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A DAMAGE TOLERANCE COMPARISON OF IM7/8551 AND IM8G/8553 CARBON/EPOXY COMPOSITES

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Materials and Processes Laboratory
Science and Engineering Directorate

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16. Abstract

A damage tolerance study of two new toughened carbon fiber/epoxy resin systems was undertaken as a continuation of ongoing work into screening new opposites for resistance to foreign object impact. This report is intended to be a supplement to NASA TP 3029 in which four new fiber/resin systems were tested for damage tolerance. Instrumented drop weight impact testing was used to inflict damage to 16-ply quasi-isotropic specimens. Instrumented output data and cross-sectional examination of the damage zone were utilized to quantify the damage. It was found that the two fiber/resin systems tested in this study were much more impact resistant than an untoughened composite such as T300/934, but were not as impact resistant as other materials previously studied.

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I. INTRODUCTION

Foreign object impact damage to carbon fiber reinforced composite materials is an area of concern for investigators because a low-damage tolerance level has been associated with the performance of this class of materials. In response to this reputation of carbon fiber composites, an effort has been made to produce more damage tolerant composites. Manufacturers of recently released polymeric resins have claims of better response to impact damage. The newer generation intermediate modulus carbon fibers have a significantly higher strain-to-failure and higher strength than their predecessors.

Low-velocity instrumented impact testing is a common and established method for studying the damage tolerance of composite systems [1–4]. Cross-sectional cutting of the impact site is also a standard means of revealing necessary information about the specimens [1,5–7]. A comparison of the data from these two experimental methods allows the correlation of impact energies with maximum load at impact, and visual damage such as delaminations and fiber breakage.

An effort is underway to characterize the performance of the newer generation carbon fiber/epoxy resin systems. In order for these composite systems to become more widely accepted and utilized in primary structures, research needs to be accomplished involving the tolerance of these materials to impacts. It is the purpose of this report to present preliminary results on two new composite systems and continue the effort made by Lance and Nettles [1].

II. DESCRIPTION

A. Materials and Test Methods

1. Materials. Two prepreg systems were utilized to prepare the specimens for this study. The fiber, resin, and prepreg for IM7/8551 and IM8G/8553 were all made by Hercules. Both fibers are intermediate modulus/high-strength fibers. Both resins have been promoted as being damage-tolerant epoxies.

A quasi-isotropic lay-up configuration $(0,-45,90,+45)_{2S}$ was used for both materials to achieve the 16-ply panels. The panels were cured according to the prepreg manufacturer's recommendation using a programmable platen press. The IM7/8551 had an average thickness of 2.71 mm. The IM8G/8553 had an average thickness of 2.26 mm. Square test specimens of 10.2 cm (4 in) were cut from the composite panels.

2. Impact Testing. The specimens were damaged using a Dynatup model 8200 instrumented drop weight apparatus with the impact information being obtained with a Dynatup 730 data acquisition system. The impactor had a mass of 1.77 kg and a hemispherical head with a diameter of 1.27 cm (0.5 in). The specimens were held fast using a pneumatic clamping mechanism which employed plates with 7.62-cm (3-in) diameter holes in each, through which the composite panels were exposed.

3. Visual Damage. The damage to the surface of each side of all test specimens was recorded and photographed using a 35 mm camera.

4. Specimen Cross Sectioning. One specimen for each impact energy level was cross-sectionally cut, perpendicular to the outer fibers, through the impact site. The cut was made with a Buehler diamond wafering blade. The specimens were examined and photographed at a ×20 magnification using a Zeiss stereo-optical microscope with a Zeiss MC100 automatic camera attachment.

B. Results

1. Plots From Impact Tests. The data acquisition system generated force-time and absorbed energy-time plots for each specimen impacted. The force-time plot displayed jagged lines as the damage occurred to the specimen. Those graphs with a sharp drop in force at the maximum load represent the impacts which resulted in fiber breakage. The absorbed energy-time curves are superimposed on the force-time plots. Damage to the materials accounts for only part of the impact energy lost, thus they are not examined in this report. The force-time and absorbed energy-time plots are presented in the appendix.

2. Maximum Load Versus Impact Energy Plots. The maximum load at impact was plotted against the impact energy for each energy level for both materials. The individual plots are nearly linear until the point where fiber breakage occurs. After fiber breakage, the maximum load-impact energy plot levels out. The peak point shows the load and energy the material can withstand before the fibers break. The individual graphs are given in figures 1 and 2. In figure 3, the two materials are compared with the maximum load of the most and least damage resistant composite materials from a previous study [1]. A graph with the maximum load normalized by surface density is given in figure 4. Surface density was used to normalize the maximum load at impact because its use emphasizes the effect of the weight of the specimen due to any thickness differences. For example, since all specimens were 16-plies thick, nominal ply thickness differences between the two materials made for slightly different overall thicknesses and thus different weights for a given square panel. To take into account this weight difference, surface density measurements were used since the increase in weight was due to the increased thickness and will be accounted for in these measurements. For the purposes of this plot, the surface density was determined to be 0.328 g/cm^2 for IM8G/8553 and 0.399 g/cm^2 for IM7/8551.

3. Surface Damage. The surface damage of each specimen was recorded after the impact. The results of both materials are given below. Photographs of several of the impacted specimens can be found in the appendix.

The IM8G/8553 plates displayed no damage until 8.6 J when a crack occurred in the bottom surface of the impacted region. A dent could be felt on the top (impacted) side at 10.3 J. A front-facing crack, similar to those in the first study [1], appeared at an impact level of 11.3 J. Fiber breakage occurred in the front dent at 14.9 J.

The IM7/8551 sustained damage on the first impact energy level of 7.4 J when a hairline crack appeared on the back surface. A front-facing crack was produced with an impact of 12.7 J. A noticeable front dent occurred at 17.4 J.

The front surface cracks were found on all IM8G/8553 specimens impacted with energies at or above 11.3 J, and all IM7/8551 specimens impacted at or above 12.7 J. Unlike the cracks in the previous study, these impact side cracks were not always perpendicular to the outer fiber direction. In one IM8G/8553 test, when fiber breakage occurred within the front dent, the cracks extended approximately 1 cm at an angle of 45° to the outer fibers.

4. Cross-Sectional Damage. A cross-sectioned cut was made through the impact side and perpendicular to the outer fibers for each specimen. Each plate was then examined and photographed. The photographs for selected impact energy levels can be found in the appendix.

The IM8G/8553 first displayed delaminations at 8.6 J. Matrix cracking occurred at 10.3 J. Fiber breakage was sustained at the 12.6 J energy level. For IM7/8551, hairline delaminations were first detected at 12.7 J. Matrix cracks were produced by a 16.2 J impact. Fiber breakage occurred at 17.4 J.

III. CONCLUSION

As a continuation of the effort to characterize new composite systems, this study was intended to show the response of two damage-tolerant composite materials to a blunt, low-velocity impact.

Low-velocity impact testing provides important data on a composite system. Using this technique, materials can be easily compared for damage tolerance.

The IM7/8551 proved to be a superior damage-resistant fiber/resin system compared to the IM8G/8553. The IM7/8551 withstood a maximum impact load of 5,264.4 N at the peak point, which was 33 percent higher than the maximum impact load of 3,955.6 N that the IM8G/8553 withstood. The cross-sectional photographs displayed in the appendix also support this conclusion.

These two fiber/resin systems were much more damage tolerant than the standard T300/934, but not quite as damage tolerant as the IM7/1962 examined in a previous study [1]. The IM7 and IM8G fibers differ only in the fact that the IM8G has a slightly higher tensile modulus. All other properties are essentially the same. This results in a lower strain-to-failure for the IM8G fiber, causing it to sustain a lower damage tolerance level.

