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An Examination of Impact Damage in Glass/Phenolic and Aluminum Honeycomb Core Composite Panels

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National Aeronautics and
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TECHNICAL PAPER

AN EXAMINATION OF IMPACT DAMAGE IN GLASS/PHENOLIC AND ALUMINUM HONEYCOMB CORE COMPOSITE PANELS

I. INTRODUCTION

In order to obtain very high stiffness and strength-to-weight ratios, sandwich panels are often utilized in structures. By placing the strong, stiff material (a carbon-fiber laminate) on the outer surfaces of a beam and using a lightweight, shear carrying material (honeycomb) in the middle, beams can have a 370 percent increase in stiffness and a 925 percent increase in strength with only a 6 percent increase in weight [1]. As with any other carbon-fiber composite material, these honeycomb sandwich panels can be very susceptible to foreign object impact damage.

Much research has been conducted involving impact damage to carbon-fiber laminates, but relatively little has been done on honeycomb structures. Rhodes [2,3] and Oplinger and Slepetz [4] conducted some of the earliest work done on this subject. More recently, Gottesman et al. [5] examined the residual compression strength of impacted facesheets of an aluminum honeycomb sandwich panel. Shih and Jang [6] looked at instrumented impact data for foam core panels, and Bernard and Lagace [7] performed an investigation to determine the extent of impact damage in sandwich panels with three different core materials. Most of these studies noticed that local core crushing directly below the point of impact was the first type of damage encountered at the lower impact energies. This can cause high bending stresses to be set up in the facing material as noted by Rhodes [2,3]. While facing damage is an important factor in the residual strength capabilities of a sandwich beam, core damage can be just as important since the core carries the shear stresses within the beam. Therefore, one of the main objectives of this investigation was to characterize the effect that the core damage would have on its ability to support shear stresses. The other objectives of this investigation were to determine the type and extent of damage observed to see what effects the honeycomb core would have on the facesheet damage (as compared to facings supported over a large hole).

II. DESCRIPTION

A. Materials and Test Methods

1. Material. Two different types of honeycomb core were tested in this study, aluminum and glass/phenolic. Both types of cores were 35-mm thick with a 4.76-mm (3/16-in) cell size and 314.3-N/m^3 (2.0-lb/ft^3) density. A test of the crush strength of the two cores yielded a value of 896 kPa for the glass/phenolic and 1,158 kPa for the aluminum. The facing material was made of T-300 carbon fiber (manufactured by Amoco), impregnated with Fiberite's 934 resin system. The layup configuration was $(0, +45, -45, 90)_s$ for all panels tested. The adhesive used to bond the facings to the core was a 177 °C cure epoxy film adhesive manufactured by Hysol and designated EA 9684.

2. Specimen Preparation. The sandwich panels were cured in a programmable platen press at a pressure of 96 kPa. This low processing pressure was chosen in order to simulate the proposed cure cycle of actual parts to be made for NASA as part of the Advanced Launch System (ALS) composite intertank program. The panels processed at the lower pressure differed from the panels cured according to the recommended cure cycle in that some small (on the order of 10 μm) voids were seen spaced out approximately 1-mm apart between some layers of the laminate. A compression strength test on 16-ply laminates showed a reduced value of about 7 percent for the 96-kPa processed panels compared to the strength of the 551-kPa (recommended cure pressure) processed panels. Beam specimens 29.2-cm long and 7.6-cm wide were cut from the processed 30.5 × 30.5-cm sandwich panels.

3. Impact Testing. The sandwich beams were impacted with the same energy at two points as shown in figure 1. The impacted areas would be in the area of shear stress during the four-point bend test. The eight-ply "skin-only specimens" (facesheet without core) were clamped between two steel plates each having a 7.6-cm diameter hole. The skin-only samples were 11.4 × 11.4 cm in size and impacted at their centers. The impact apparatus consisted of a Dynatup model 8200 drop weight tower with a 1.2-kg impacting tup of 1.27-cm (0.5-in) diameter and a Dyantup 730 data acquisition system.

4. Four-Point Bend Testing. Three beams were tested for each of the eight drop heights used with the glass/phenolic core material and each of the five drop heights used for the aluminum honeycomb material. Testing was performed on an Instron 1125 load frame at a rate of 2.54 mm/min. The dimensions of the supports and loads are shown in figure 2.

5. Cross-Sectioning of Specimens. For each impact energy level on each type of specimen tested, a cut was made through the point of impact as shown in figure 3. A Buehler diamond wafering blade made the cuts and a Zeiss stereo-optical microscope was used to examine the specimens at ranges from 8 x to 12 x magnification.

B. Test Results and Discussion

1. Visible Surface Damage. The visible surface damage was checked and recorded after each impact event. The results are given for each of the three types of specimens tested. Figure 4 shows some of these surface impacts.

a. Glass/Phenolic Core. The first noticeable damage was a small dent felt on the surface of some of the specimens at the 1.0-J impact energy level. For the 1.5-J and 2.0-J impact energy levels, the outer surface damage continued to be small dents that could be felt, with visible dents not occurring until the 2.4-J energy level was reached. Larger dents with visible fiber breakage occurred at the 3.3-J energy level, and at the 4.2-J energy level complete penetration occurred.

b. Aluminum Core. The aluminum core exhibited identical surface damage as the glass/phenolic core except that a small dent was felt at an impact energy of 0.7 J in the aluminum core specimens. This is due to the aluminum core holding a deformation since it behaves in more of a plastic manner than the brittle glass/phenolic core.

c. Skin-Only Specimens. No visible damage was seen until the 1.1-J impact energy level where a small split on the back face parallel to the outer fibers was detected. Top surface (impacted side)

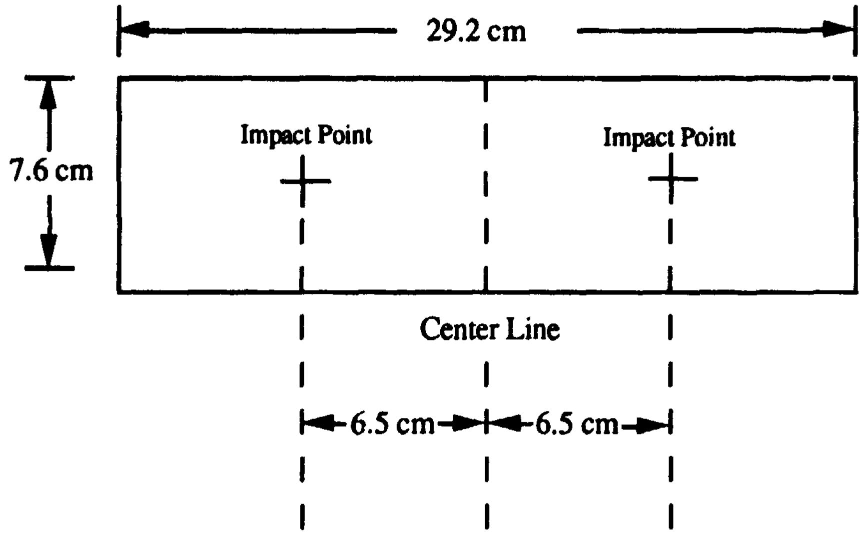

Figure 1. Points of impact on sandwich beams.

