Impact Damage Mechanisms in Fiber-Metal Laminates

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Abstract
Impact-induced damage mechanisms in Glare and ARALL fiber-metal laminates subject to instrumented drop-weight impacts at various impact energies and temperatures were studied. Damage in pure aluminum panels impacted by foreign objects was mainly characterized by large plastic deformation surrounding a deep penetration dent. On the other hand, plastic deformation in fiber-metal laminates was often not as severe although the penetration dent was still produced. The more stiff fiber-reinforced epoxy layers provided better bending rigidity; thus, enhancing impact damage tolerance. Severe cracking, however, occurred due to the use of these more brittle fiber-reinforced epoxy layers. Fracture behaviors were greatly affected by the lay-up configuration and the number of layers, which implies that effects of both fiber orientation and thickness are significant for the panels tested in this study. Temperature, on the other hand, does not play a significant role in this study.

Introduction
Fiber-metal laminates are hybrid materials built up from interlacing layers of thin metals and fiber-reinforced adhesives. They were developed in late 1970’s [1-2] and have gained wide attention in the aerospace and space industries since late 1980. There are two types of commercially available fiber-metal laminates: Glare and ARALL. The former is made of alternating glass-epoxy and aluminum layers whereas the latter is formed by alternating aramid-epoxy and aluminum layers. Taking advantage of the hybrid nature from their two key constituents: metals and fiber-reinforced laminae, these composites offer several advantages, such as better damage tolerance to fatigue crack growth, foreign object damage, and corrosion, etc., for engineering design.

Damage mechanisms due to low energy impact onto composite panels have been studied extensively (see the review in [3]). In general they are characterized by incomplete penetration with damage consisting of delamination, matrix cracking, and fiber failure. However, the exact failure mode and damage evolution sequence are greatly affected by the constituent properties, lay-up configuration, thickness, and bending rigidity. For instance, experimental studies consistently report that very often delamination occurs at the interface between plies with different fiber orientation. On the other hand considerably fewer studies have been conducted on impact damages [4-5] and other thermomechanical behaviors [6-7] of fiber-metal laminates. The main objective of this study is to develop preliminary understanding of damages caused by low-energy impact in these relatively newer engineering composites. A typical example of our results can be seen in Fig. 1, which depicts drop-weight impact damages of panels made of (a) 0.063"-thick 2024-T3 aluminum alloy and (b) 0.056"-thick Glare 2, a fiber-metal laminate formed by alternating 2024-T3 aluminum sheets with unidirectional glass-epoxy laminae (fiber volume fraction, Vf =50%). When subject to an impact energy of 30 J at room temperature, the thicker and heavier aluminum panel incurs severe damage, including partial punching through; whereas the thinner and lighter Glare 2 panel suffers only a minor indentation with a crack running in parallel with the fiber direction.

![Figure 1](image1.png)

**Figure 1.** Typical damages in 2024-T3 and Glare 2 panels subject to a drop-weight impact of 30 J at room temperature.

The Experimental Procedure
In this study tests were conducted in an Instron-Dynatup 8520 pneumatic-assisted, instrumented drop-weight impact tester equipped with an environmental chamber (−60 to 350°F) and a pneumatic break to avoid multiple strikes. Square specimens with dimensions of 100 mm x 100 mm (or 4” x 4”) were first clamped circumferentially along a diameter of 76 mm (or 3”) in the specimen fixture. The fixture-
specimen assembly was then placed in the environmental chamber. Temperature in the chamber was raised or lowered to the desired setting with the fixture-specimen assembly being soaked at that temperature for about 20 minutes to ensure no initial stress resulting from temperature change. A 16 mm- (or 5/8”-) diameter spherical impactor with a weight of 6.1 kg (or 13.4 lbs) was then dropped from a predetermined height to cause damage. Time histories of impact load were recorded by a PC-controlled high-speed A/D converter. After impact the specimen was then carefully removed from the environmental chamber for post-mortem inspection and photography.

Figure 2. Damage patterns in Glare 1 and ARALL 3 panels subject to a drop-weight impact with different impact energies at room temperature.

Results and Discussion

In order to study fully impact damages in fiber-metal laminates, various factors in the selection of materials and specimen configurations were taken into consideration.

For example, both Glare 1 and ARALL 3 are laminates composed of alternating 0.012” 7475-T76 aluminum alloy sheets with unidirectional glass-epoxy and aramid-epoxy layers, respectively (both with Vf = 50%). In these tests the Glare 1 and ARALL 3 panels have a thickness of 0.056” and 0.053”, respectively. Figure 2 shows impact damage patterns in panels made of these two composites subject to different impact energies at room temperature. It is clear that Glare 1 possesses higher impact damage tolerance than ARALL 3.
The corresponding load-times histories of these tests are shown in Fig. 3(a). As shown in Fig. 2, only plastic indentation but not fracture may have occurred only in the test of Glare 1 under the 10 J impact condition. From Fig. 3(a) one can see that other than some fluctuation in the initial phase, the load vs. time curve corresponding to this test is fairly smooth; indicating excessive kinetic energy was mainly attenuated out through damping. On the other hand, for the remaining tests, the load was drastically reduced; indicating the onset of fracture. This phenomenon is similar to impact damage in aluminum/acrylic sandwich plates [8].

The second set of tests involved the Glare panels with different aluminum alloys (the stronger yet brittle 7475-T76 for Glare 1 vs the ductile but tougher 2024-T3 for Glare 2). Results of their load-time histories are shown in Fig. 3(b), which indicates that Glare offers better impact resistance when it incorporates the ductile but tougher 2024-T3.

The third set of tests considered the effect of lay-up configuration in the prepreg. The results show that in terms of impact load and crack formation, the quasi-isotropic configuration ($[0^\circ/45^\circ/-45^\circ/90^\circ]$) has the best tolerance for impact damage with the cross-ply configuration ($[0^\circ/90^\circ/90^\circ/0^\circ]$) being the second while the unidirectional configuration ($[0^\circ]$) performing the worst.

The effect of number of layers was assessed in the fourth set of tests in this study. Cross-ply Glare 5 panels with total thickness varying from 0.044" to 0.172" were tested at room temperature and the minimum impact energy required to caused cracking on the bottom face (opposite to the impact site) of the panel was measured. The result is shown in Fig. 4, which indicates that this minimum cracking energy is proportional parabolically to the thickness of the impacted panel.

Finally the cross-ply Glare 5 panels were impacted at 30 J under a temperature range within −51 to 95°C. As shown in Fig. 5 no appreciable difference in the impact load-time histories was observed. Figure 6 shows the almost identical indentations in Glare 5 panels subject to 30 J impact at 88°C (190°F) and −51°C (−60°F), respectively. It implies that temperature effect, if any, is not significant in impact damages of fiber-metal laminates.

**Conclusions**

From this study one can conclude that
- Compared to aluminum alloys, impact damage tolerance is better in Glare while may be worse in ARALL;
- Impact damage tolerance can be improved by using the ductile but tougher aluminum alloy (such as 2024-T3);
- Quasi-isotropic lay-up configuration provides the best impact resistance whereas unidirectional laminate offers the worst;
- The minimum impact energy required to cause cracking is approximately proportional parabolically to thickness;
- Unlike aluminum/acrylic sandwich, temperature does play a significant role in impact resistance.

![Figure 5](image1.png)

**Figure 5.** Impact load-time histories of Glare 5 panels subject to a 30 J impact energy at various temperatures.

![Figure 6](image2.png)

**Figure 6.** Comparison of damages of Glare 5 panels subject to 30 J impact at two different temperatures.
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References