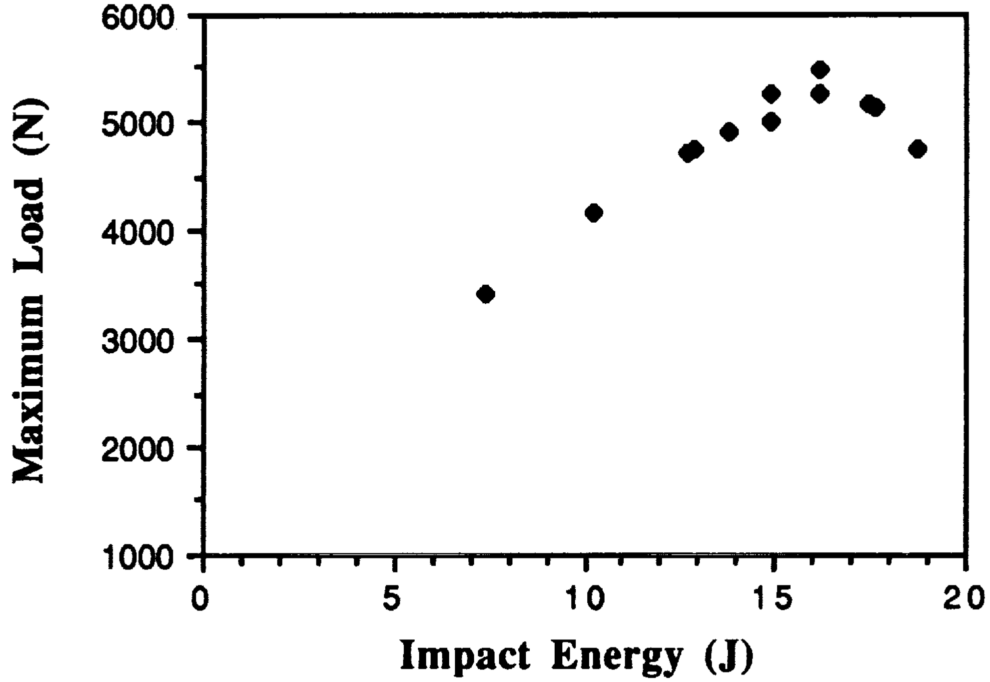


Figure 1. Maximum load versus impact energy for IM7/8551.

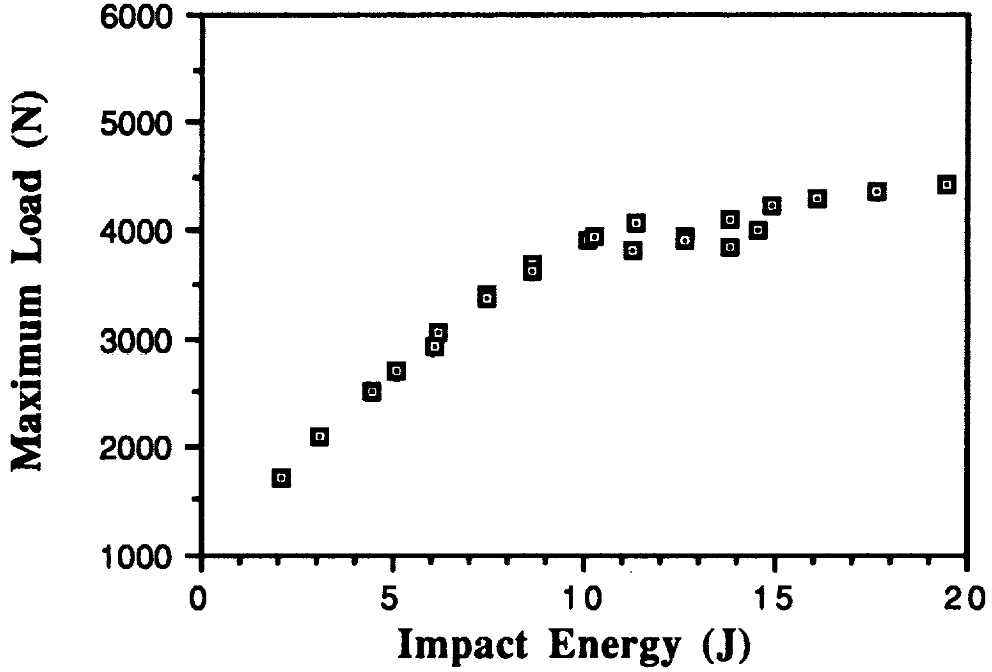


Figure 2. Maximum load versus impact energy for IM8G/8553.

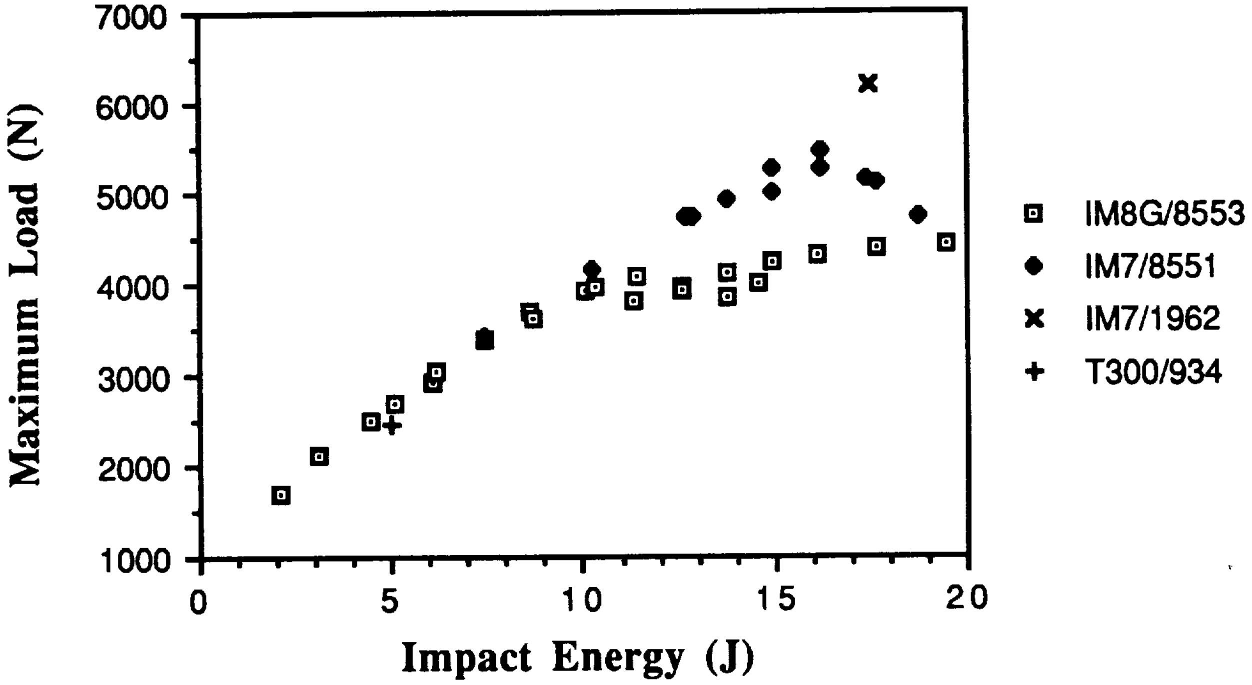


Figure 3. Comparison of test systems with maximum load point of IM7/1962 and T300/934.