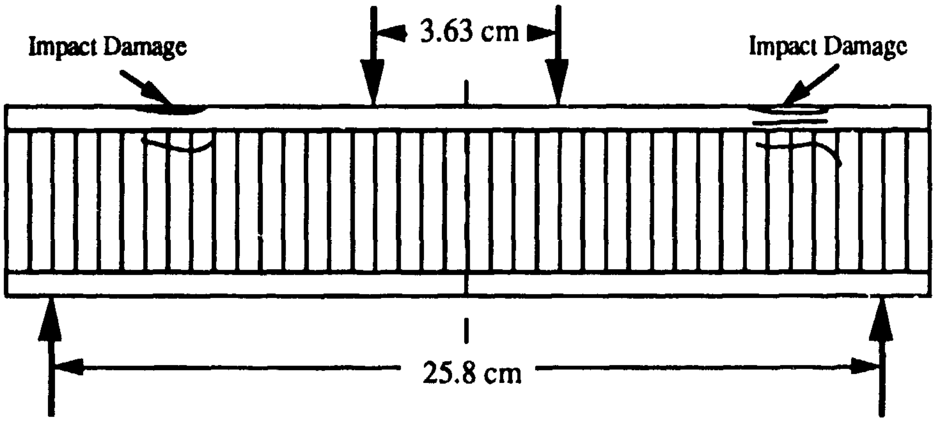

Figure 2. Dimensions of four-point bend tests.

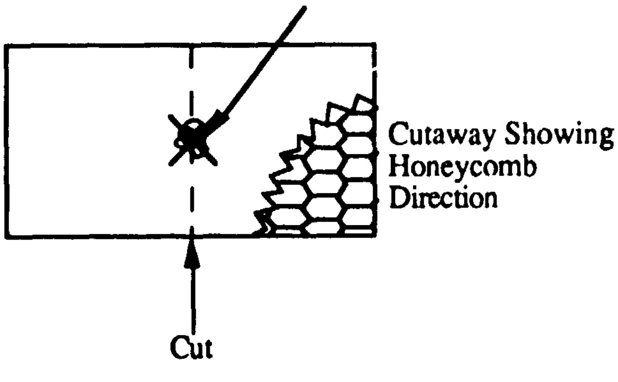

Figure 3. Cross-sectional cut made on damaged specimens.

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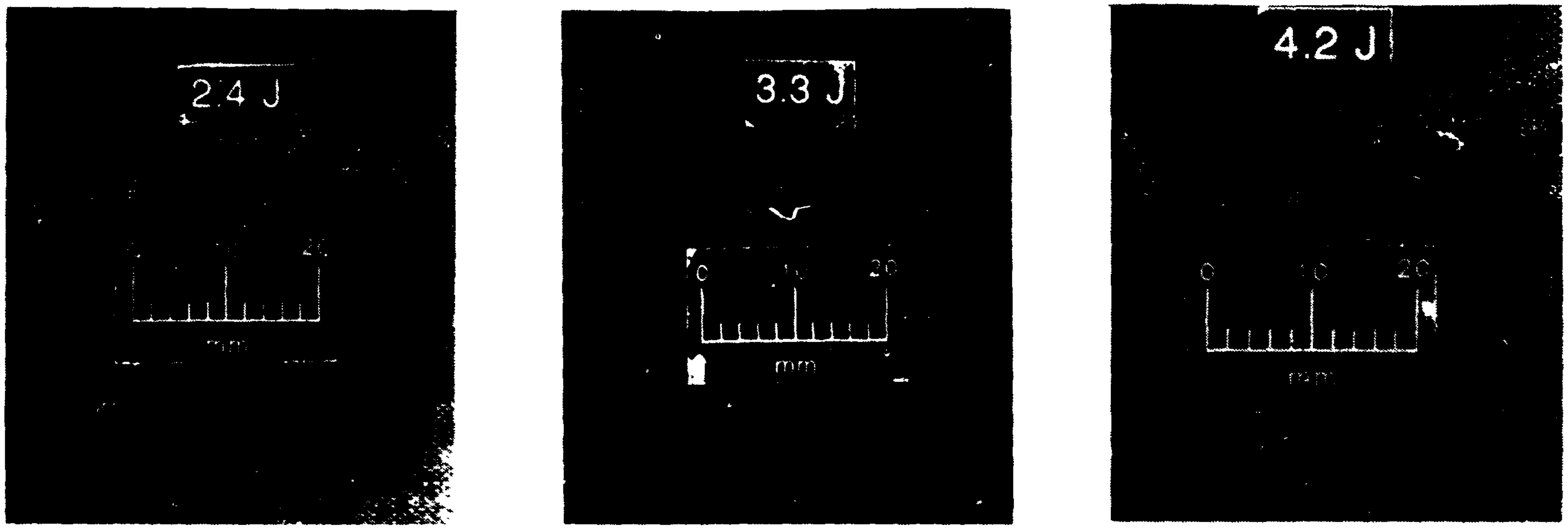
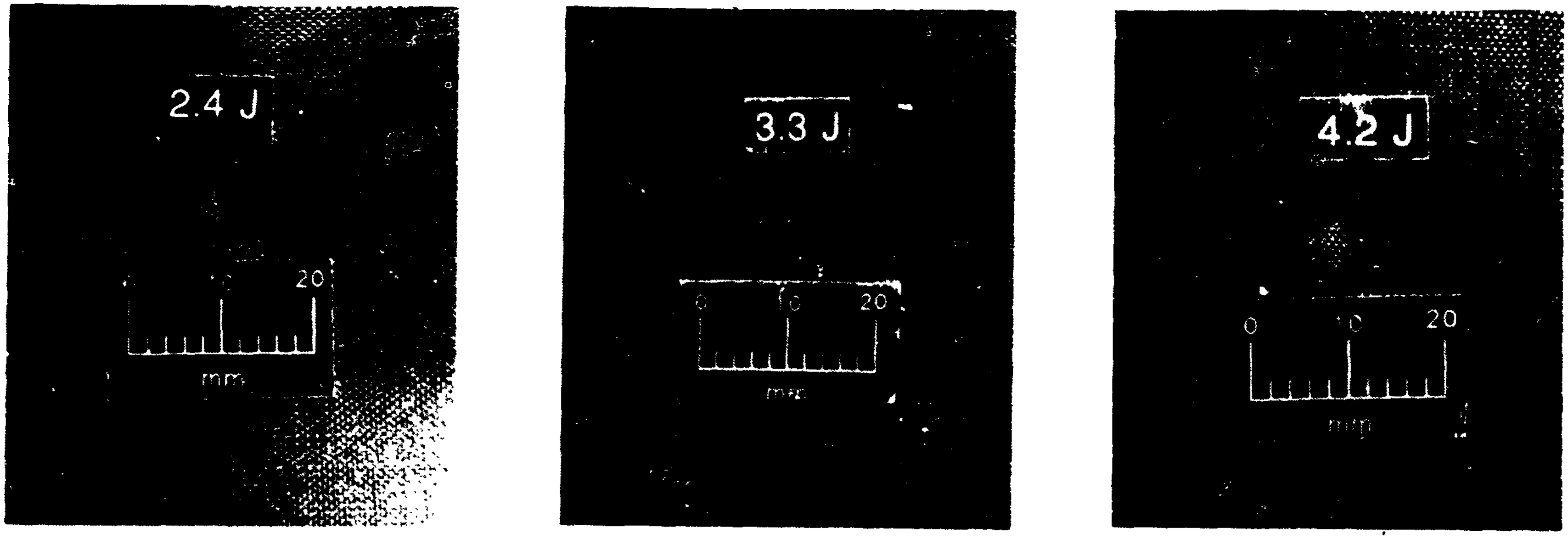


Glass/Phenolic Honeycomb Core Specimens



Aluminum Honeycomb Core Specimens

Figure 4. Photographs of surface damage to glass/phenolic and aluminum core specimens.

damage was not detected until 2.0 J of impact energy was used. Visual damage at this point consisted of a small dent with no fiber breakage on either the top or bottom surface. Fiber breakage on the top surface was noticed at 2.4 J, and back-face fiber breakage was not present until a hole was formed at the 4.2-J impact energy level.

