENETRATION; PANEL DEFOR-MATION ABOVE IMPACT POINT 1-1/4 IN. DEEP POCKET, SOME PULLING IN BOLT HOLES
19	.250	6-73	NO DOCUMENTED HISTORY			PANEL PENET-RATED ALONG TOP BOLT HOLES	714	544	NO PENETRATION; PANEL DEFOR-MATION ABOVE IMPACT POINT 1-1/2 IN. DEEP POCKET, PULLING IN TOP BOLT HOLES, FRACTURE OCCURRED IN PANEL WHEN UNCLAMPING FROM FRAME

TABLE 3 POLYCARBONATE 7 YEAR OLD MATERIAL

TEST NO	PANEL THICKNESS IN	PREVIOUS PANEL HISTORY, PANEL ANGLE 45°, AMBIENT, EDGE DESIGN Fig. 3(a)					PRESENT TEST CONDITIONS, 2lb BIRD, 45° PANEL ANGLE, AMBIENT, EDGE DESIGN Fig. 3(b)		
		DATE OF TEST	PACK WT (lbs)	PENETRATION VELOCITY ft/sec (Ref.2)	IMPACT VELOCITY ft/sec	RESULTS	PENETRATION VELOCITY AS-EXTRUDED MATERIAL ft/sec	IMPACT VELOCITY ft/sec	RESULTS
1	.125	6-73	2	390	373	NO PANEL DEFORMATION SLIGHT PULLING IN UPPER BOLT HOLES	500	397	NO PENETRATION; PANEL DEFORMATION ABOVE IMPACT POINT 1-7/8 IN. DEEP POCKET
2	.125	6-73	1	469	432	AS IN TEST 1	500	449	NO PENETRATION; DEFORMATION ABOVE IMPACT POINT 2-3/4 IN. DEEP POCKET

TABLE 4 POLYCARBONATE 5 YEAR OLD MATERIAL

TEST NO	PANEL THICKNESS IN	PREVIOUS PANEL HISTORY, PANEL ANGLE 45°, AMBIENT, EDGE DESIGN Fig. 3(a)					PRESENT TEST CONDITIONS, 2lb BIRD, 45° PANEL ANGLE, AMBIENT, EDGE DESIGN Fig. 3(b)		
		DATE OF TEST	PACK WT (lbs)	PENETRATION VELOCITY ft/sec (Ref.2)	IMPACT VELOCITY ft/sec	RESULTS	PENETRATION VELOCITY AS-EXTRUDED MATERIAL ft/sec	IMPACT VELOCITY ft/sec	RESULTS
7	.250	5-75	1	690	469	NO PANEL DAMAGE	714	585	PENETRATION; 80% OF PANEL DESTROYED. SIGNS OF SIGNIFICANT YIELDING ALONG TOP EDGE AND ABOVE IMPACT POINT, BRITTLE TYPE FAILURE ONE LARGE PIECE APPROX. 1 ft^2, 90% OF PIECES FOUND IN FRONT OF TEST STAND
11	.250	6-75	1 1 1	690 690 690	510 518 554	NO PANEL DAMAGE	714	598	NO PENETRATION; PANEL DEFORMATION ABOVE IMPACT POINT 1-5/8 IN. DEEP POCKET YIELDING ALONG 4 SIDES THROUGH BOLT HOLES, INCREASING PENETRATION VELOCITY

TABLE 5 POLYCARBONATE 2 YEAR OLD MATERIAL

TEST	PANEL THICK-NESS IN	MATERIAL HISTORY					IMPACT VELOCITY ft/sec	RESULTS
		ESTIMATED AGE	HEAT TREATMENT (HOURS)					
			DRY CYCLE @ 265°F	POLISH CYCLE @ 305°F	FORMING CYCLE @ 305°F	AGING CYCLE @ 265°F		
20	.250	2 yrs.	———	———	———	———	658	PENETRATION; YIELDING BEFORE FAILURE - DUCTILE TYPE
21	.250	2 yrs.	———	———	———	———	588	NO PENETRATION; PANEL DEFORMATION 1-1/2 IN. DEEP POCKET ABOVE IMPACT POINT
22	.250	2 yrs.	———	———	———	———	634	NO PENETRATION; PANEL DEFORMATION 2 IN. DEEP POCKET ABOVE IMPACT POINT

TABLE 6: POLYCARBONATE NEW MATERIAL - HEAT TREATED

TEST	PANEL THICK-NESS IN	MATERIAL HISTORY					IMPACT VELOCITY FT/SEC	RESULTS
		ESTIMATED AGE	HEAT TREATMENT (HOURS)					
			DRY CYCLE @ 265°F	POLISH CYCLE @ 305°F	FORMING CYCLE @ 305°F	AGING CYCLE @ 265°F		
12	.250	NEW MATERIAL				100	557	PENETRATION; 40% OF PANEL DESTROYED. YIELDING ALONG TOP EDGE AND 1¼in. DEEP POCKET ABOVE IMPACT POINT. BRITTLE TYPE FAILURE.
13	.250	NEW MATERIAL				100	525	NO PENETRATION ; YIELDING ALONG TOP EDGE. NO PANEL DEFORMATION ABOVE IMPACT POINT NORMALLY PRODUCED.
14	.250	NEW MATERIAL				100	563	NO PENETRATION; PANEL DEFORMATION ABOVE IMPACT POINT ¾ in. DEEP POCKET ¼ in. LONG FRACTURE ON BACK SURFACE AT MAXIMUM POINT OF DEFORMATION.
16	.250	NEW MATERIAL	18	2	2		639	NO PENETRATION; PANEL DEFORMATION 2 in. DEEP POCKET ABOVE IMPACT POINT.
17	.250	NEW MATERIAL	18	2	2		685	PENETRATION ; SHEARED ALONG TOP EDGE. PANEL YIELDING BEFORE DUCTILE TYPE FAILURE.

TABLE 7

SUMMARY OF RESULTS

.250 tk. Polycarbonate, Panel 45° to Horiztonal, Clamped Edge, Ambient Conditions, 2lb Bird Package Impacts.