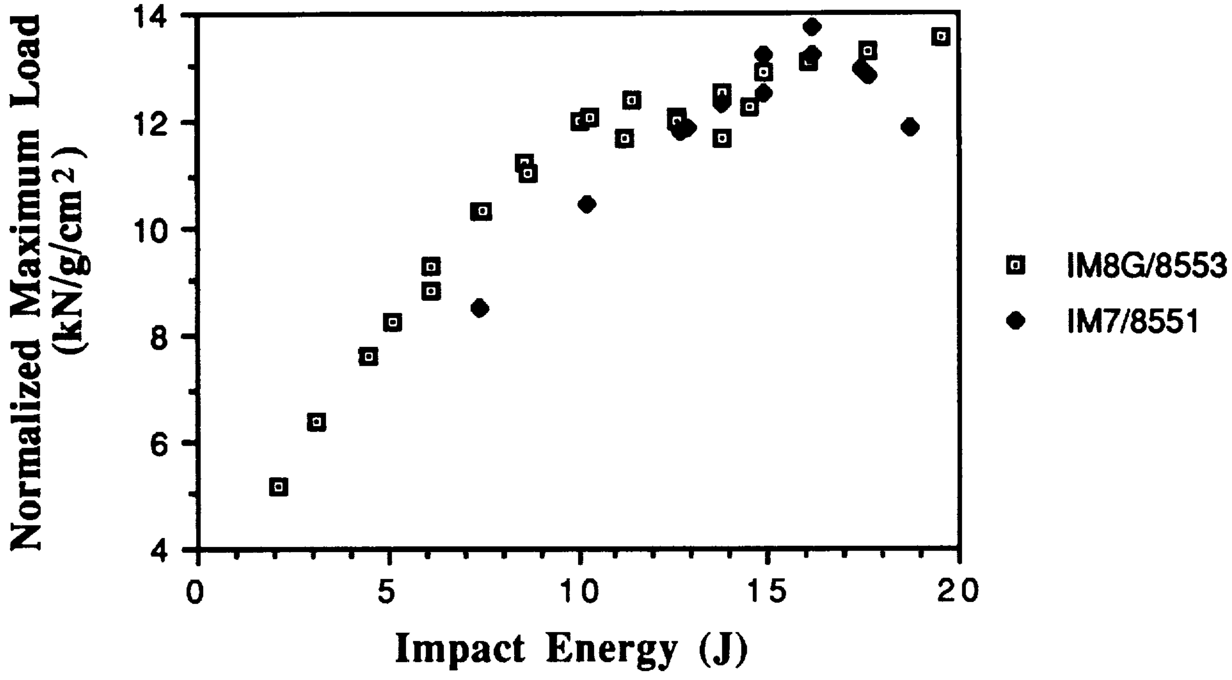
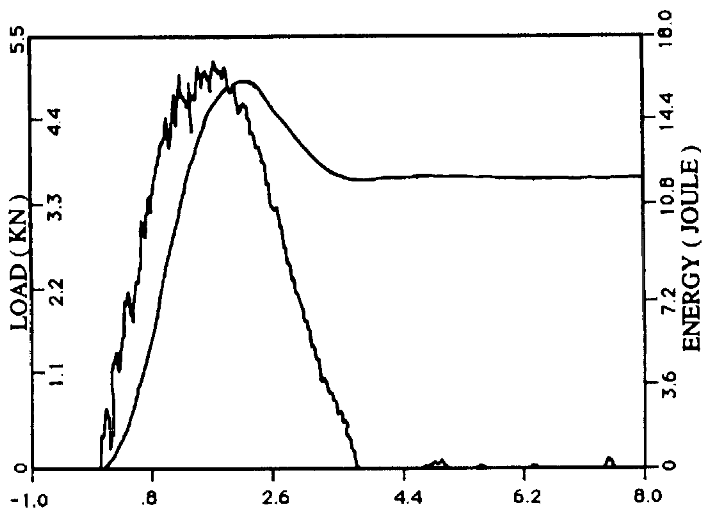


Figure 4. Maximum load normalized by surface density versus impact energy.

APPENDIX

Instrumented Output, Cross-Sectional Photographs, and Surface Photographs for Selected Energy Levels



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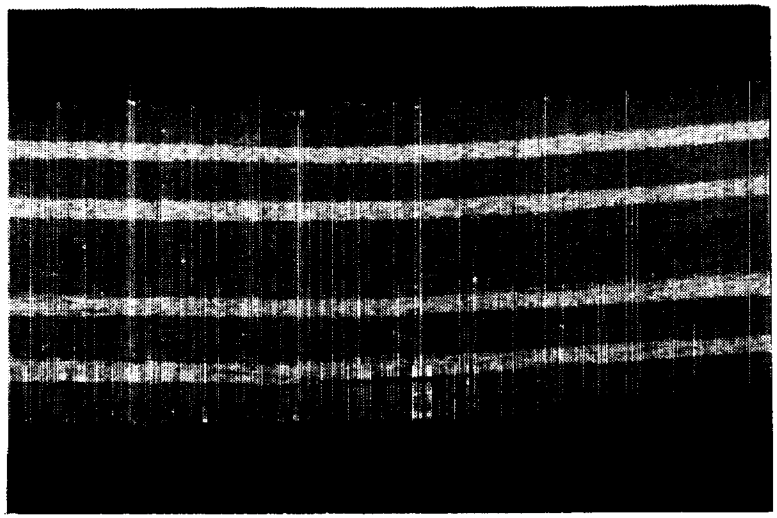

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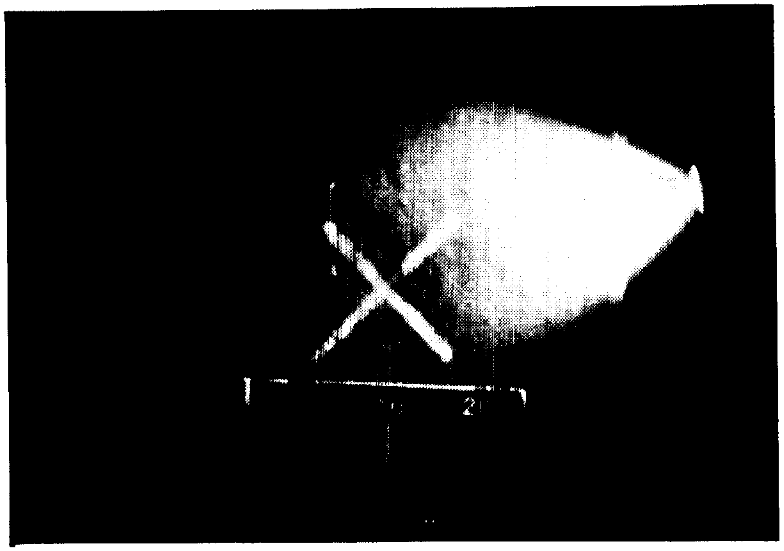

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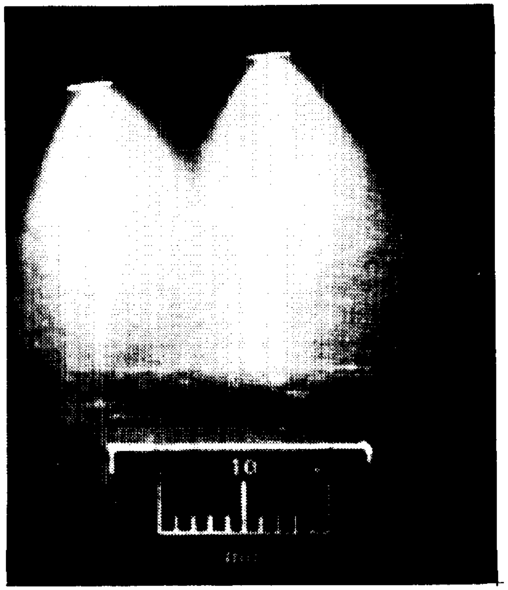