2. Cross-Sectional Examination. In order to give a more thorough report on the type and extent of impact damage that was found in this study, photographs of cross-sectional views of the damage zone of each type of specimen impacted at each energy level are presented in the appendix.

a. Core Damage. It was observed in both types of honeycomb that core buckling below the point of impact was the first type of damage observed. For the glass/phenolic core, core buckling is the term used to indicate that the phenolic resin has been sufficiently damaged to allow some of the glass yarns to bend freely and is so named since the resulting damage looks very much like a ductile buckle. This type of core damage occurred at very low (0.7-J) energy levels and reached a maximum length of about five damaged cells at 2.0 J of impact energy. Further increases in impact energy did not cause much core damage beyond this five-cell width. The glass/phenolic core first demonstrated core cracking at 2.0 J of impact energy. Core cracking implies breakage of the glass fiber reinforcement within the core.

The aluminum core also exhibited core buckling at the 0.7-J energy level, but the maximum extent of damage peaked out at about 12 buckled cells, which is over twice that of the glass/phenolic core. This maximum damage length occurred at the 3.3-J impact energy level. In general, the aluminum core exhibited a much larger extent of core buckling than the glass/phenolic core. This is probably due to the aluminum core retaining more of the deformation from impact than the glass/phenolic core, i.e., the aluminum core behaves in a plastic fashion and does not retain much elastic energy that can be recovered by the material returning to its original undamaged state. This conclusion is also supported by the absorbed energy data given in figure 5. These data indicate that about 84 percent of the impact energy was lost when the glass/phenolic core specimens were hit compared to 93 percent for the aluminum core specimens. It should also be noted that the skin-only specimens only lost about 73 percent of the initial impact energy. These data imply that the more rigid the core, the less elastic deformation can take place, and therefore the less energy can be given back to the impactor. The data presented are for impact energy levels that did not cause fiber breakage in the facings since a sharp increase in absorbed energy is noticed at this point (up to 100 percent of the initial impact energy is being lost during the impact event).

b. Facing Damage. It should be noted that even with no impact damage the specimens exhibit some small delaminations above some of the cells. This is caused by the prepreg draping into the cells before the epoxy has hardened. These small delaminations are probably the source of larger delaminations noted when specime are subjected to the high bending and shear forces set up by the impact event.

The aluminum honeycomb specimen exhibited a significant delamination in the facing at the lowest impact energy used (0.7 J). A delamination about 6-mm long between the third and fourth layers from the top (impacted side) of the specimen is seen at this point, whereas the glass/phenolic core material did not exhibit any impact-induced delaminations until 2.0 J of impact energy was used. The facings of the aluminum core material continued exhibiting delaminations of increasing length with increasing impact energy up until 2.4 J of impact energy was used. At this drop height no delaminations

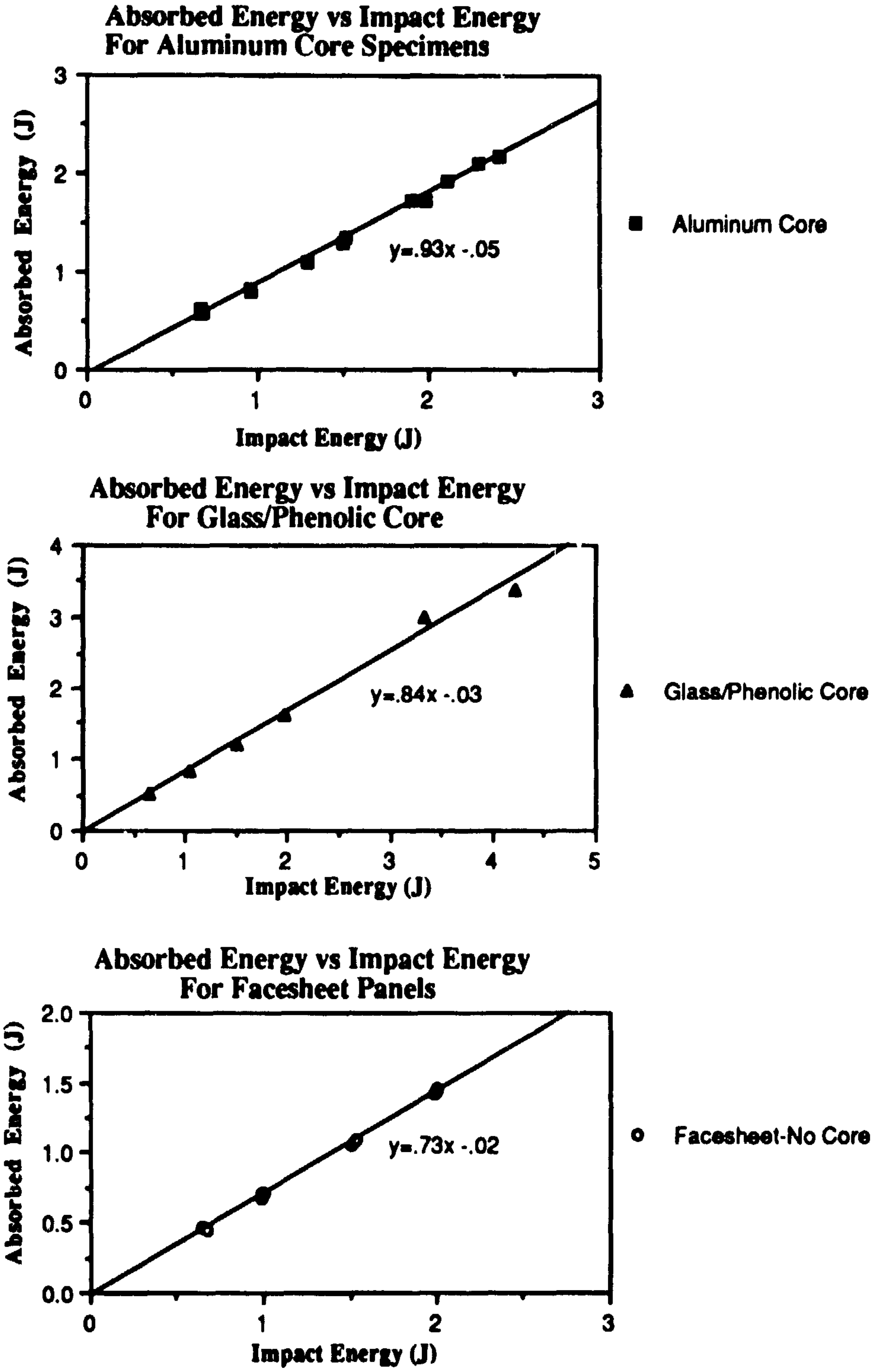


Figure 5. Absorbed energy versus impact energy plots for specimens tested.

were present, but at the next highest energy level used (3.3 J), major delaminations with fiber breakage occurred. Fiber breakage and major delaminations were observed in the facings of the glass/phenolic core material at 2.4 J of impact energy.