Panel History	Penetration Velocity ft/sec	% Decrease From New As-Extruded Panels	Failure Mode (Brittle) (Ductile)
As-Extruded New Material	714± 22		Duct.
As-Extruded 7 Year Old	526±17	26	Brit.
As-Extruded 5 Year Old	<585	>18	Brit.
As-Extruded 2 Year Old	646±12	10	Duct.
As-Extruded New Material Artificially Aged	560±5	22	Brit.
As-Extruded New Material, Dried, Polish Heat, Forming Heat	638±1	11	Duct.
As-Extruded New Material, Dried, Polish Heat, Forming Heat, Artificially Aged	515±10	28	Brit.

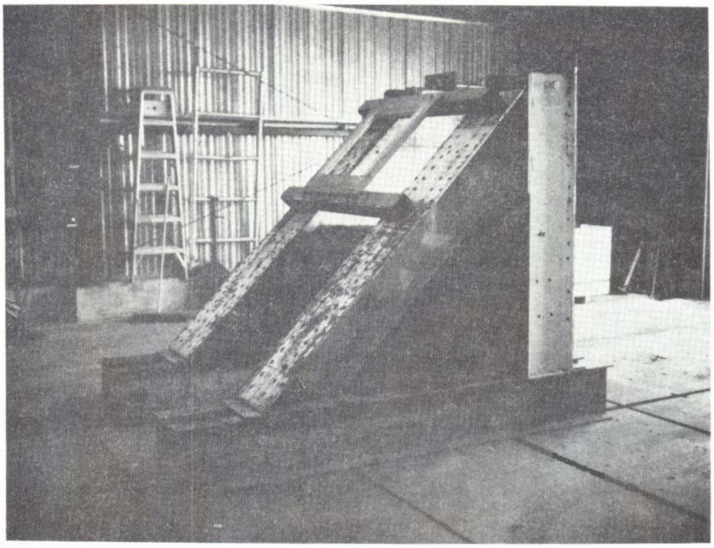


FIG. 1 TEST ARTICLE

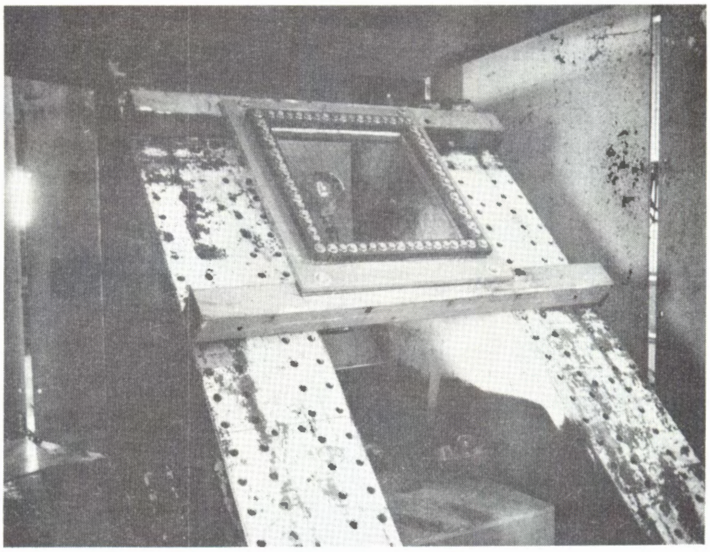


FIG. 2 TEST SPECIMEN SET-UP

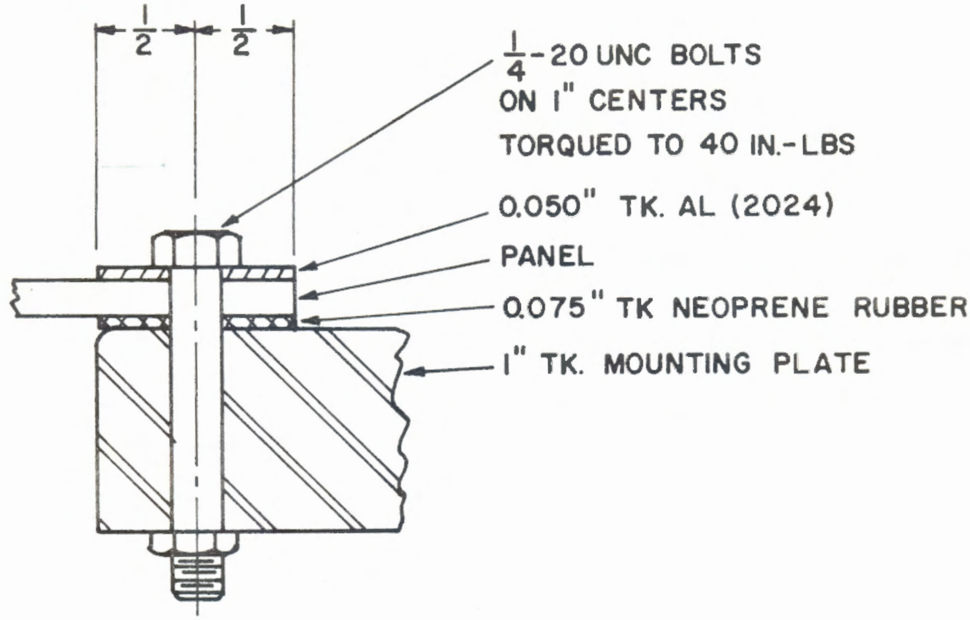


FIG. 3(a) PANEL EDGE RESTRAINT
BOLTED METHOD

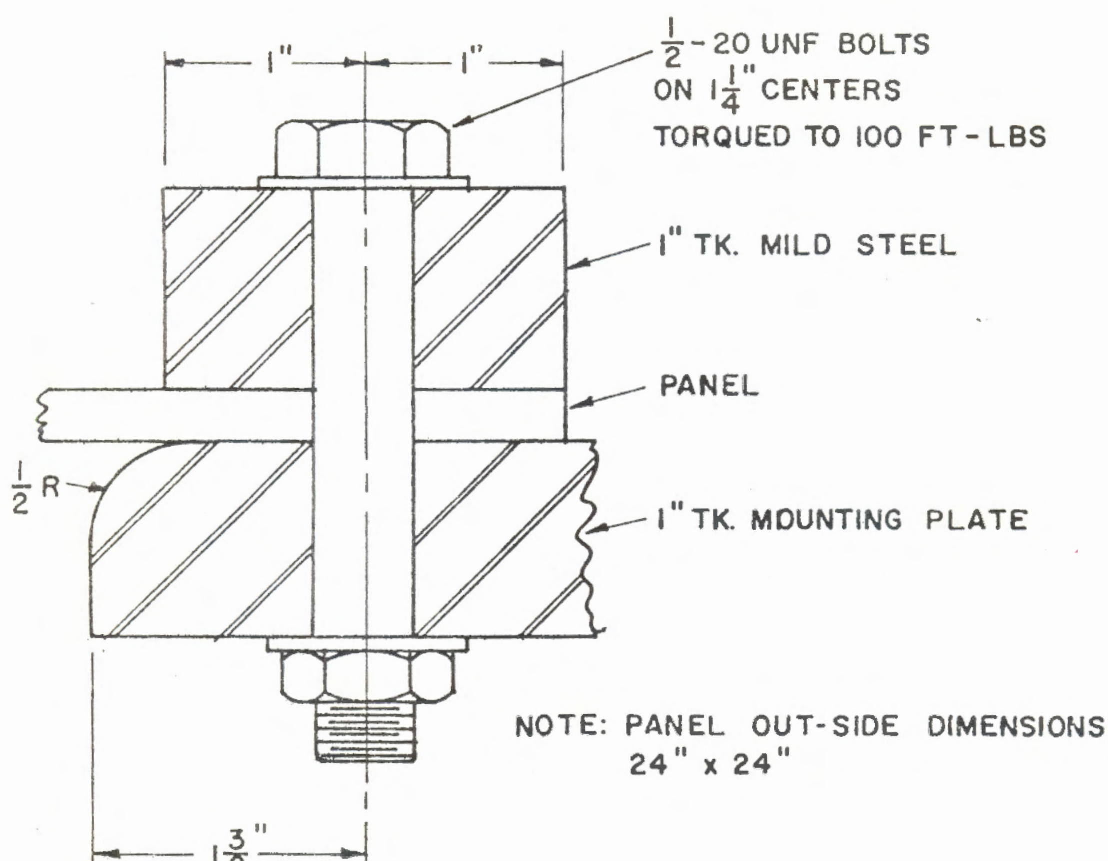
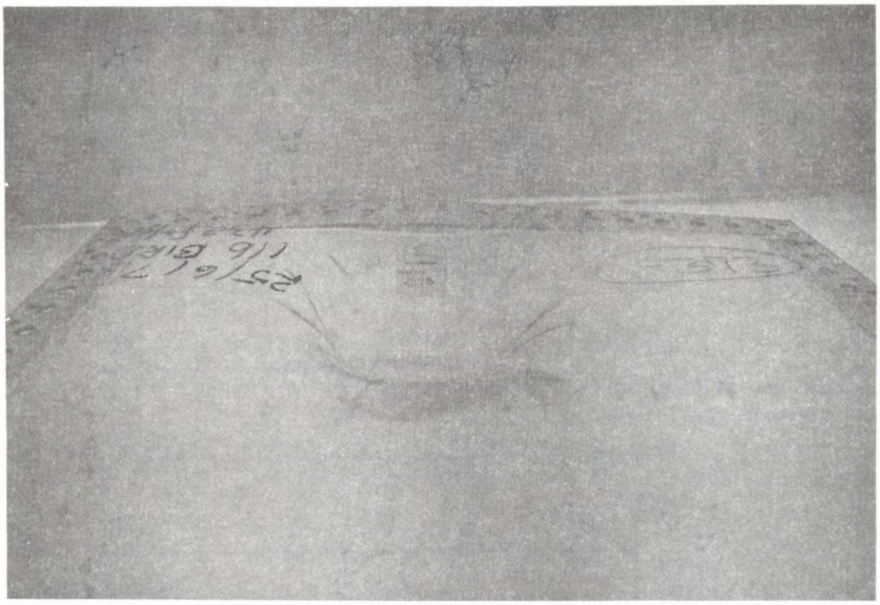
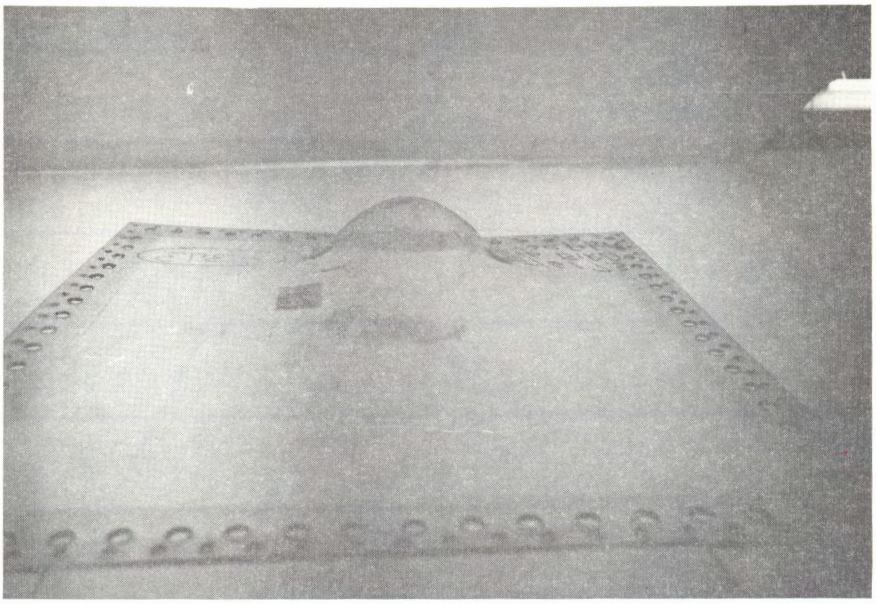