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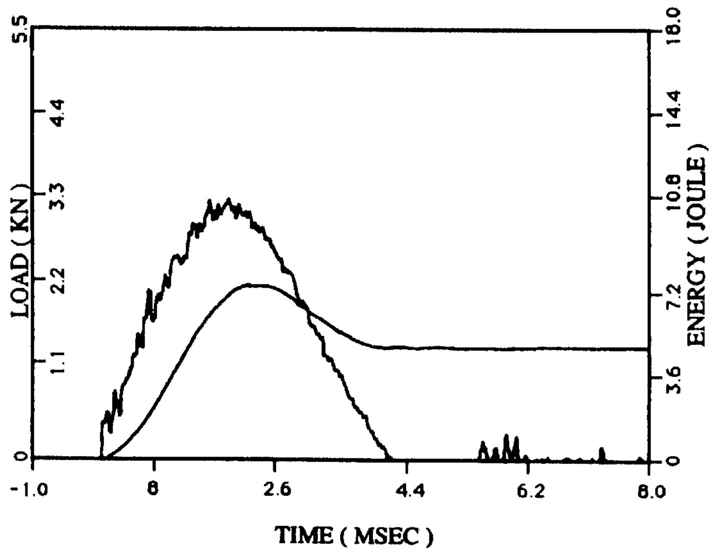
IM7/8551 IMPACT ENERGY 16.2 J



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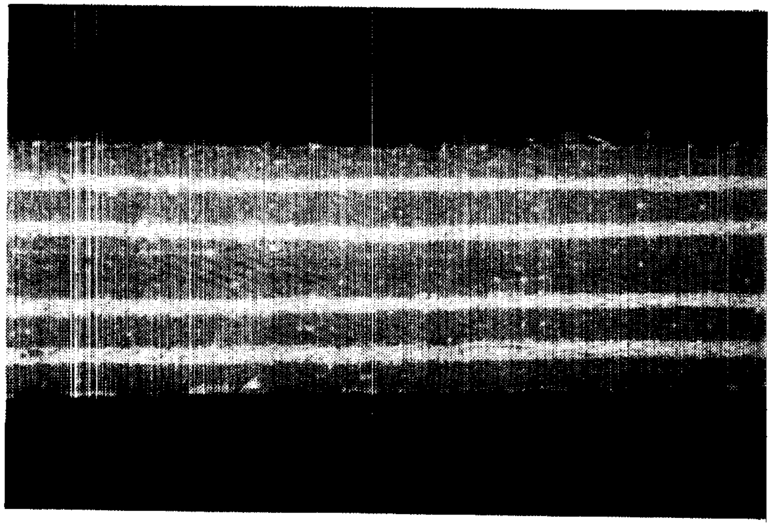

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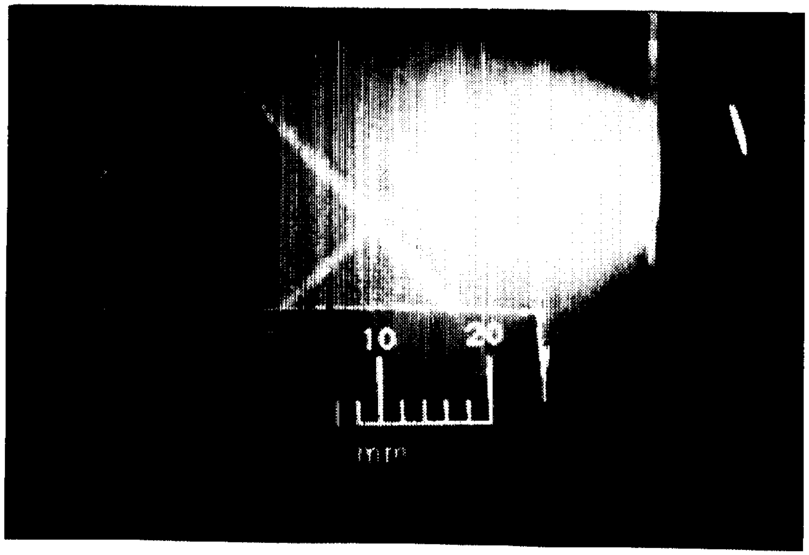

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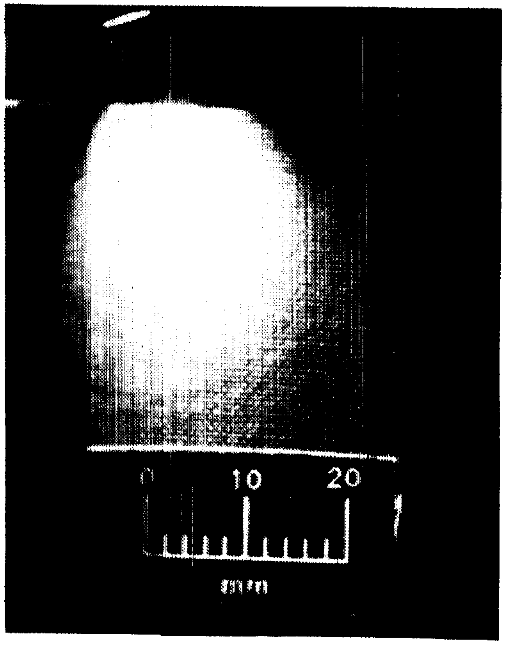

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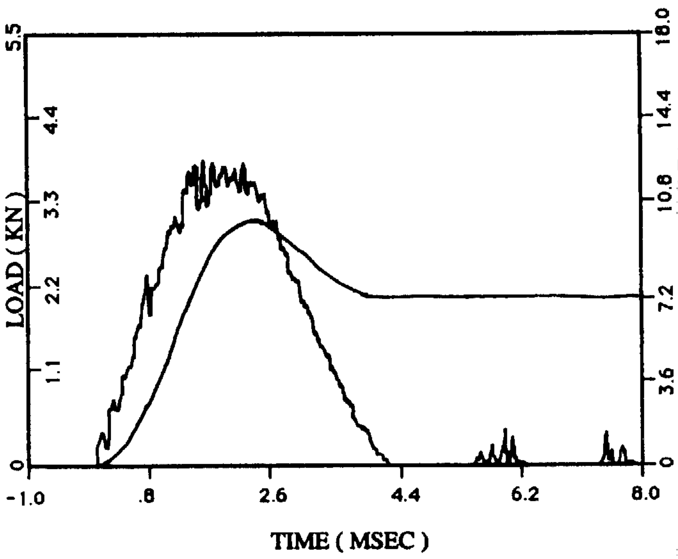
IM8G/8553 IMPACT ENERGY 7.4 J