With the exception of the 2.4 J-energy level, the aluminum core specimens were more susceptible to facing damage than the glass/phenolic core specimens. The higher crush modulus of the aluminum core may be the reason for this since a higher impact force is generated because the impactor has less distance to decelerate in. Figure 6 presents data for maximum force of impact versus impact energy and shows that the aluminum core samples are subject to the higher maximum load for a given impact energy. This difference becomes larger with increasing impact energy until the peak force is [illegible] at which point the honeycomb specimens show a sharp decrease in maximum load. The skin-only samples did not exhibit such a drastic drop in maximum load. This phenomena is probably due to the honeycomb core samples failing in a shear-type puncture as opposed to the skin-only samples which fail by tensile breakage of fibers on the bottom surface. These skin-only samples showed a smaller maximum force in the lower energy ranges, as might be expected since they have no rigid foundation preventing them from flexing and thus driving up the maximum force value.

c. Skin-Only Damage. Photographs of damage to the eight-ply skin-only specimens are given in the appendix The 0.9-J and 1.0-J impact energy levels produced no impact-induced damage, but the next highest level tested (1.5 J) did show some delaminations. At 2.0 J, a longer delamination was present and major matrix cracking is seen. The 2.4-J energy level produces major delaminations between every layer with very extensive matrix cracking and fiber breakage.

The results of cross-sectional examination of the glass/phenolic core specimens and the skin-only specimens are surprisingly similar. It was originally predicted that the honeycomb would not allow as much flexing of the composite facesheet as the skin-only samples supported over the relatively large diameter (7.6-cm) hole. Apparently the crushing of the glass/phenolic core was extensive enough to allow the facesheet to deform similarly to the skin-only samples. The aluminum honeycomb apparently did provide a more rigid base for the facings, thus producing more delaminations for a given impact energy as noted earlier.

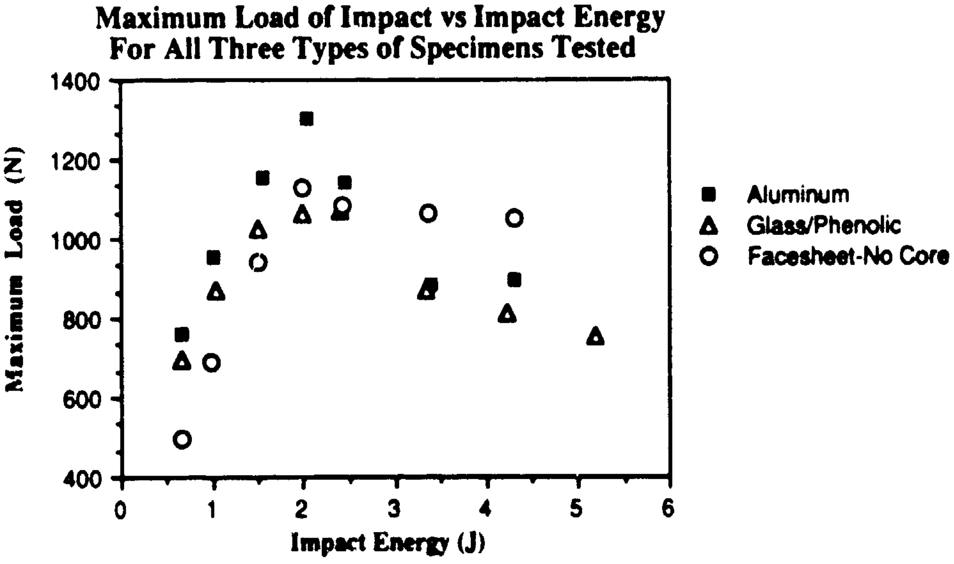


Figure 6. Maximum load of impact versus impact energy.

3. Four-Point Bend Testing. For both types of core material, three beams, impacted as shown in figure 1, were tested in four-point bend for each energy level used. The results are averaged and presented with standard deviation bars in figure 7.

a. Glass/Phenolic Core. These specimens all failed by core shearing as would be expected since the eight-ply facings are relatively thick for this type of honeycomb. A drop in ultimate shear stress is seen at the impact energy which produced core cracking (not buckling). The maximum shear stress of impacted beams remained at a fairly constant level after this initial, sharp decrease which corresponds with the constant size of damage to the core after 2.0 J of impact energy, as noted earlier. The overall maximum damage is about 2.3-cm long with core cracking being about 1.6 cm of this length. If the 1.6-cm value is used as a measure of the amount of core that can no longer carry shear loads, a drop in strength of about 80 percent is predicted. This would correspond to a drop in shear strength from the undamaged value of 693 kPa to 550 kPa which comes fairly close to the data presented in figure 7. This implies that damage to the core is only significant as far as it takes away from the effective cross-sectional area that can carry shear loads.

b. Aluminum Core. These specimens also failed by core shear. However, unlike the glass/phenolic samples, the aluminum core sandwich beams retained a very high percentage of undamaged strength. It is apparent that aluminum honeycomb that has been damaged and exhibits multiple cell buckles is still able to carry a shear load through the damage zone. As noted earlier, more cells were buckled for a given impact energy in the aluminum specimens than the glass/phenolic samples, yet it is evident that less shear strength is lost within the specimen.

It is interesting to note that the undamaged ultimate shear strength of the aluminum honeycomb material is about 250 kPa greater than the ultimate shear strength of the glass/phenolic core, even though the cores are of the same density

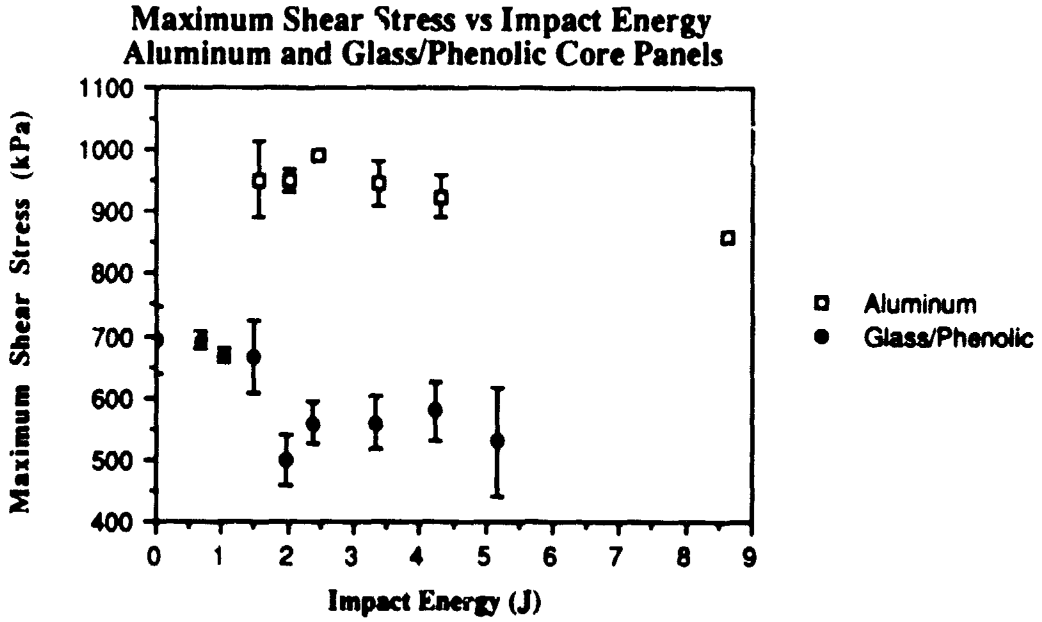


Figure 7. Maximum shear stress versus impact energy.