FIG. 3(b) PANEL EDGE RESTRAINT
"CLAMPED" METHOD



(a) VIEW OF OUTBOARD SURFACE



(b) VIEW OF INBOARD SURFACE

FIG. 4 0.125 IN. TK. POLYCARBONATE
7 YEARS OLD - TYPICAL FAILURE

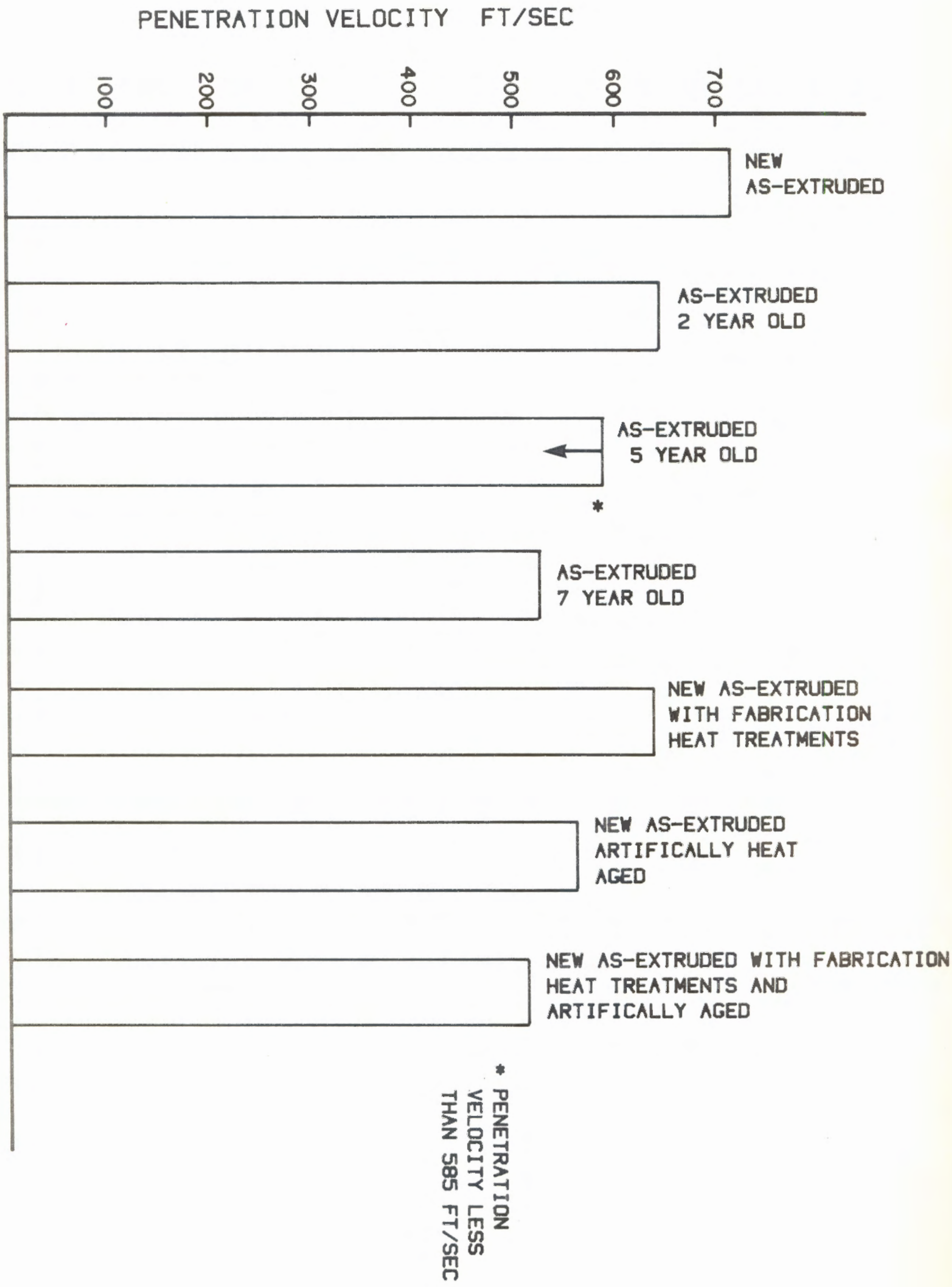


FIG. 5 EFFECT OF MATERIAL HISTORY ON PENETRATION VELOCITY OF POLYCARBONATE

