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EFFECTS OF SURFACE FLAWS ON IMPACT
RESISTANCE OF UNCOATED POLYCARBONATE

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Interim Technical Report for Period June 1981 - July 1981

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Uncoated aircraft transparency polycarbonate is highly susceptible to surface abrasions. This report describes an experimental effort of limited scope to determine the effects of flaws on the resistance of polycarbonate to the impulsed, high energy loading conditions of bird impact. Test fixturing for flaw formation and high rate load application to polycarbonate beam specimens is described. It is demonstrated that polycarbonate is sensitive to changes in scratch profile and is less sensitive to changes in scratch depth. Net absorbed

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energy decreases with increasing scratch depth. However, scratches of any depth produce fracture if the scratch has a sharp, "V"-shaped profile.

FOREWORD

The investigation documented herein was performed by the Applied Mechanics Group, Aerospace Mechanics Division of the University of Dayton Research Institute, Dayton, Ohio, under contract F33615-80-C-3401, Project 1926, "Birdstrike Resistant Crew Enclosure," for the Air Force Flight Dynamics Laboratory, Wright-Patterson Air Force Base, Ohio. Air Force administrative direction was provided by Lt. Robert Simmons, AFWAL/FIEA, the Program Manager. The effort was conducted from June 1981 to July 1981, under the supervision of Mr. Dale H. Whitford, Supervisor, Aerospace Mechanics Division, Mr. Blaine S. West, Head, Applied Mechanics Group, and Mr. Gregory J. Stenger, Project Engineer.

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SECTION 1

TEST PURPOSE AND METHOD

An experimental program of limited scope was conducted to determine the effect of flaw size on the impact resistance of uncoated monolithic polycarbonate. The testing was accomplished using a high rate (2000 in/min) MTS testing machine and a three-point bending fixture to bend the specimens so that the flawed surfaces were in tension. The span between fixture supports was four inches and the support and impactor radii were 0.125 inches. The polycarbonate was machined to a size of 0.5 x 1.00 x 7 ±0.1, with a scratch 0.33 inches in length centered across the width at the beam's mid-length, as shown in Figure 1. The scratches were made using three methods: the needle point of a draftsman's compass; 600-grit dry emery paper; and a thin steel, circular blade (ground from a used milling machine cutter) rigidly held in place by a fixture chucked in a milling machine. The latter method gave good repeatability of scratch depth and length.

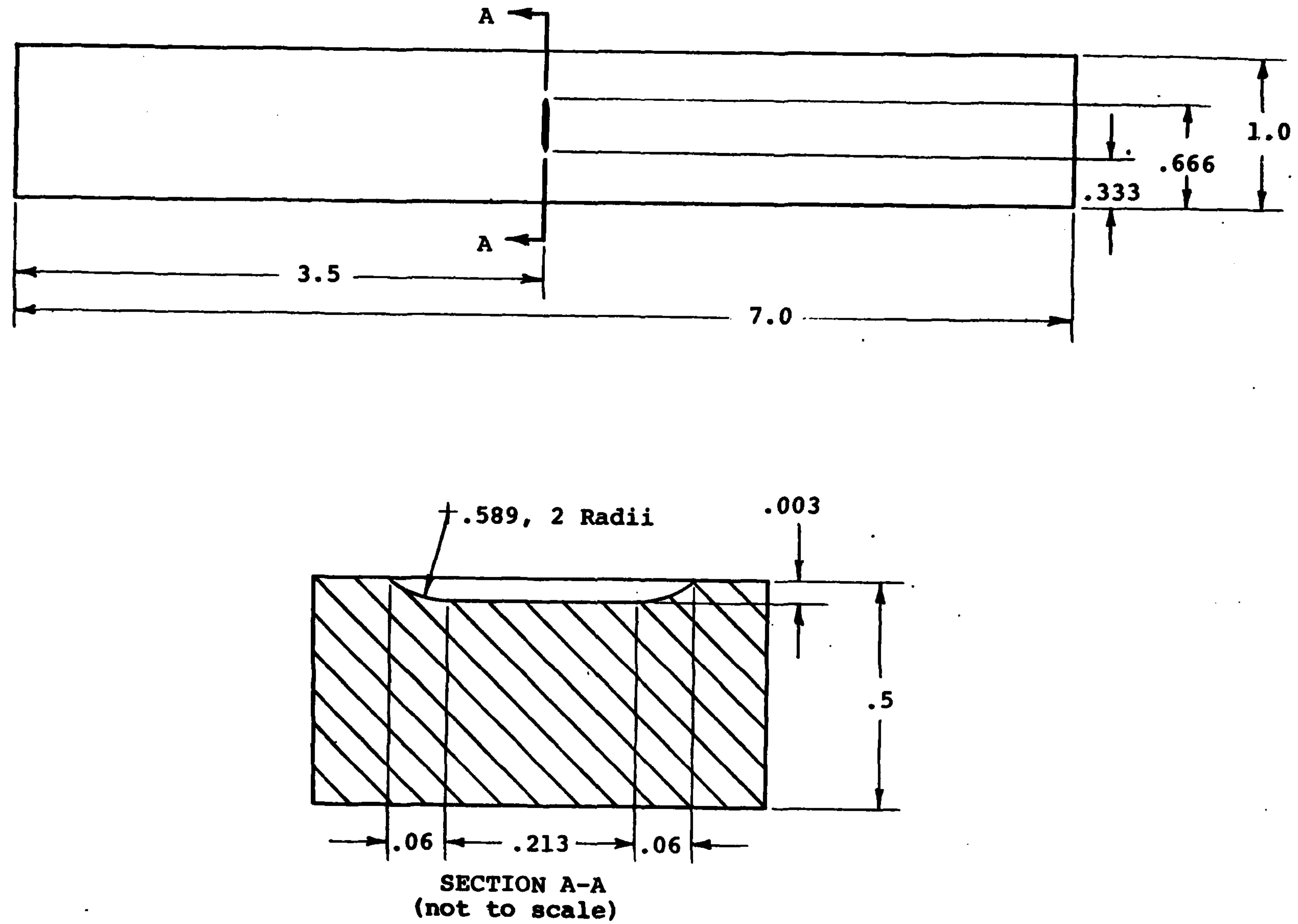


Figure 1. Test Specimen for Scratch Depth Study.