III. CONCLUSIONS

For low velocity impact testing of glass/phenolic and aluminum honeycomb sandwich panels at an equivalent density of 314.3 N/m^3 (2.0 lb/ft^3) and with eight-ply facesheets of T300/934 carbon/epoxy, the following conclusions can be drawn from this study.

1. For a given impact energy, the facesheets on the aluminum core samples demonstrated more delaminations than the glass/phenolic core.

2. Both glass/phenolic and aluminum core specimens displayed core buckling as the first damage mode, followed by delaminations in the facings, matrix cracking, core cracking (for the glass/phenolic samples), and finally fiber breakage in the facings.

3. The size of the damage zone to the core materials reached a steady level after a critical impact energy level. This size was 5 buckled cells for the glass/phenolic and 12 buckled cells for the aluminum.

4. Four-point bend tests on impacted beams showed that for the glass/phenolic samples a sharp drop in shear load carrying capabilites was present at an impact energy level that caused core cracking. The aluminum core demonstrated very little decrease in shear load carrying capabilities, even at the higher ranges of impact energies used in this study.

APPENDIX

Cross-Sectional Views of Damaged Specimens

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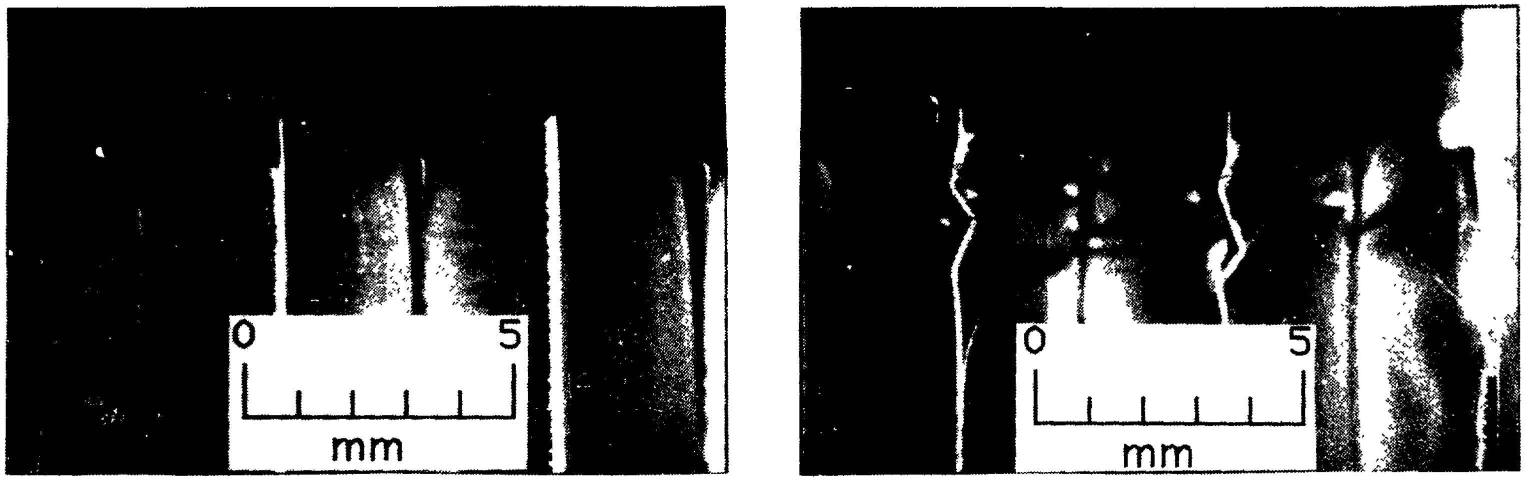

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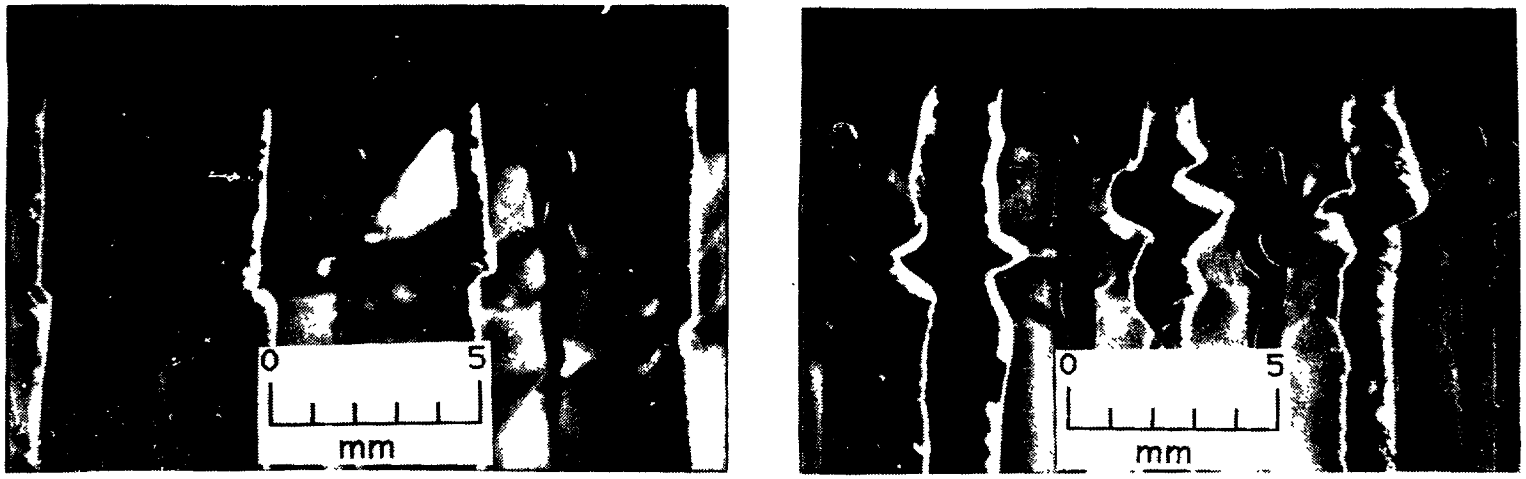
0.7 Joules