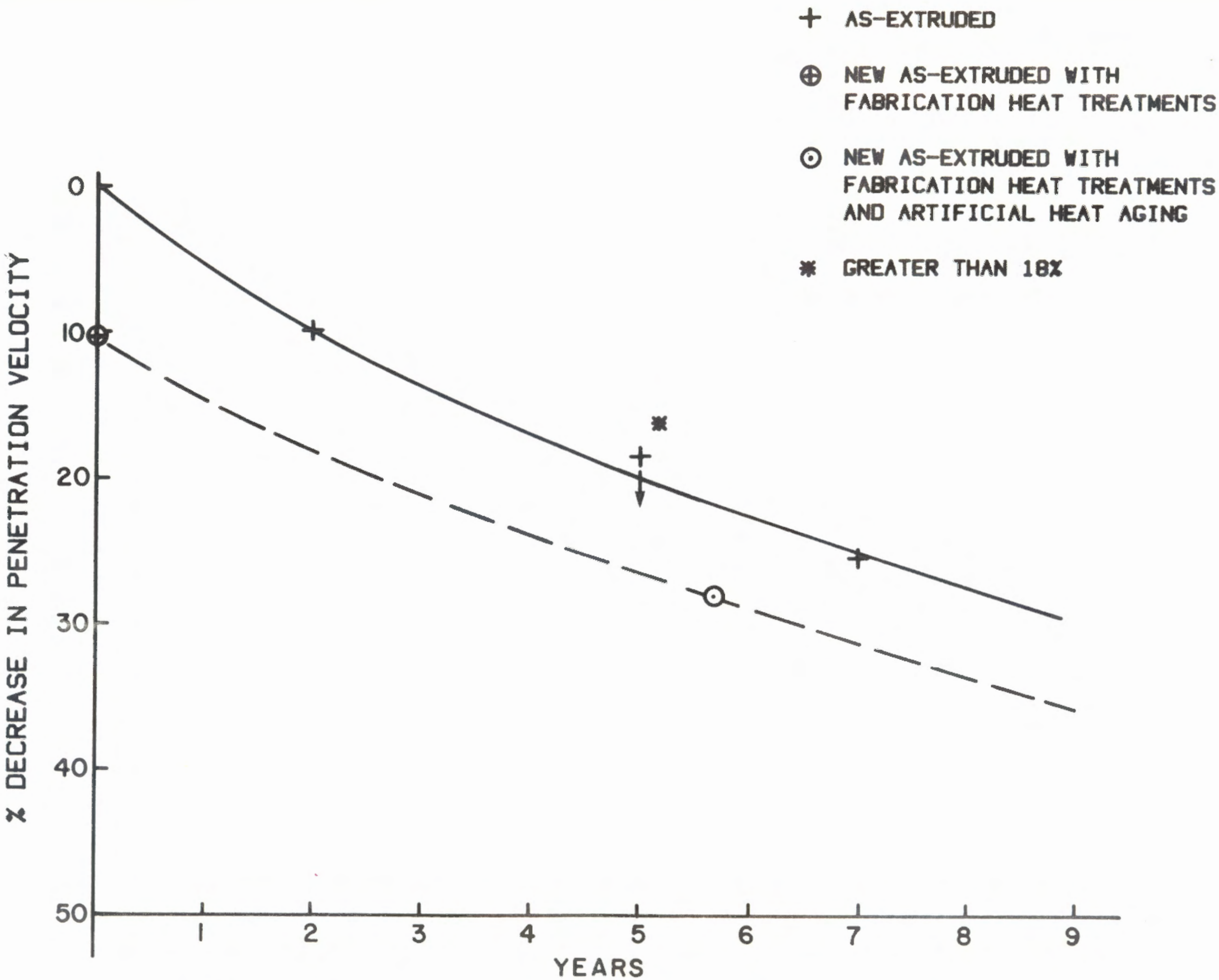
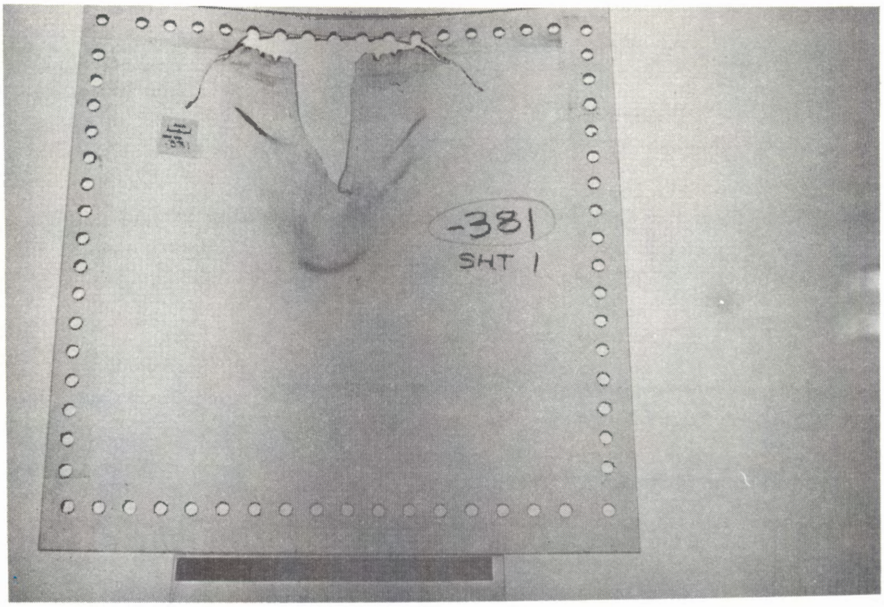
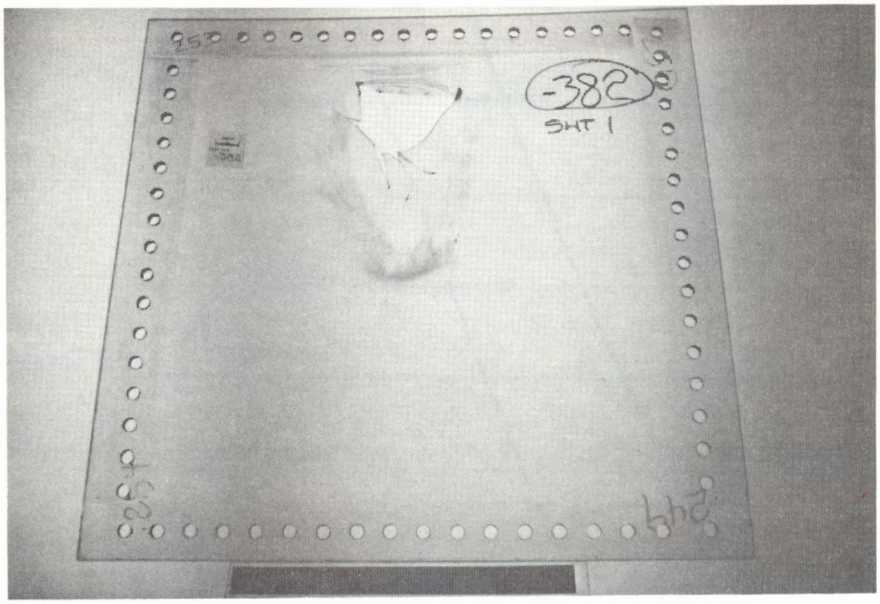


FIG. 6 EFFECT ON PENETRATION VELOCITY OF NATURAL AGING OF POLYCARBONATE (RELATED TO NEW AS-EXTRUDED MATERIAL)

