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دانشکده مهندسی هوافضا

Energy absorption and damage mechanism of UHMWPE-aluminum hybrid laminate under impact loading

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Abstract

This research presents an experimental investigation on impact behavior of a Fiber Metal Laminate (FML) made of ultra-high molecular weight polyethylene (UHMWPE) fiber composite and aluminum alloy. The effect of different parameters such as projectile type, thicknesses of aluminum layers and composite core, and lay-up sequence on impact performance is studied. The results imply that increasing the thickness of the composite core increases the specific energy absorption (SEA). Damage patterns show that in this material, metal layers and composite core deforme proportionally that leads to more energy absorption. Compared with glass fiber metal laminate (GLARE), the results show that the proposed FML with less weight has the much stronger impact resistance.

Introduction

Fiber Metal Laminates are hybrid composite structures formed from the combination of metal layers sandwiching a fiber-reinforced laminate. UHMWPE fibers are one of the best fibers in terms of specific strength, low density, high stiffness and strength and biocompatibility. However, this composite material has some disadvantages, such as poor compressive properties, poor adhesion to resin matrices, and week shear strength. To overcome these limitations, some researchers have tried to utilize UHMWPE composite in hybrid structures. The results show a positive effect of hybridization and better structural behavior.

The main objective of this research is to investigate the impact behavior of a polyethylene reinforced aluminum laminate (PERALL) experimentally. The samples are tested against two different types of projectiles and the modes of damage and failure are described and compared. Two lay-ups including 2/1 and 3/2 configurations are studied. Also, a PERALL specimen is compared with a GLARE sample in similar impact loading conditions.

Experimental procedure

Al_2024_T3 aluminum alloy sheet with two thicknesses of 0.5 and 0.8 mm is used for metal parts of PERALL specimens. UHMWPE pre-preg plies in the form of two-layer cross-ply [0°/90°] coated with polyurethane resin is used for fiber reinforced part of FML samples. Epoxy resin was used as an adhesive to bond composite laminates to aluminum layers.

To make FML samples, the composite fabrics were pressed together. Then, aluminum sheets and the compacted UHMWPE composite laminate were bonded together as shown in Fig. 1. Three types of PERALL specimens were produced (Table 1) with a dimension of 110×110 mm. The high-speed tests for PERALL samples were carried out using a gas gun. Two types of projectiles were used: a spherical steel projectile with a diameter of 8.7mm and a constant speed of about 235 m/s; and a conical tip steel projectile with a speed of 184 m/s.

Table 1. Configuration and geometric properties of PERALL samples

Specimen code - Configuration	Thickness of Al layers (mm)	Composite Core Layup	Total Thickness (mm)
A – 2/1	t = 0.5	$[0°/90°]_4$	1.54
B – 2/1	t= 0.5	$[0°/90°]_8$	2.09
C – 2/1	t= 0.5	$[0°/90°]_{12}$	2.64
D – 3/2	t= 0.5	$[0°/90°]_4$	2.60
E – 2/1	t= 0.8	$[0°/90°]_6$	2.42
F – 2/1	t= 0.8	$[0°/90°]_{12}$	3.24

Result and discussion

The failure pattern of specimen A is shown in Fig. 2. In this specimen, the projectile passes through the target leaving a relatively clean hole in the front surface, and there were four dominant petals in the rear surface.

For the other specimens, the projectile did not pass through the specimen and the total energy was absorbed because of the higher thickness of the composite core. In these cases, the projectile causes damage to the front surface and the sample exhibits a large area of deformation with obvious bulging at the rear surface (see Fig. 2). Then, samples of all types (A to F) were tested with conical projectiles. In all samples, the projectile passed through the target leaving a relatively clean hole. The failure shape of sample A is shown in Fig. 3. As the figure shows, the aluminum layers failed in the form of petals and plugging.