1.5 Joules

2.0 Joules

Aluminum Core Specimens

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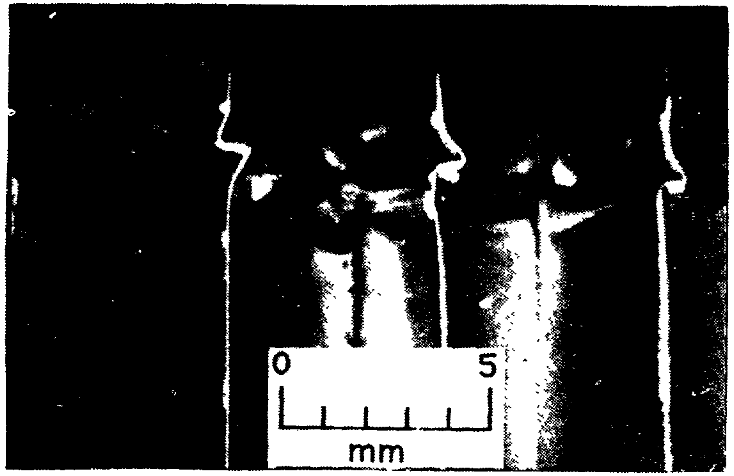
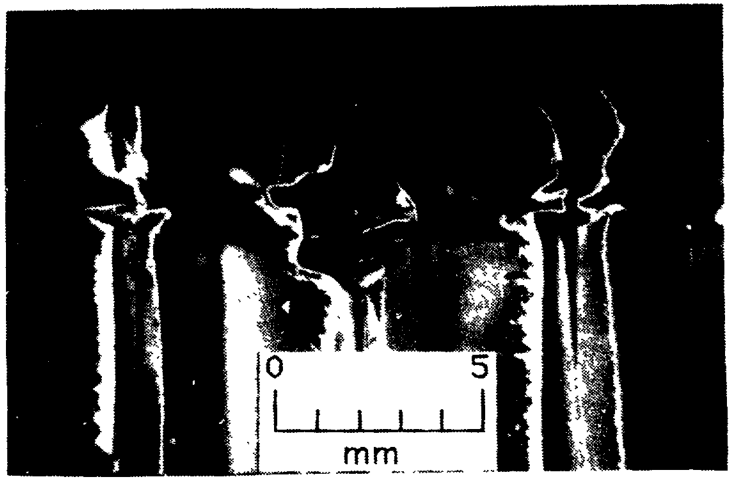


2.4 Joules



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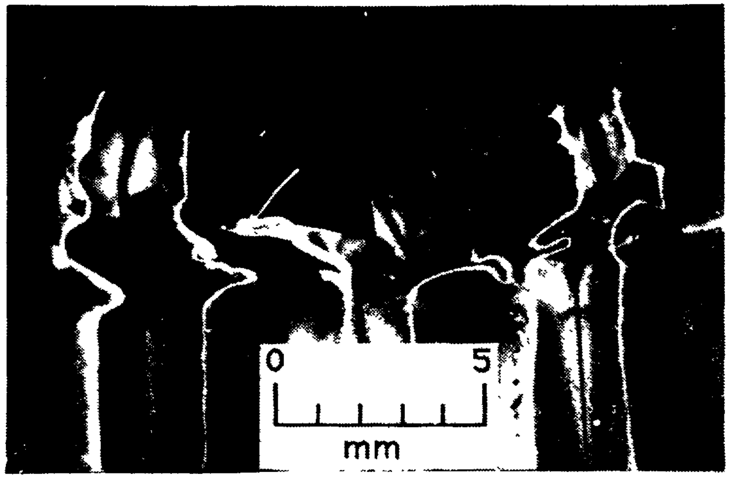

4.2 Joules

Aluminum Core Specimens

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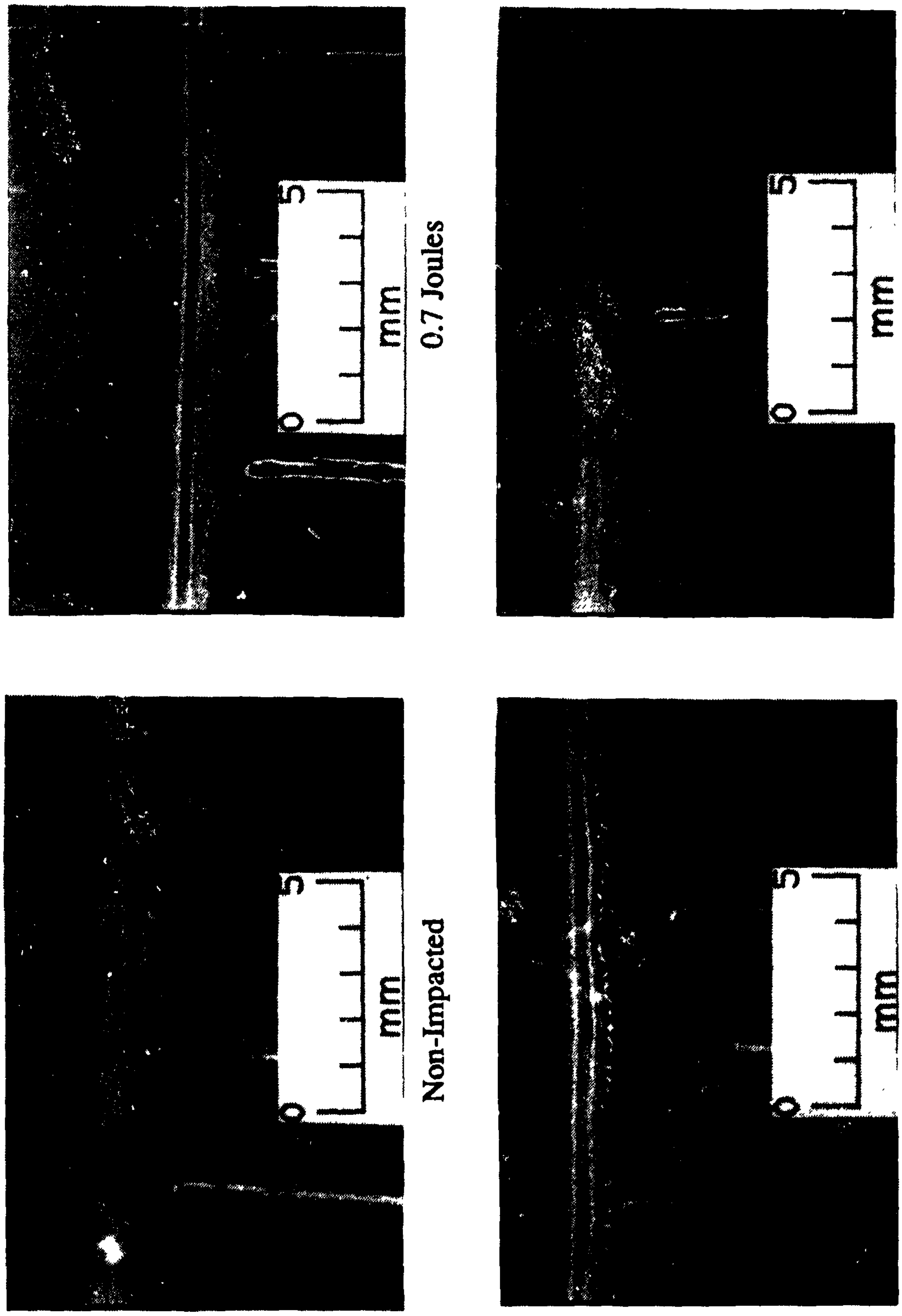
Glass/Phenolic Core Specimens



1.5 Joules

1.0 Joules

0.7 Joules

Non-Impacted

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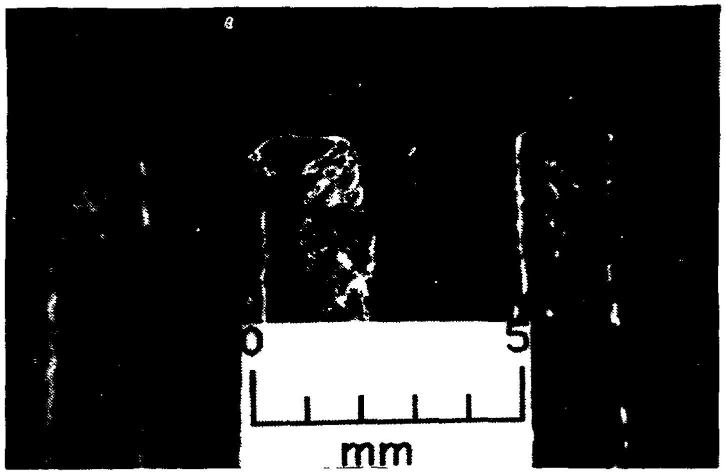