SECTION 2
TESTS AND RESULTS

Six specimens were initially tested: two unflawed, two with a scratch depth of 0.003 inches, and two with a scratch depth of 0.020 inches. (See Figures 3 and 4 for photomicrographs of the profiles of two of these scratches.) These flaw sizes were chosen because they were representative of actual flaw sizes and because the great difference in depths would make apparent any correlation of scratch depth with impact resistance and mode of failure. The scratches were made using the circular blade.

Under load, the unflawed specimens plastically deformed, but did not break. The average yield stress (defined using the 0.2 percent offset method) was 10,830 psi and the average net energy absorbed was 1025 ft.•lb. Figure 5 shows the load-displacement curve for one of the samples. The flawed specimens, on the other hand, broke under load. The yield stress for these specimens averaged 10,640 psi for those with the deeper scratches (.020 inches) and 10,730 psi for those with the shallower scratches (.003 inches). Because of breaking, the net absorbed energy was reduced to 552 ft.•lb., for the deep-scratched beams and to 592 ft.•lb., for the shallow-scratched beams. Figures 6 and 7 give load-displacement curves for the two scratched specimen types.

Because breakage appeared to be independent of scratch depth in the initial series of tests, it was decided to test beams with scratches between 0.000 inches and 0.003 inches in depth to verify this observation. Five follow-on tests of three types were carried out for this purpose. The first type consisted of two samples scratched to a depth of approximately 0.001 inches by the circular blade. The second type consisted of two samples hand-scratched to a depth of approximately 0.0005 inches with the sharp point of a draftsman's compass (see Figure 2). The last type consisted of one sample abraded by rubbing the surface with 600-grit dry emery paper.

Load displacement curves for these tests appear in Figures 8-10. The blade-scratched and grit-scratched beams broke under load. The yield stress averaged 10,920 psi for both types. The net absorbed energy was 625 ft.·lbs., for the blade-scratched specimens and 930 ft.·lb., for the grit-scratched specimens. From these energies, plus those obtained from the initial six tests, it appears that the net absorbed energy for the beams which fail by breaking decreases as scratch depth increases (see Table 1). The compass-scratched specimens, which yielded at 10,330 psi and absorbed a net energy of 1000 ft. lb., (see Figure 9), did not break under load. It is believed that the reason they did not break is because the compass point was too blunt to produce a sharp, "V"-shaped scratch (as do the circular blade and emery paper).

SECTION 3
CONCLUSIONS

Based on the 11 beam tests performed to date it has been found that surface scratches in uncoated monolithic polycarbonate reduce the impact resistance and ductility of the material. Sharp, "V"-shaped scratches, when in tension across the beam width, cause polycarbonate to fracture without yielding. As the sharpness of the scratch increases, the tendency toward brittle fracture increases. A blunt scratch may or may not cause brittle fracture, depending on scratch depth. However, scratch depth has no effect in changing the mode of failure from brittle fracture to inelastic yielding as long as the scratch profile is a sharp "V" shape. Thus shallow, sharp scratches produce the same brittle failure mode in polycarbonate as deep, sharp scratches do. Changing the depth does, however, affect the impact resistance (net absorbed energy). As the depth of scratch increases, the net absorbed energy decreases. Finally, it should be noted that the geometry along the length of the scratch (as shown in Figure 1) may affect the impact resistance and mode of failure.

Recommendations

1. Perform more extensive laboratory testing on specimens scratched to various depths, lengths, and profiles to substantiate the results of this study. The effects of crazing should also be included in this investigation.

2. Obtain better characterization data for in-service scratches (length, depth, profile) correlating the scratches with their causes, if possible.

3. Perform more extensive laboratory testing on specimens with scratches similar to in-service ones. Investigate the effects of weathering, stressing, and solvents on the scratches (i.e., do these factors sharpen the scratch profile or propagate cracks from the scratch tip?).

4. If required, perform similar tests with monolithic stretched and/or as-cast acrylic.

5. Establish a method of viewing and measuring scratch profile that does not require sectioning of the specimen (which could smear the scratch profile or induce cracks at the scratch tip).