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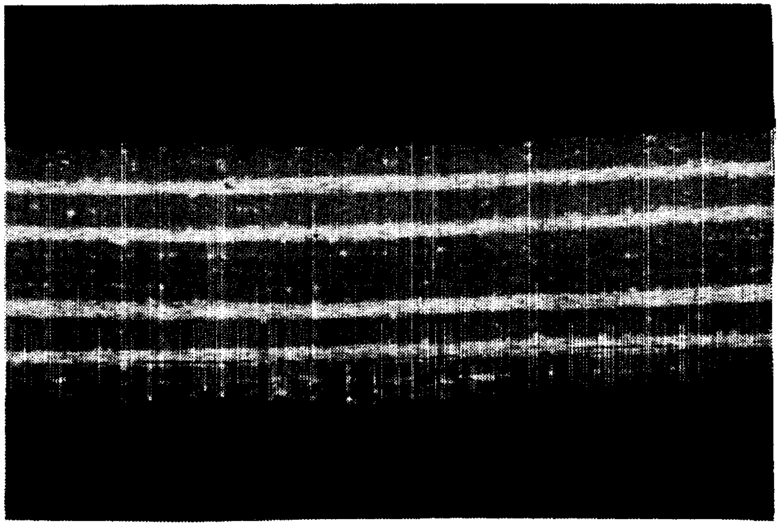

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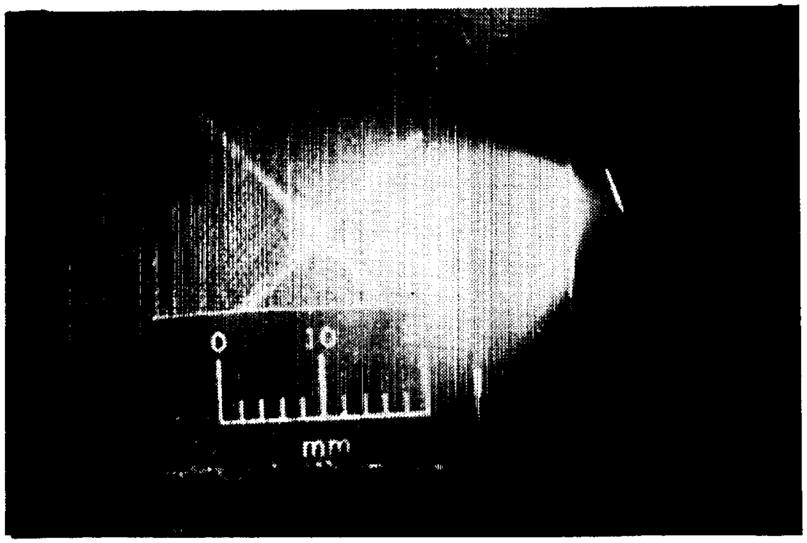

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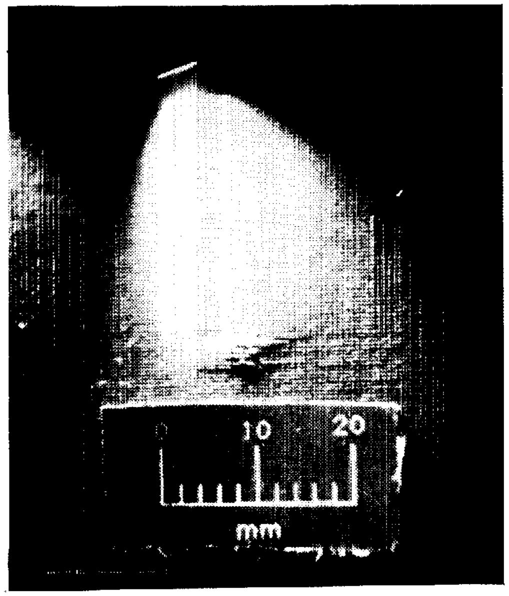

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IM8G/8553 IMPACT ENERGY 10.3 J

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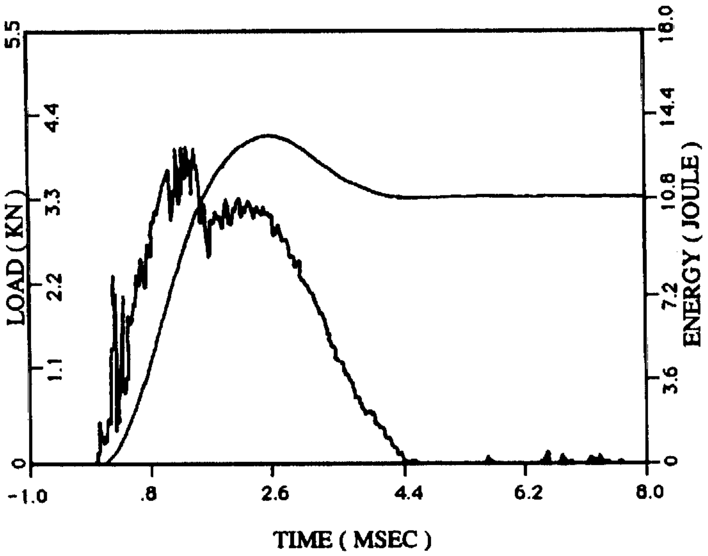

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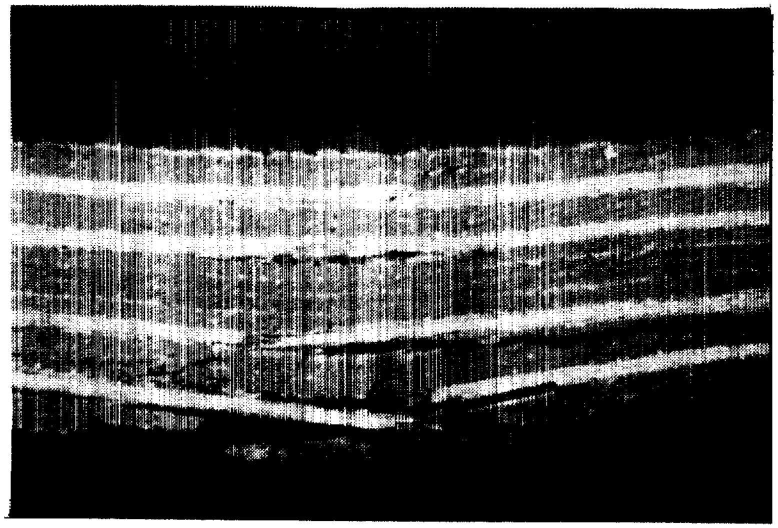

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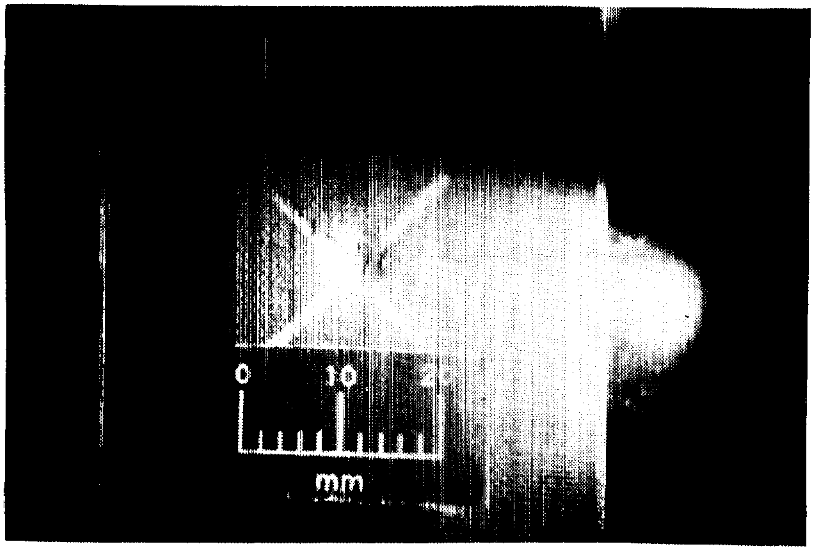