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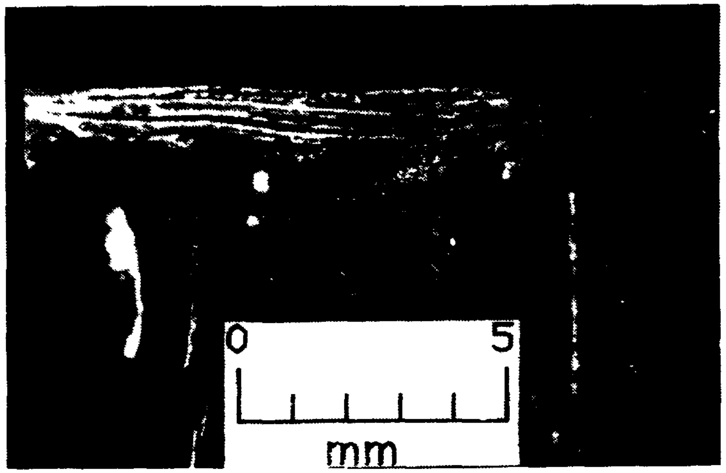

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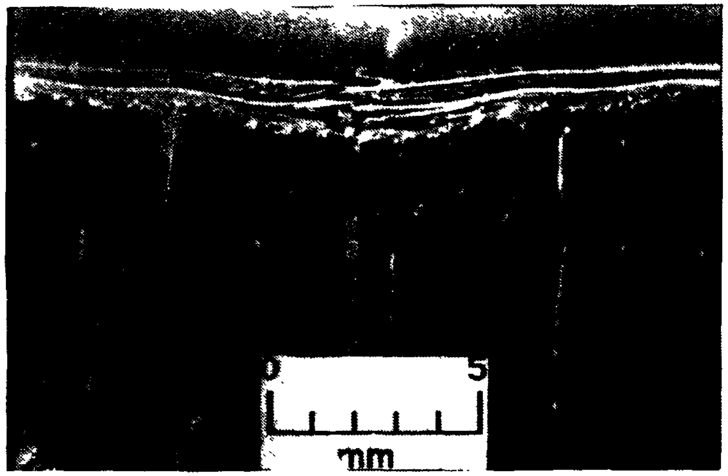

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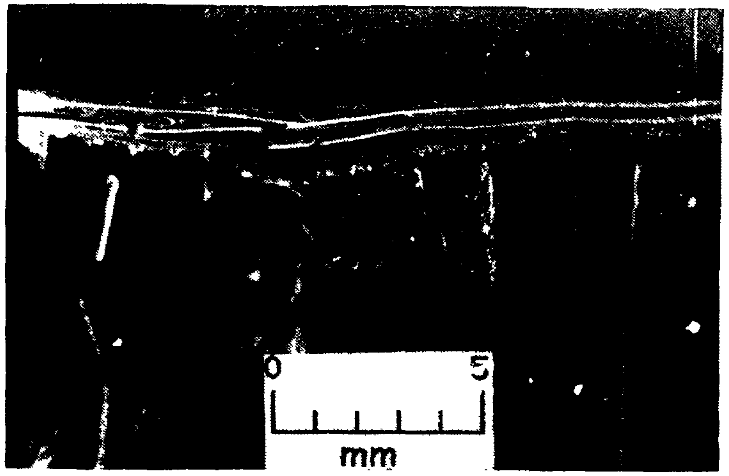

4.2 Joules

Glass/Phenolic Core Specimens

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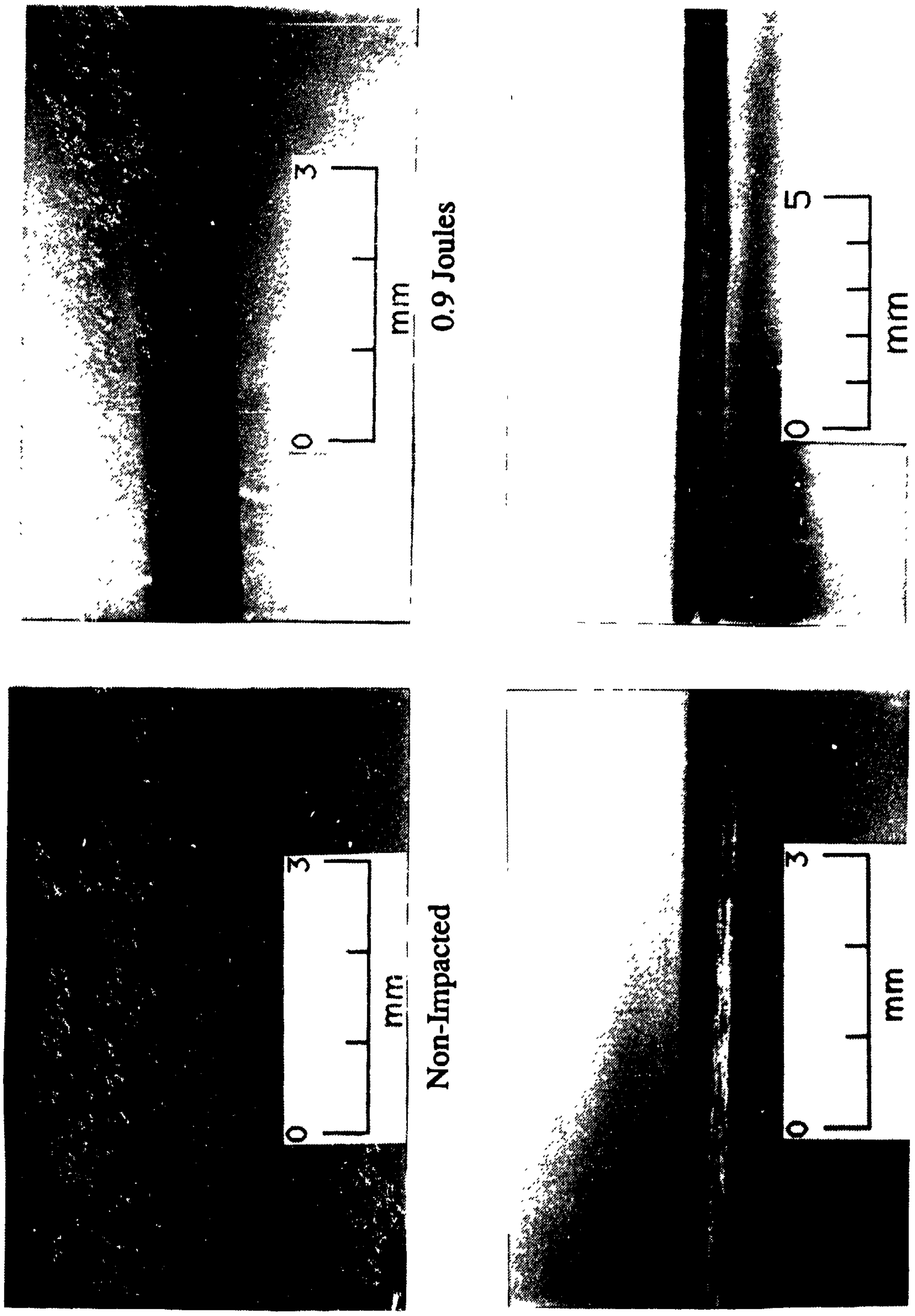