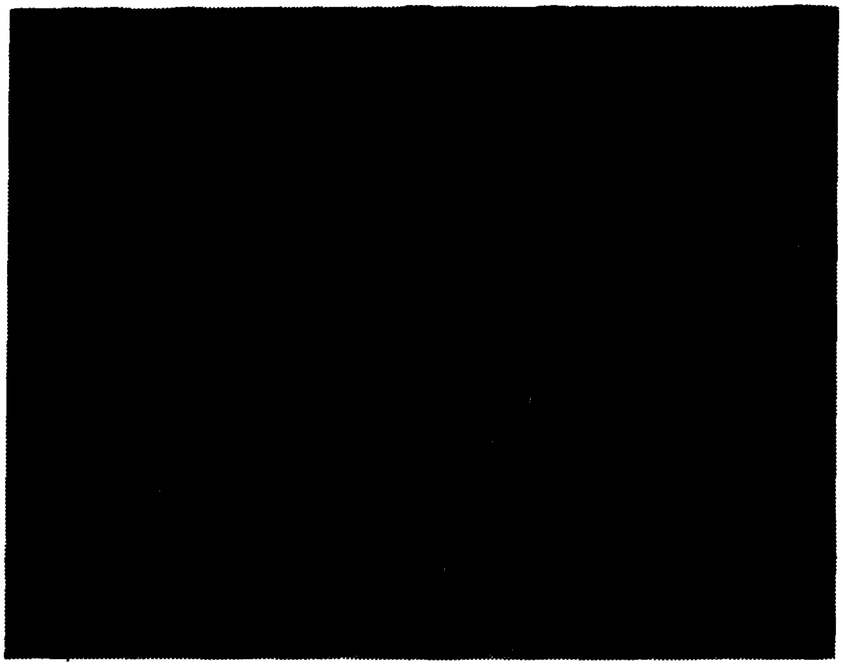


Figure 2. Profile of a Scratch Having a Depth of 0.00034 inches (Magnification = 294X).

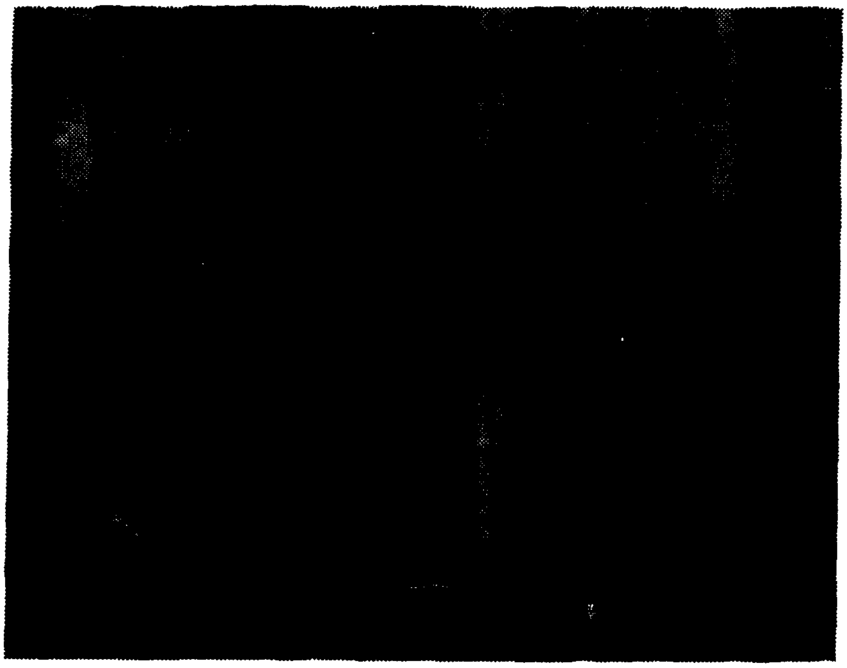
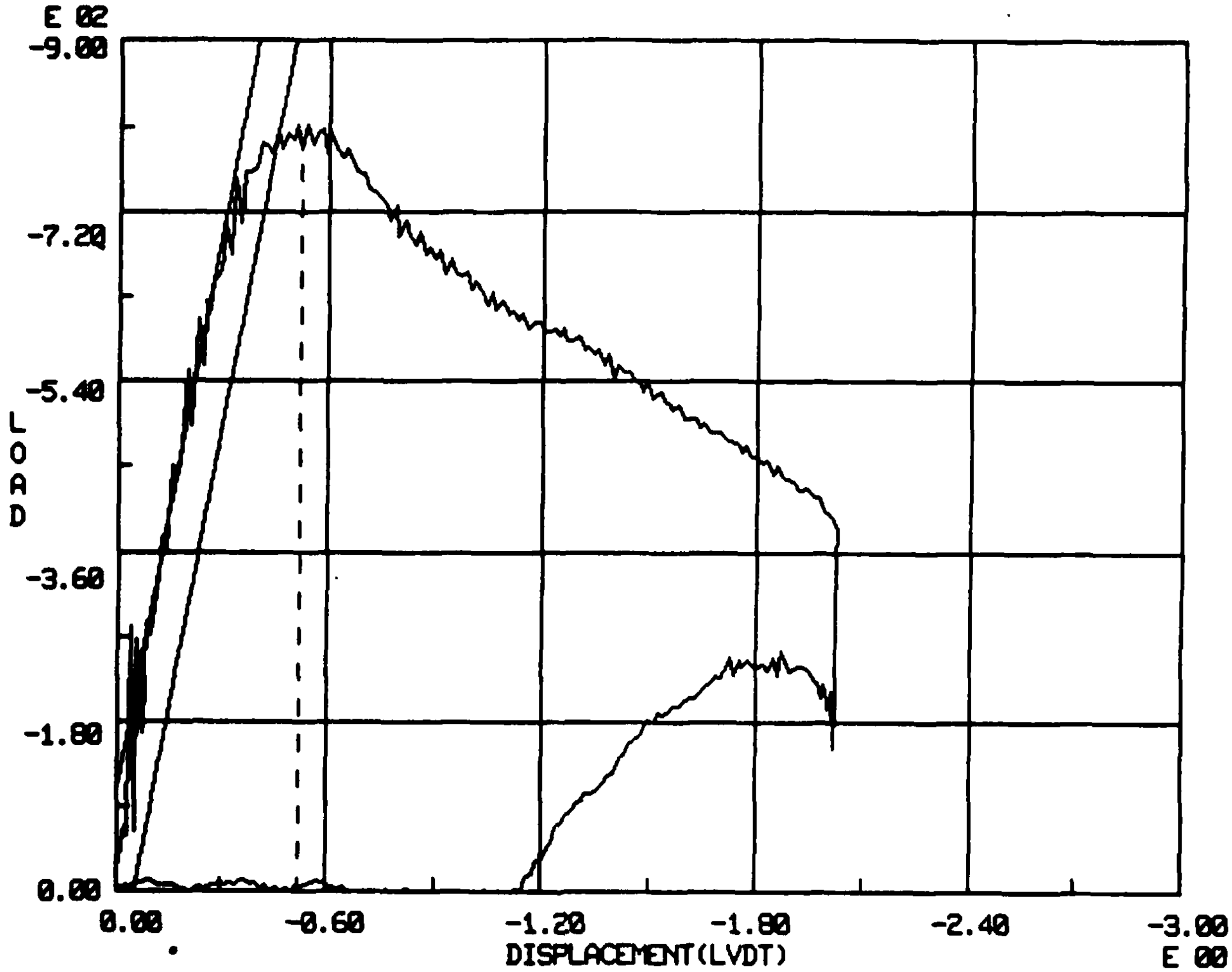