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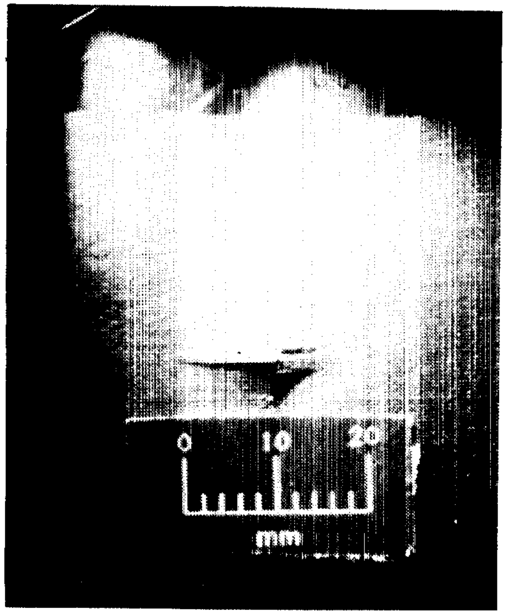

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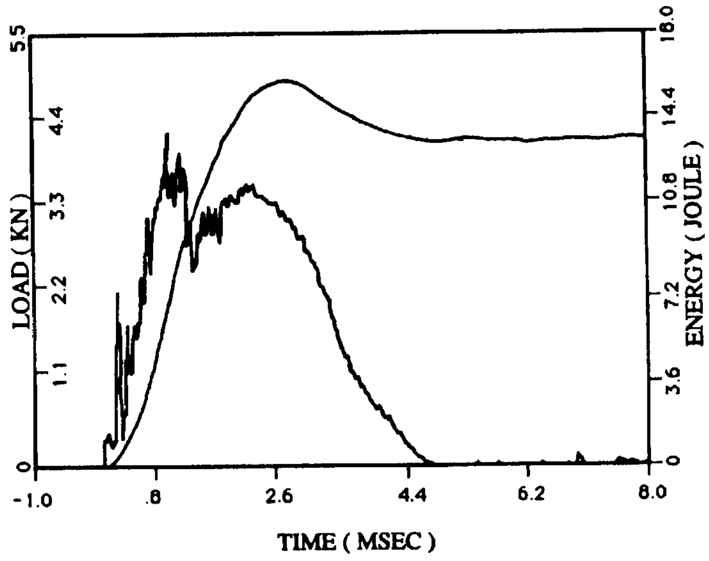
IM8G/8553 IMPACT ENERGY 13.8 J



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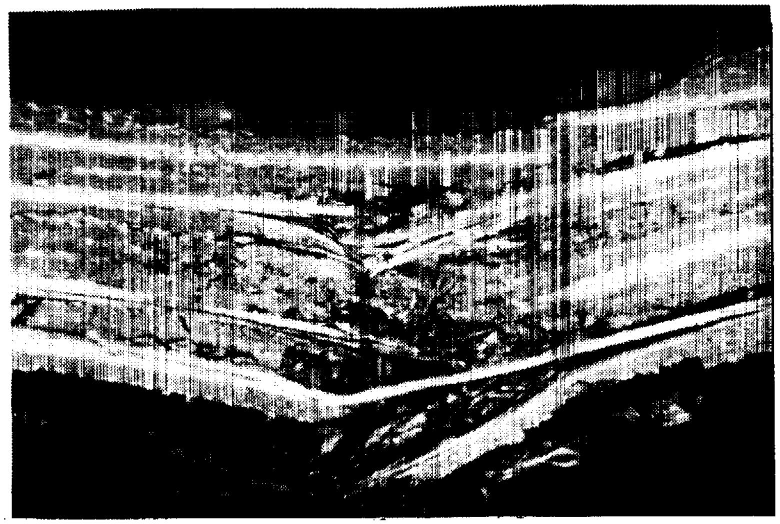

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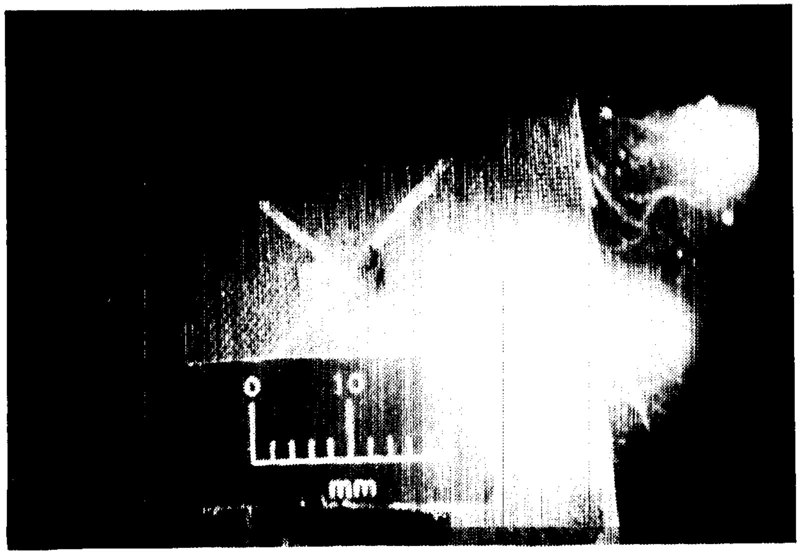

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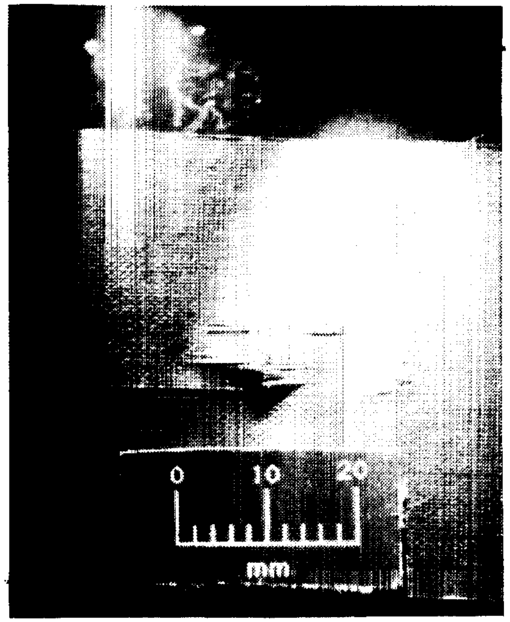

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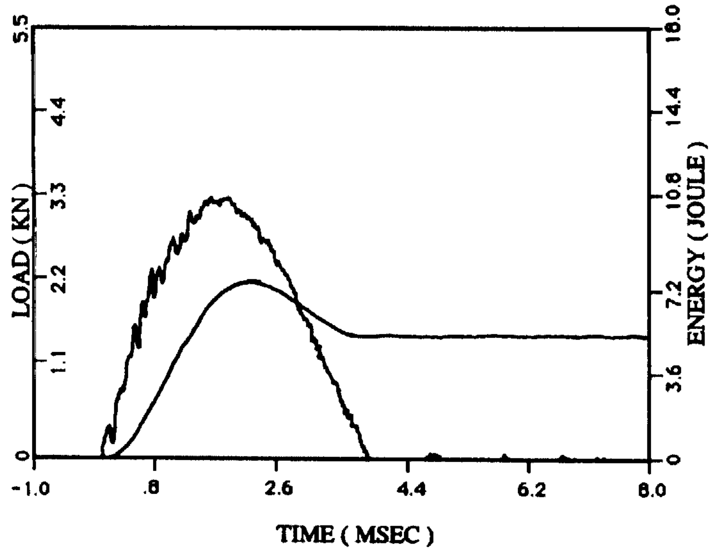