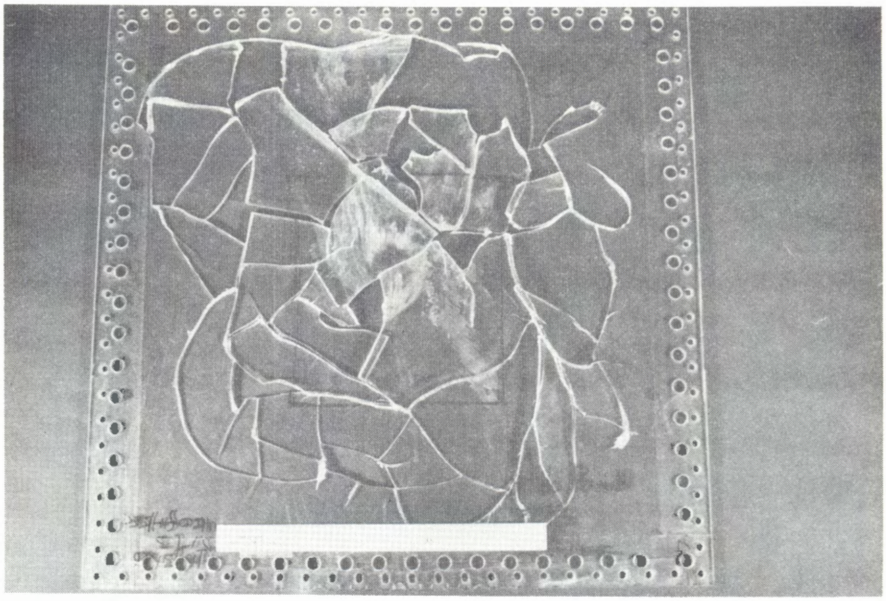


(a) TEST 8 FAILURE INDICATES INSUFFICIENT CLAMPING

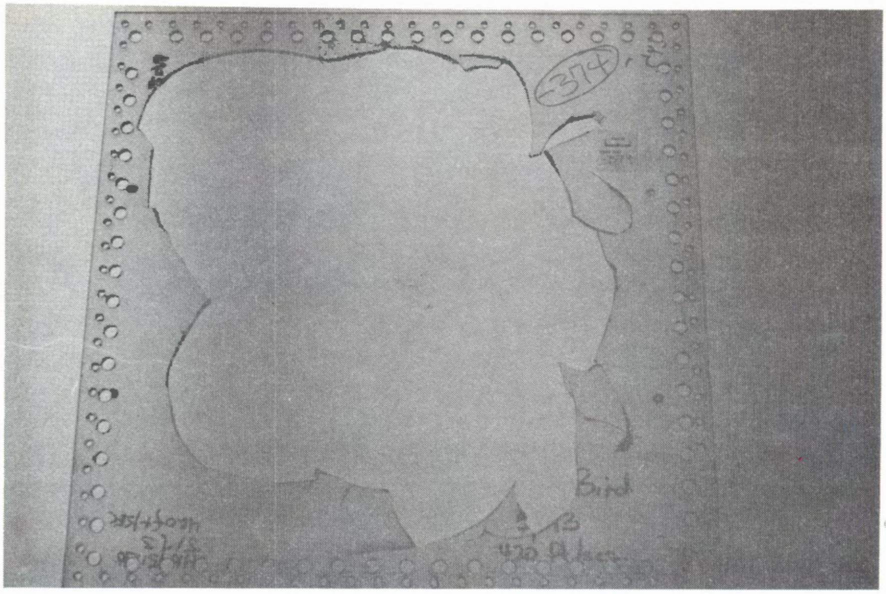


(b) TEST 9 MATERIAL FAILURE, NO EDGE EFFECT

FIG. 7 0.250 IN. TK. POLYCARBONATE
NEW MATERIAL - TYPICAL FAILURE

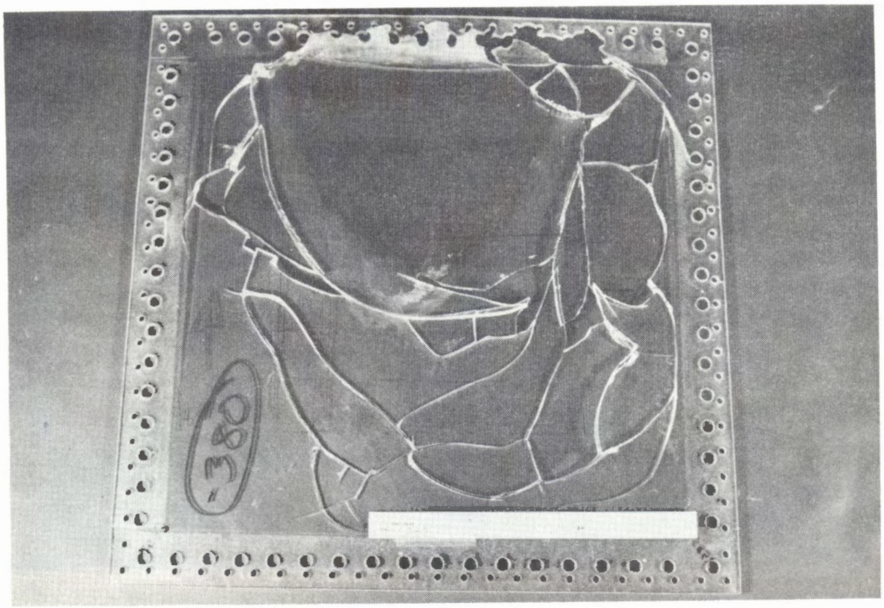


(a) TEST 1 (RECONSTRUCTED FRAGMENTS)



(b) TEST 1

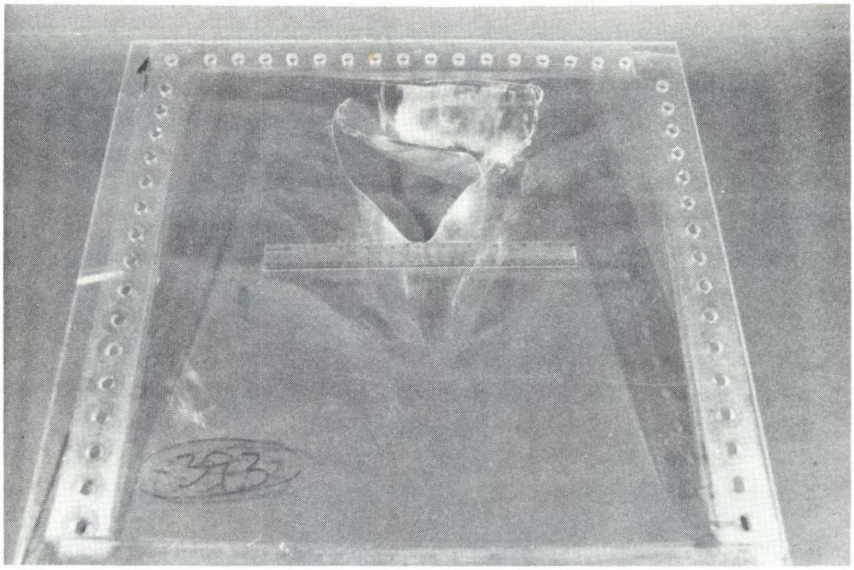
FIG. 8 0.250 IN. TK. POLYCARBONATE
7 YEARS OLD - TYPICAL FAILURE