Figure 3. Profile of a Scratch Having a Depth of .01771 Inches (Magnification = 52X).

Figure 4. Profile of a Scratch Having a Depth of .00315 Inches (Magnification = 208X).



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UD TEST NUMBER 1 DESCRIPTION— ZC-9 POLYCARBONATE BEAM
RATE OF TEST 2000 OFFSET STRAIN 2 PERCENT
WIDTH 1.001 INCHES THICKNESS .501 INCHES
TEST SPAN 4 INCHES

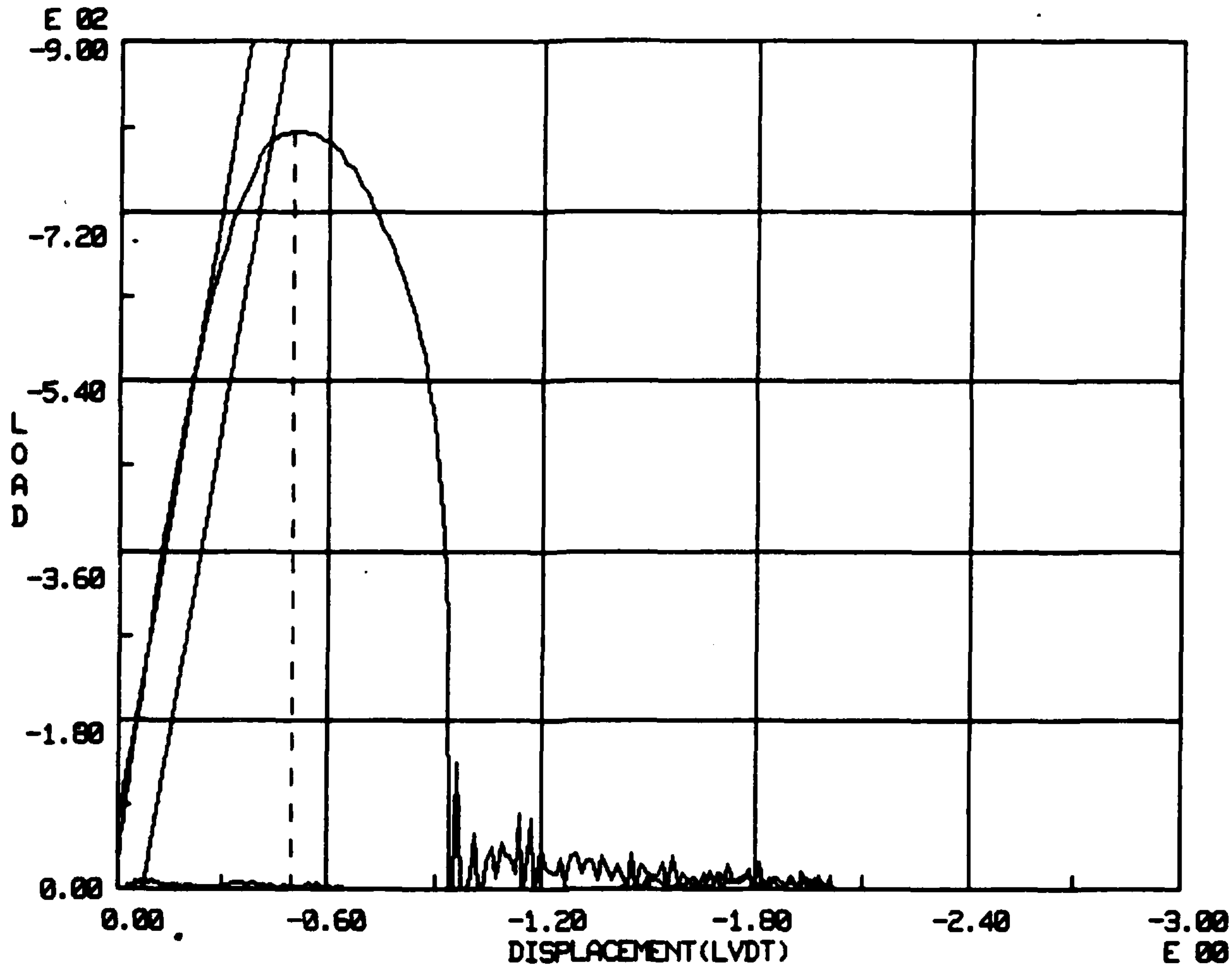
********************ENGINEERING ANALYSIS****************************