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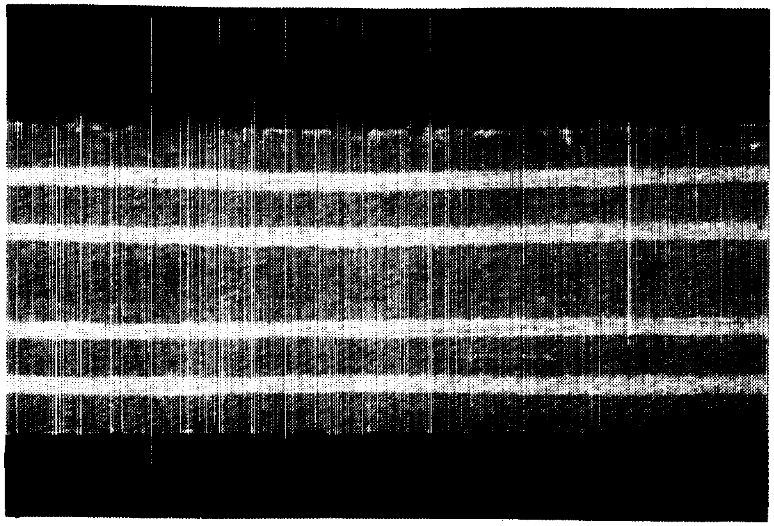

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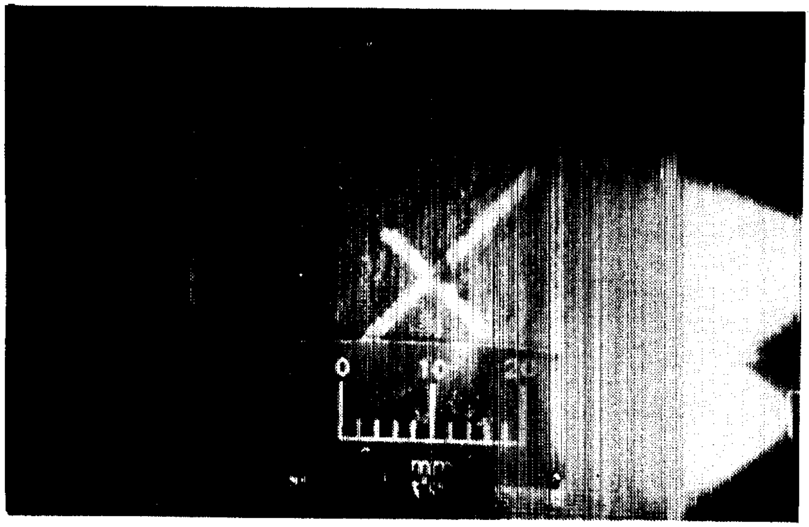

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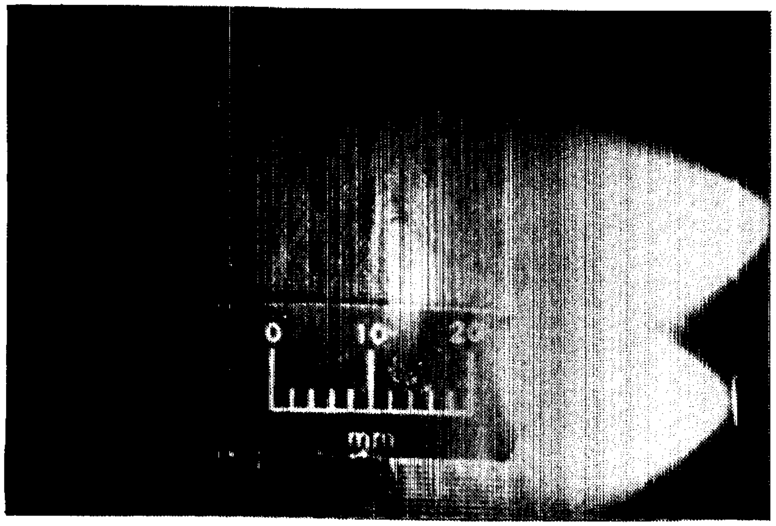

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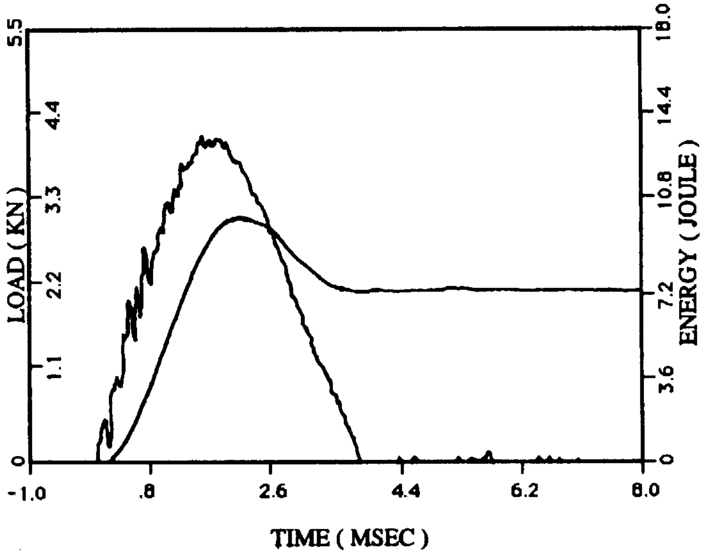

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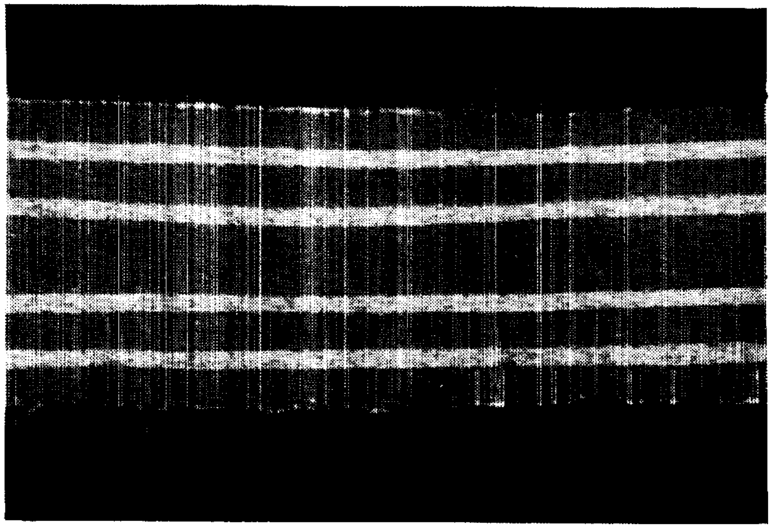