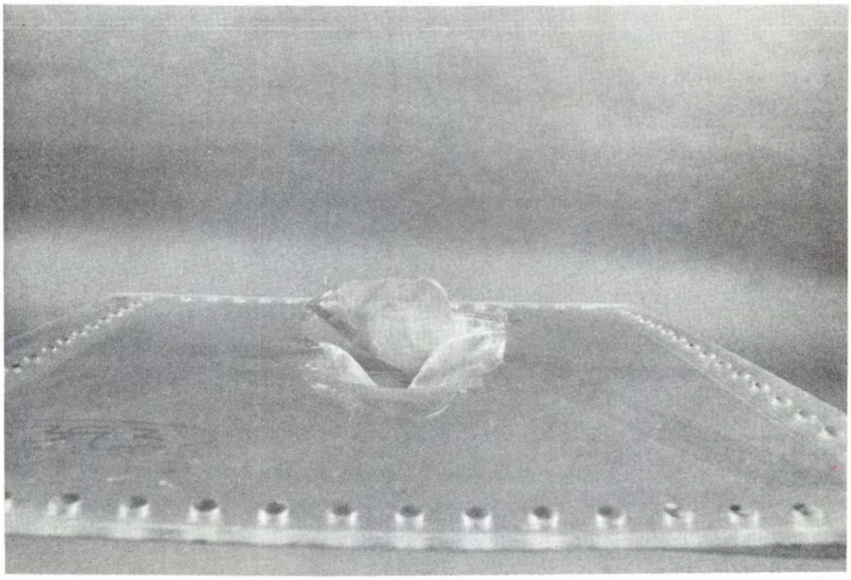
(a) TEST 7 (RECONSTRUCTED FRAGMENTS)

(b) TEST 7

FIG. 9 0.250 IN. TK. POLYCARBONATE
5 YEARS OLD - TYPICAL FAILURE

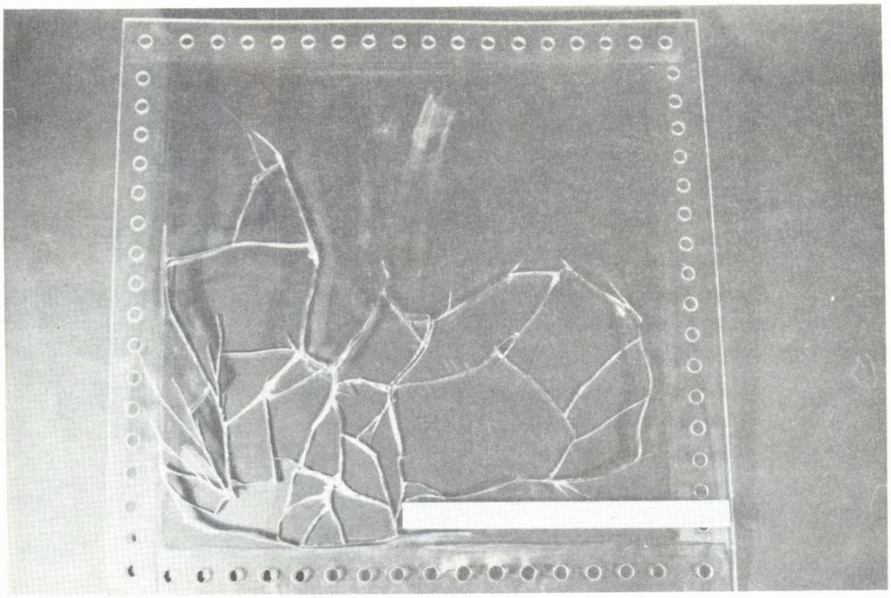


(a) TEST 20 OUTBOARD SURFACE

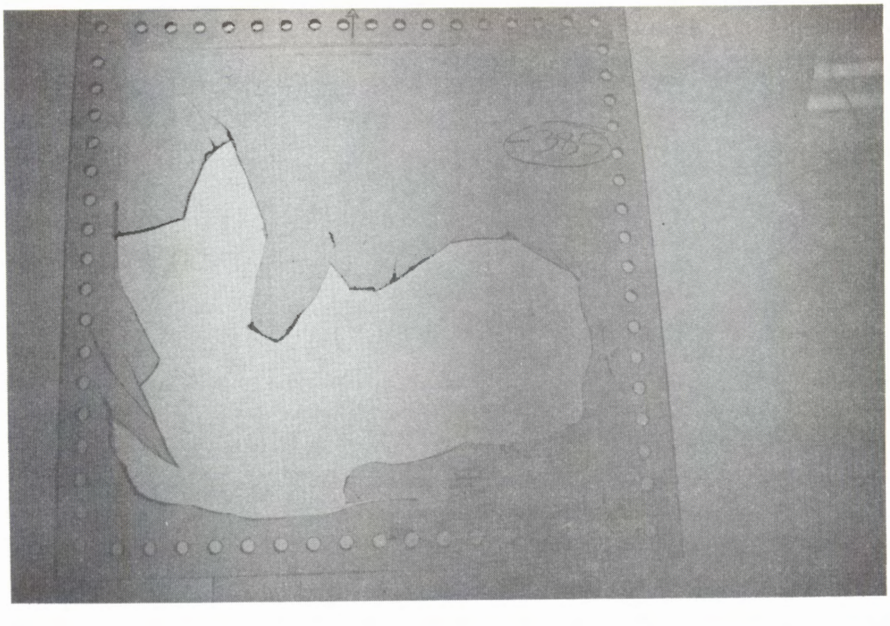


(b) TEST 20 VIEW ALONG OUTBOARD SURFACE

FIG. 10 0.250 IN. TK. POLYCARBONATE
2 YEARS OLD - TYPICAL FAILURE

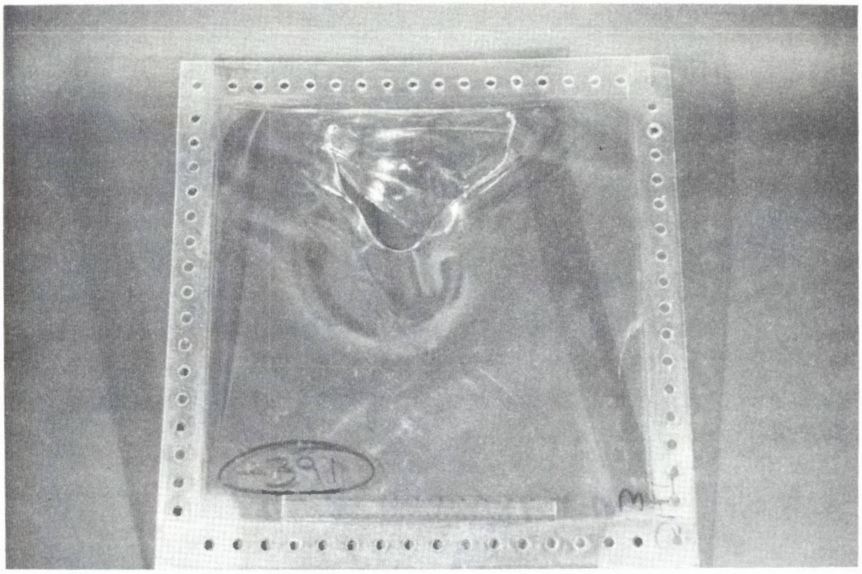


(a) TEST 12 (RECONSTRUCTED FRAGMENTS)