STIFFNESS 1978 YIELD LOAD -805 ULTIMATE LOAD -785
MODULUS 251420 YIELD STRESS -10928 ULTIMATE STRESS -10973
YIELD STRAIN -.086 ULTIMATE STRAIN -.098

LOAD AT MAX. DISP. -383 ENERGY TO ULTIMATE 288
STRESS AT MAX. DISP. -12816 ENERGY TO MAX. DISP. 1173
STRAIN AT MAX. DISP. -.381 NET ENERGY 1016

DISP. TO YIELD -.456 MAXIMUM DISP. -2.026
DISP. TO ULTIMATE -.523 RESIDUAL DISP. -4.00000E-03

Figure 5. Load Displacement Curve for Unscratched Specimen.



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UD TEST NUMBER 4 DESCRIPTION-- ZC-8 SCRATCHED P/C BEAM
RATE OF TEST 2000 OFFSET STRAIN 2 PERCENT
WIDTH 1.005 INCHES THICKNESS .5 INCHES
TEST SPAN 4 INCHES

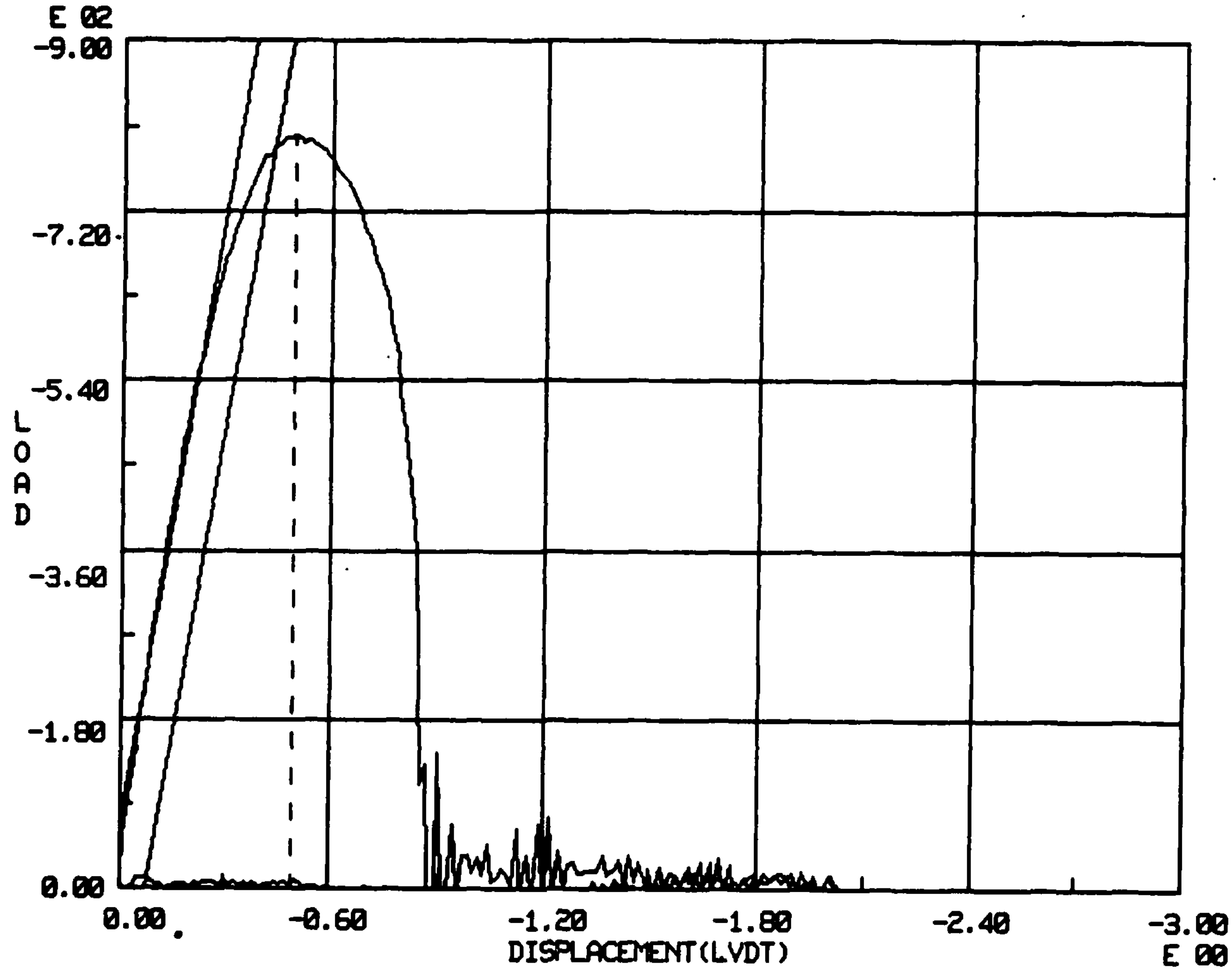
************************ENGINEERING ANALYSIS*********************************

STIFFNESS 2191 YIELD LOAD -796 ULTIMATE LOAD -804
MODULUS 279053 YIELD STRESS -10682 ULTIMATE STRESS -11105
YIELD STRAIN -.081 ULTIMATE STRAIN -.094

LOAD AT MAX. DISP. 1 ENERGY TO ULTIMATE 271
STRESS AT MAX. DISP. 33 ENERGY TO MAX. DISP. 596
STRAIN AT MAX. DISP. -.38 NET ENERGY 585

DISP. TO YIELD -.432 MAXIMUM DISP. -2.025
DISP. TO ULTIMATE -.501 RESIDUAL DISP. 4.00000E-03

Figure 6. Load Displacement Curve for Scratched Specimen (0.003 in. deep).