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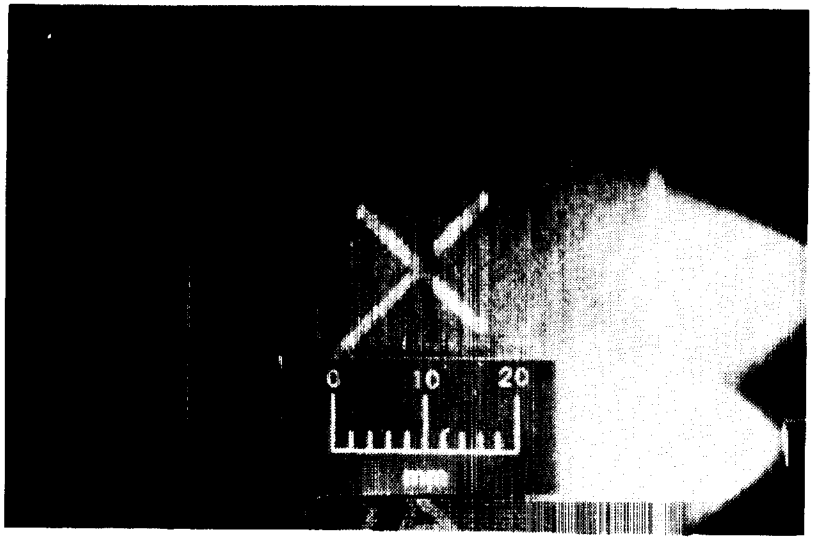

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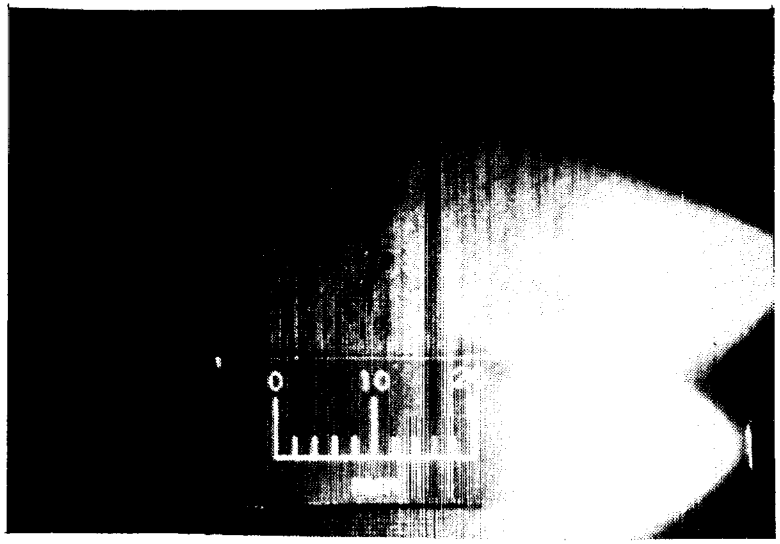

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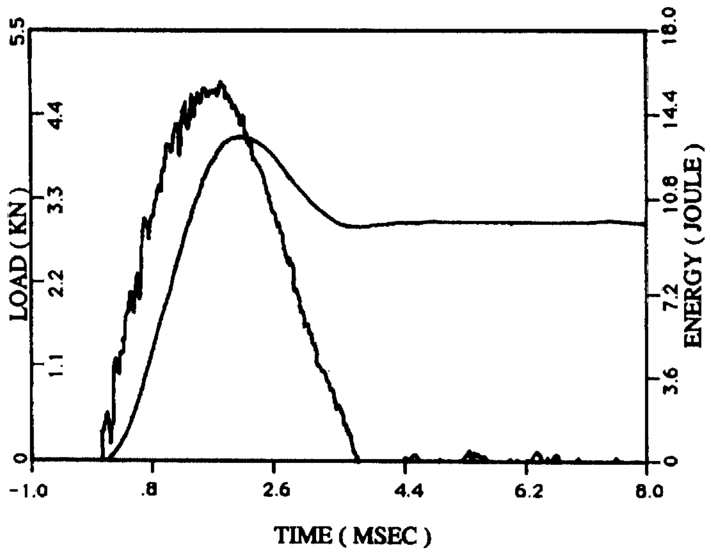

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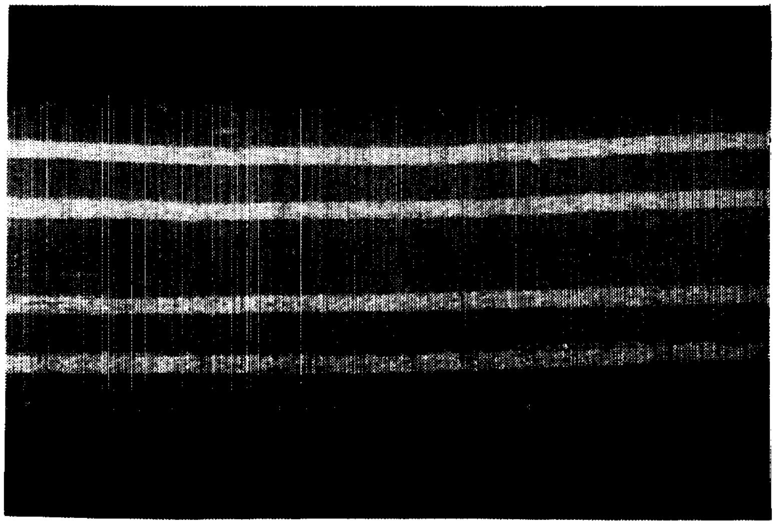

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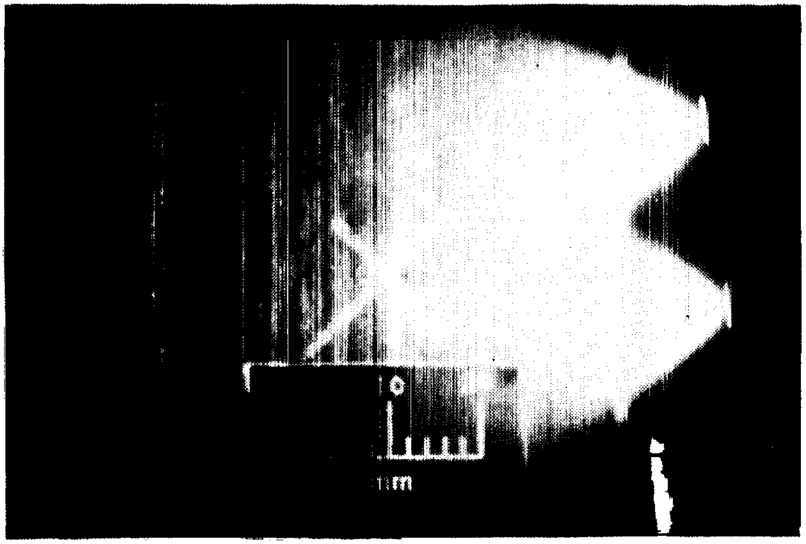

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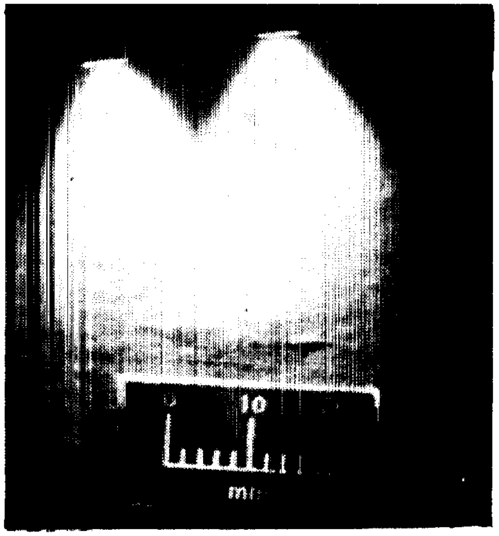

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IM7/8551 IMPACT ENERGY 13.8 J

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APPROVAL

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By D.G. Lance and A.T. Nettles

The information in this report has been reviewed for technical content. Review of any information concerning Department of Defense or nuclear energy activities or programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

Paul H. Schuerer

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Director, Materials and Processes Laboratory

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