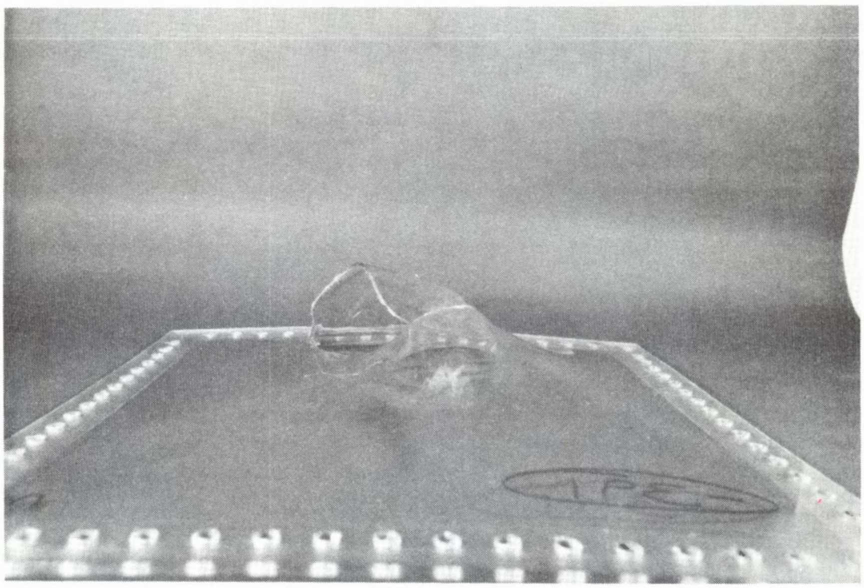


(b) TEST 12

FIG. 11 0.250 IN. TK. POLYCARBONATE
NEW MATERIAL - HEAT AGED
TYPICAL FAILURE

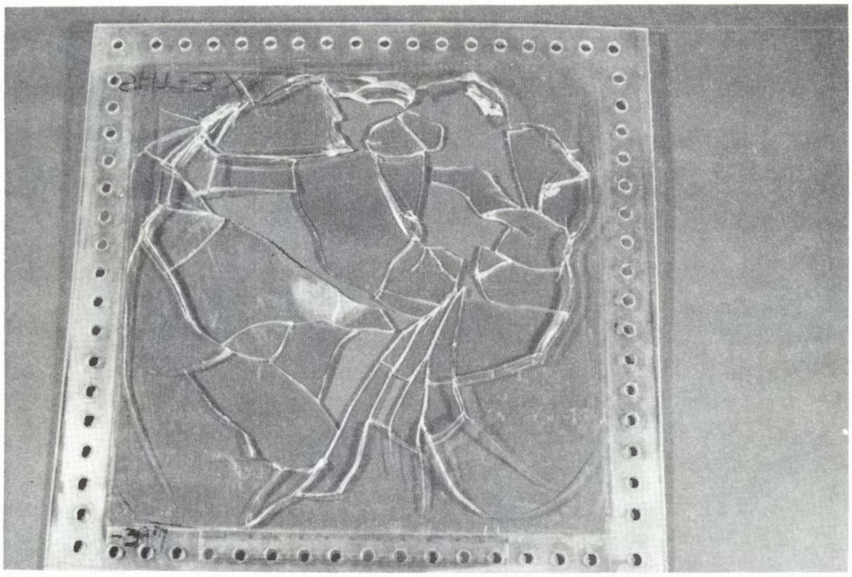


(a) TEST 18 OUTBOARD SURFACE

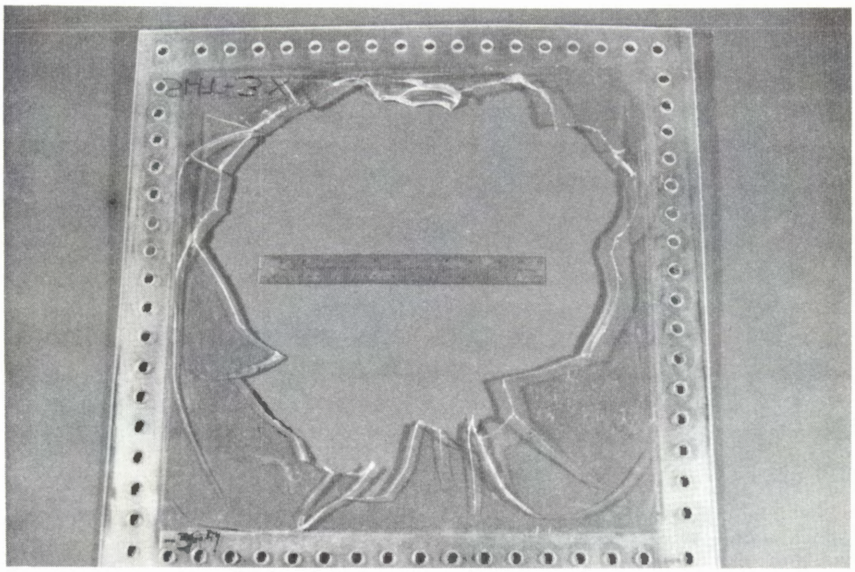


(b) TEST 18 VIEW ALONG INBOARD SURFACE

FIG. 12 0.250 IN. TK. POLYCARBONATE, NEW MATERIAL - HEAT TREATED (DRY, POLISH, FORM) TYPICAL FAILURE



(a) TEST 24 (RECONSTRUCTED FRAGMENTS)



(b) TEST 24

FIG. 13 0.250 IN. TK. POLYCARBONATE, NEW MATERIAL - ARTIFICALLY AGED - HEAT TREATED (DRY, POLISH, FORM) - TYPICAL FAILURE