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UD TEST NUMBER 5 DESCRIPTION-- ZC-16 SCRATCHED P/C BEAM
RATE OF TEST 2000 OFFSET STRAIN 2 PERCENT
WIDTH 1 INCHES THICKNESS .501 INCHES
TEST SPAN 4 INCHES

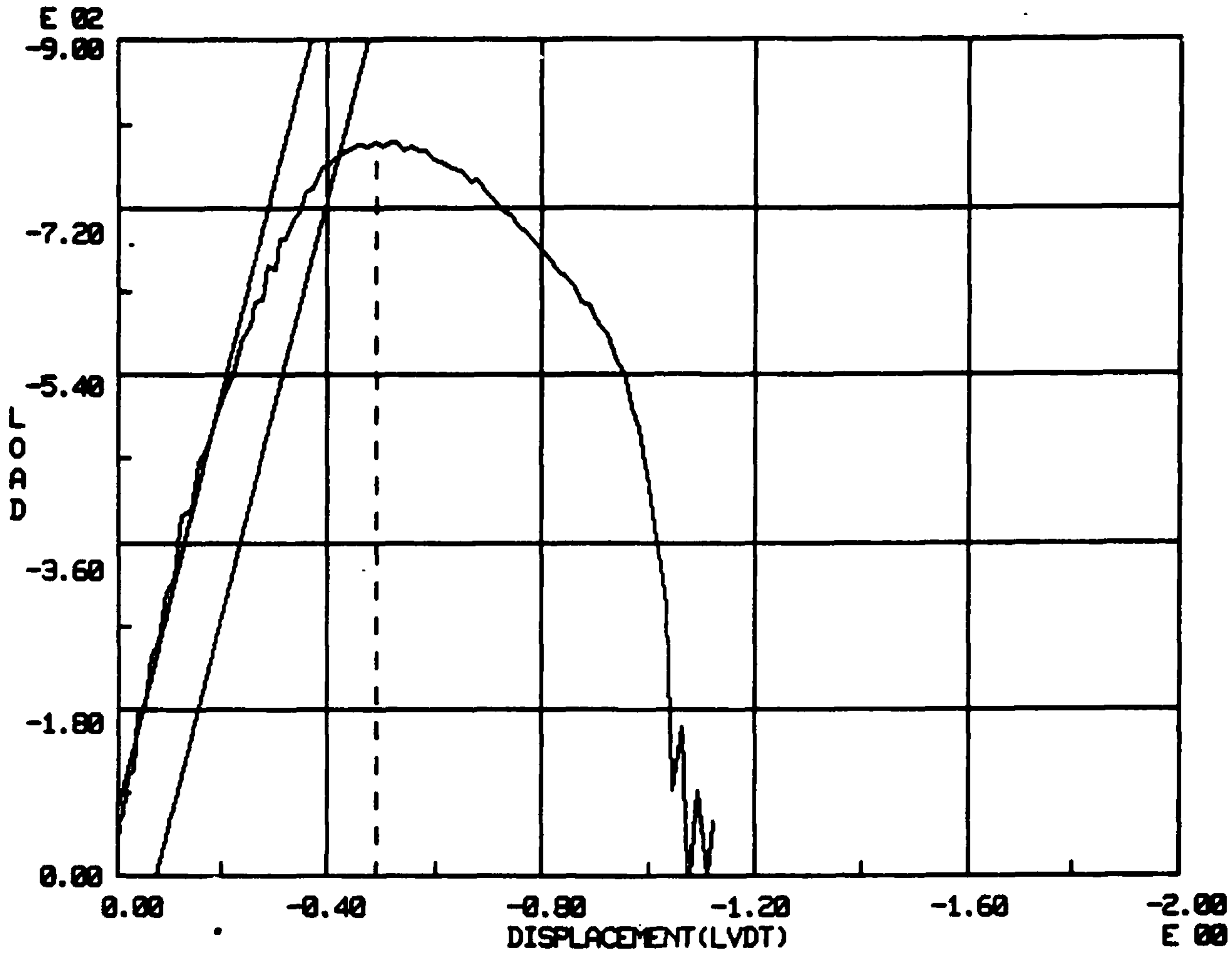
**************ENGINEERING ANALYSIS**************

STIFFNESS 2161 YIELD LOAD -791 ULTIMATE LOAD -799
MODULUS 274955 YIELD STRESS -10665 ULTIMATE STRESS -11042
YIELD STRAIN -.082 ULTIMATE STRAIN -.093

LOAD AT MAX. DISP. 0 ENERGY TO ULTIMATE 265
STRESS AT MAX. DISP. 16 ENERGY TO MAX. DISP. 534
STRAIN AT MAX. DISP. -.381 NET ENERGY 522

DISP. TO YIELD -.436 MAXIMUM DISP. -2.029
DISP. TO ULTIMATE -.496 RESIDUAL DISP. 4.00000E-03

Figure 7. Load Displacement Curve for Scratched Specimen (0.020 in. deep).