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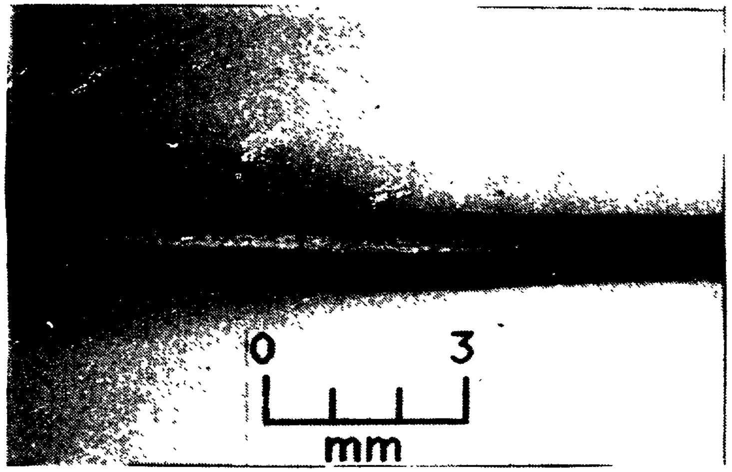
0.9 Joules

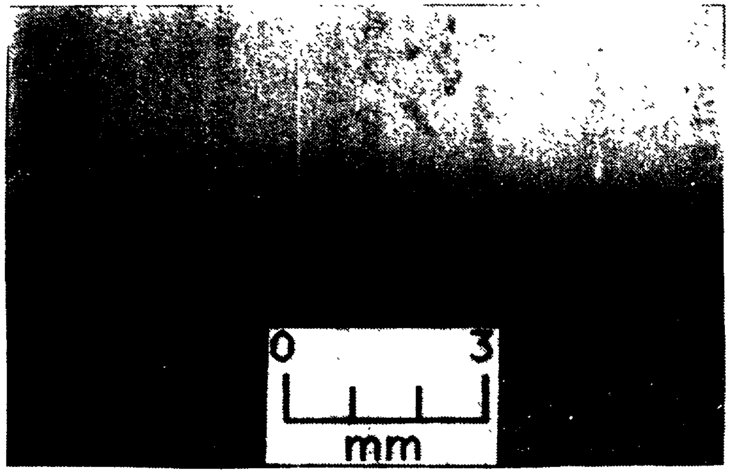
1.0 Joules

1.5 Joules

Skin Only Specimens



2.0 Joules



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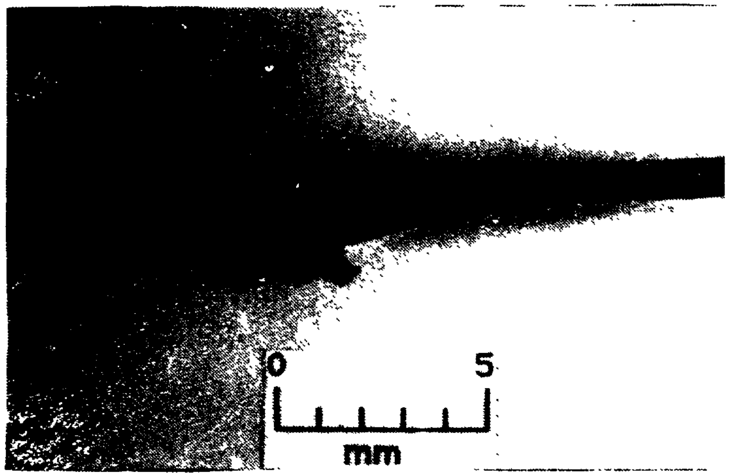

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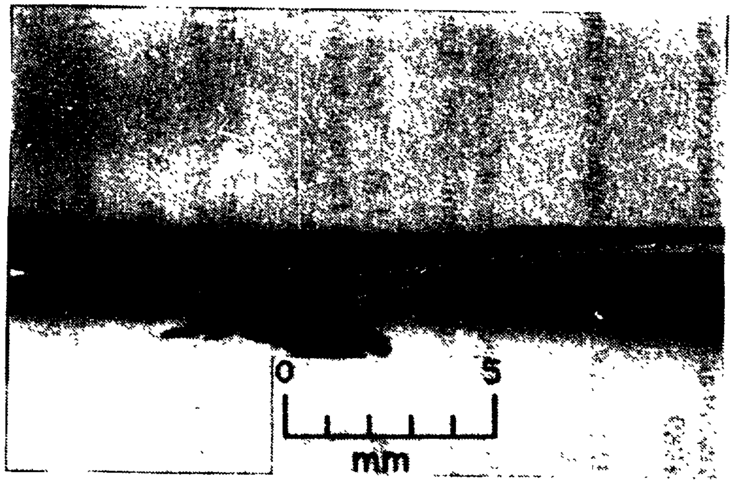

4.2 Joules

Skin Only Specimens

REFERENCES

1. Hexcel International: "Bonded Honeycomb Sandwich Construction." Hexcel TSB 124, Dublin, California, 1989.

2. Rhodes, M.D.: "Low Velocity Impact on Composite Sandwich Structures." AFFDL-TR-74-103, September 1974.

3. Rhodes, M.D.: "Impact Fracture of Composite Sandwich Structures." AIAA Paper No. 75-748, 16th Structures, Structural Dynamics, and Materials Conference, May 1975.

4. Oplinger, D.W., and Slepetz, J.M.: "Impact Damage Tolerance of Graphite/Epoxy Sandwich Panels." Foreign Object Impact Damage to Composites, ASTM STP 560, American Society for Testing and Materials, 1975, pp. 30–48.

5. Gottesman, T., Bass, M., and Samuel, A.: "Criticality of Impact Damage in Composite Sandwich Structures." ICCM and ECCM, Vol. 3, F.L. Matthews ed., Elsevier Applied Science Publishers, London and New York, 1987, pp. 3.27–3.35.

6. Shih, W.K., and Jang, B.Z.: "Instrumented Impact Testing of Composite Sandwich Panels." Journal of Reinforced Plastics and Composites, Vol. 8, May 1989, pp. 270–298.

7. Bernard, M.L., and Lagace, P.A.: "Impact Resistance of Composite Sandwich Plates." Journal of Reinforced Plastics and Composites, Vol. 8, September 1987, pp. 432–445.

APPROVAL

AN EXAMINATION OF IMPACT DAMAGE IN GLASS/PHENOLIC AND ALUMINUM HONEYCOMB CORE COMPOSITE PANELS

By. A.T. Nettles, D.G. Lance, and A.J. Hodge

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.

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16. Abstract

An examination of low velocity impact damage to glass/phenolic and aluminum core honeycomb sandwich panels with carbon/epoxy facesheets is presented. An instrumented drop weight impact test apparatus was utilized to inflict damage at energy ranges between 0.7 and 4.2 Joules. Specimens were checked for extent of damage by cross-sectional examination. The effect of core damage was assessed by subjecting impact-damaged beams to four-point bend tests. Skin-only specimens (facings not bonded to honeycomb) were also tested for comparison purposes. Results show that core buckling is the first damage mode, followed by delaminations in the facings, matrix cracking, and finally fiber breakage. The aluminum honeycomb panels exhibited a larger core damage zone and more facing delaminations than the glass/phenolic core, but could withstand more shear stress when damaged than the glass/phenolic core specimens.

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