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UD TEST NUMBER 4   DESCRIPTION-- POLYCARBONATE BEAM ZC-15
RATE OF TEST 2000   OFFSET STRAIN 2 PERCENT
WIDTH 1 INCHES   THICKNESS .5 INCHES
TEST SPAN 4 INCHES

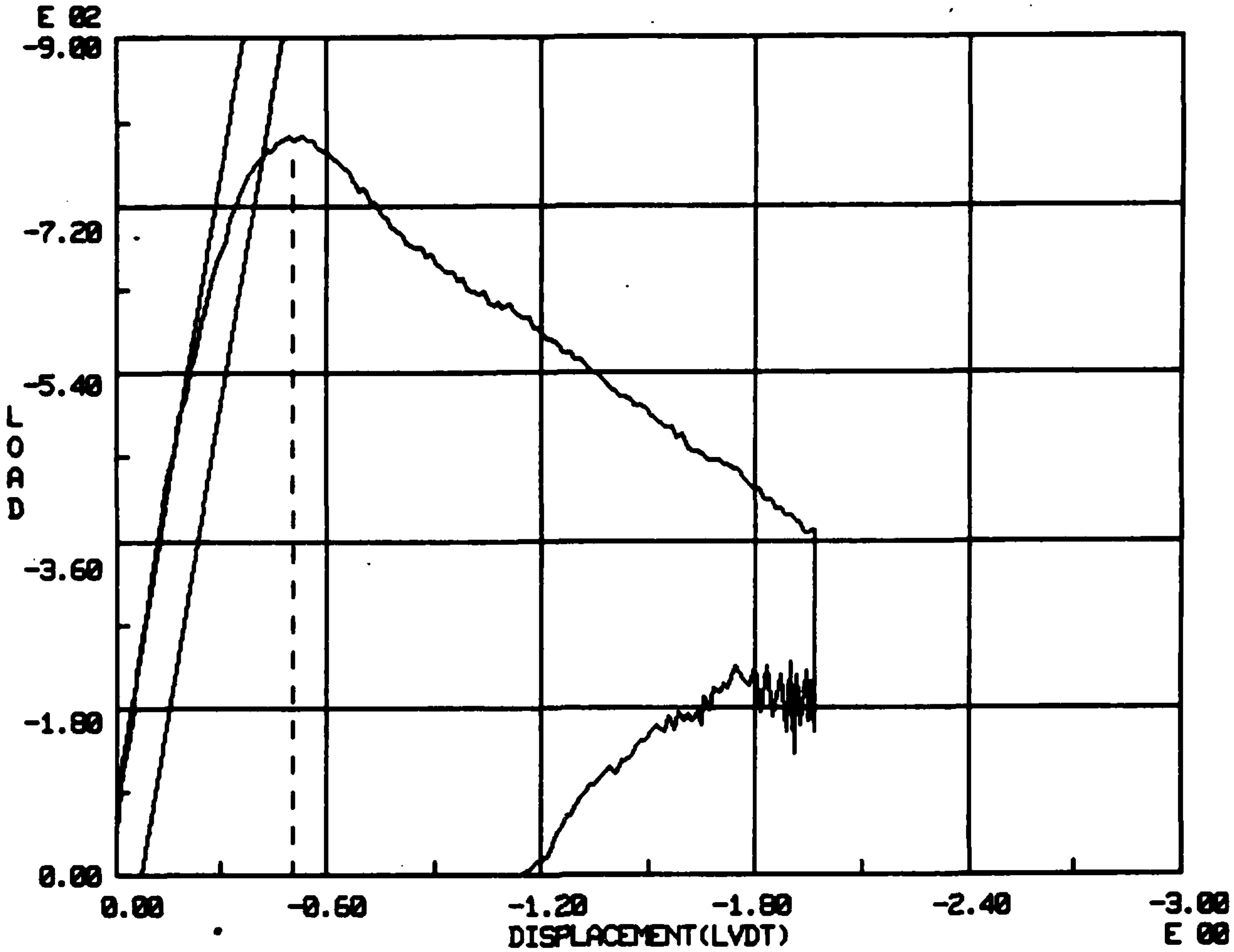
*********************ENGINEERING ANALYSIS************************************

STIFFNESS 2244   YIELD LOAD -769   ULTIMATE LOAD -791
MODULUS 287232   YIELD STRESS -10280   ULTIMATE STRESS -10932
YIELD STRAIN -.076   ULTIMATE STRAIN -.092

LOAD AT MAX. DISP. -61   ENERGY TO ULTIMATE 262
STRESS AT MAX. DISP. -1183   ENERGY TO MAX. DISP. 632
STRAIN AT MAX. DISP. -.211   NET ENERGY 632

DISP. TO YIELD -.408   MAXIMUM DISP. -1.124
DISP. TO ULTIMATE -.49   RESIDUAL DISP. -1.124

Figure 8. Load Displacement Curve for Scratched Specimen (0.001 in. deep).



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UD TEST NUMBER 3   DESCRIPTION-- POLYCARBONATE BEAM ZC-14
RATE OF TEST 2000   OFFSET STRAIN 2 PERCENT
WIDTH 1 INCHES   THICKNESS .5 INCHES
TEST SPAN 4 INCHES

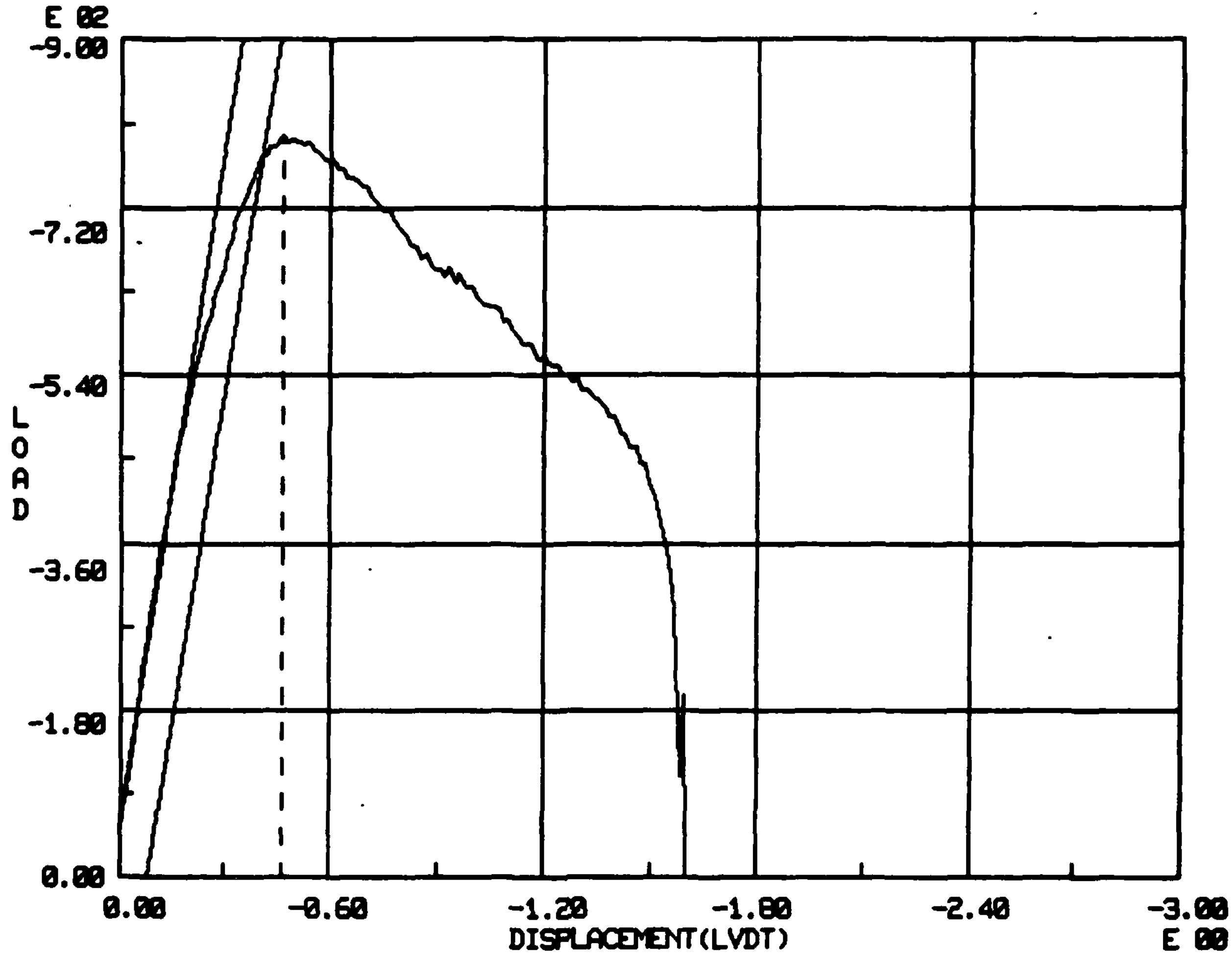
*******************ENGINEERING ANALYSIS***************************

STIFFNESS 2225   YIELD LOAD -769   ULTIMATE LOAD -790
MODULUS 284800   YIELD STRESS -10314   ULTIMATE STRESS -10985
YIELD STRAIN -.078   ULTIMATE STRAIN -.095

LOAD AT MAX. DISP. -365   ENERGY TO ULTIMATE 275
STRESS AT MAX. DISP. -11830   ENERGY TO MAX. DISP. 1116
STRAIN AT MAX. DISP. -.369   NET ENERGY 1000

DISP. TO YIELD -.416   MAXIMUM DISP. -1.969
DISP. TO ULTIMATE -.504   RESIDUAL DISP. -1.181

Figure 9. Load Displacement Curve for Scratched Specimen (0.005 in. deep).



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UD TEST NUMBER 5 DESCRIPTION-- POLYCARBONATE BEAM ZC-6
RATE OF TEST 2000 OFFSET STRAIN 2 PERCENT
WIDTH 1 INCHES THICKNESS .5 INCHES
TEST SPAN 4 INCHES

*************************ENGINEERING ANALYSIS**************************************

STIFFNESS 2376 YIELD LOAD -773 ULTIMATE LOAD -798
MODULUS 304128 YIELD STRESS -10290 ULTIMATE STRESS -10898
YIELD STRAIN -.075 ULTIMATE STRAIN -.087

LOAD AT MAX. DISP. 112 ENERGY TO ULTIMATE 242
STRESS AT MAX. DISP. 2938 ENERGY TO MAX. DISP. 931
STRAIN AT MAX. DISP. -.303 NET ENERGY 928

DISP. TO YIELD -.398 MAXIMUM DISP. -1.615
DISP. TO ULTIMATE -.464 RESIDUAL DISP. -1.596

Figure 10. Load Displacement Curve for Abraded Specimen (600-grit Emery Paper).

TABLE 1

NET ABSORBED ENERGIES FOR BROKEN SPECIMENS

Scratch Depth (in.)	Net Absorbed Energies (ft.lb)
0.020	522
0.020	522
0.003	599
0.003	585
0.001	616
0.001	632
unknown*	928

*Scratches caused by 600-grit emery paper

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