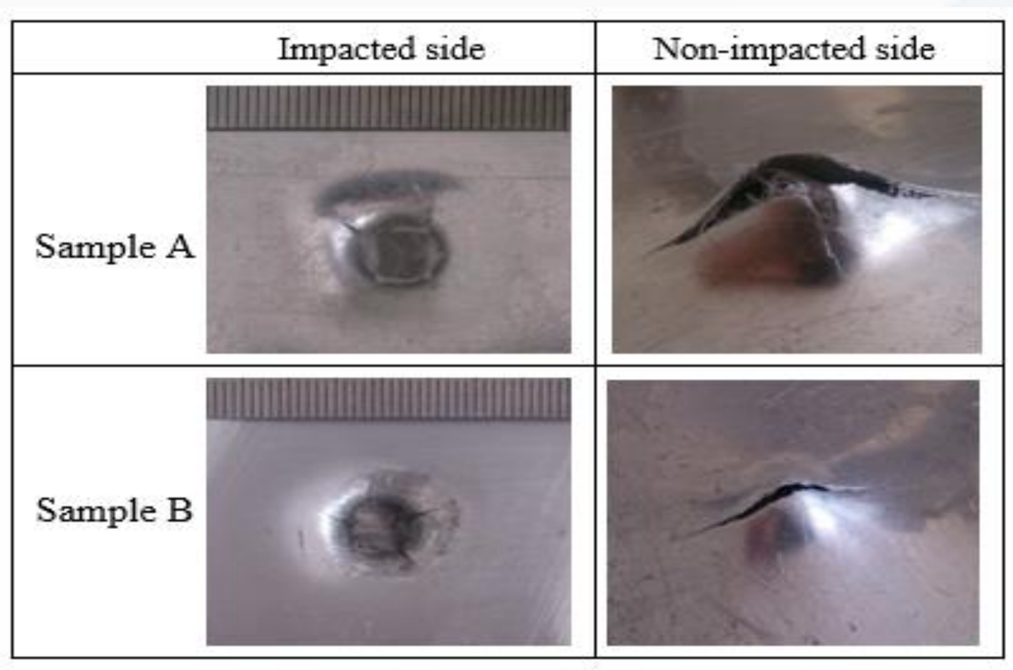

Figure 2. Failure pattern observed after impact tests with spherical projectile

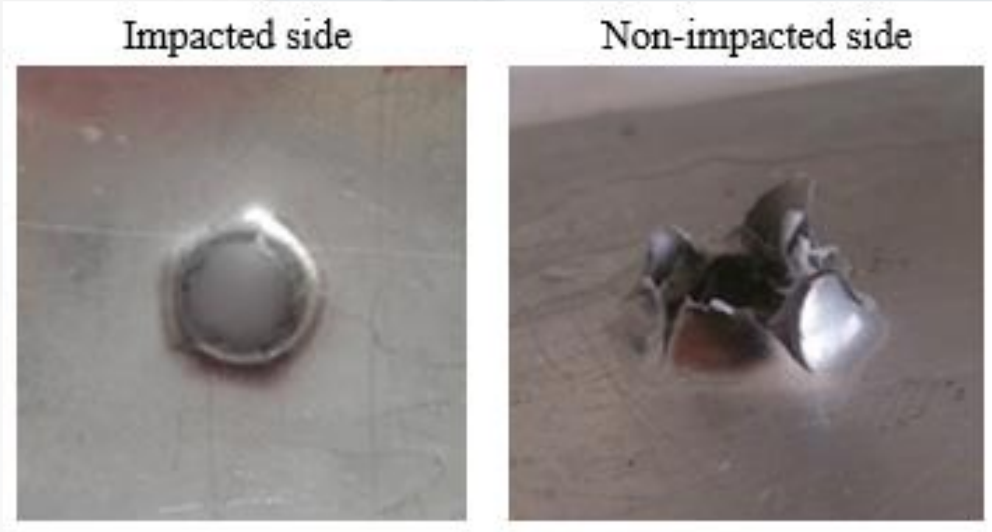

Fig. 2. Failure patterns for sample A after the high velocity impact tests with conical projectile

Deformation of the composite core is in the form of a flexural deformation. In fact, presence of ductile Aluminum sheets as well as high shear strength of epoxy adhesive prevent membrane stretching in the whole UHMWPE sample; resulting in flexural deformation around the impact zone.

In Fig. 3, damage mechanisms in a GLARE sample with a 1.6 mm thick composite core subjected to similar test conditions is shown and compared with sample E. For GLARE sample, the projectile has fully penetrated and the damage to the front aluminum layer is a failure in the impact zone, with a small plastic deformation. In specimen E, the damage to the front aluminum sheet involves a larger plastic deformation area. This plastic deformation is also seen.

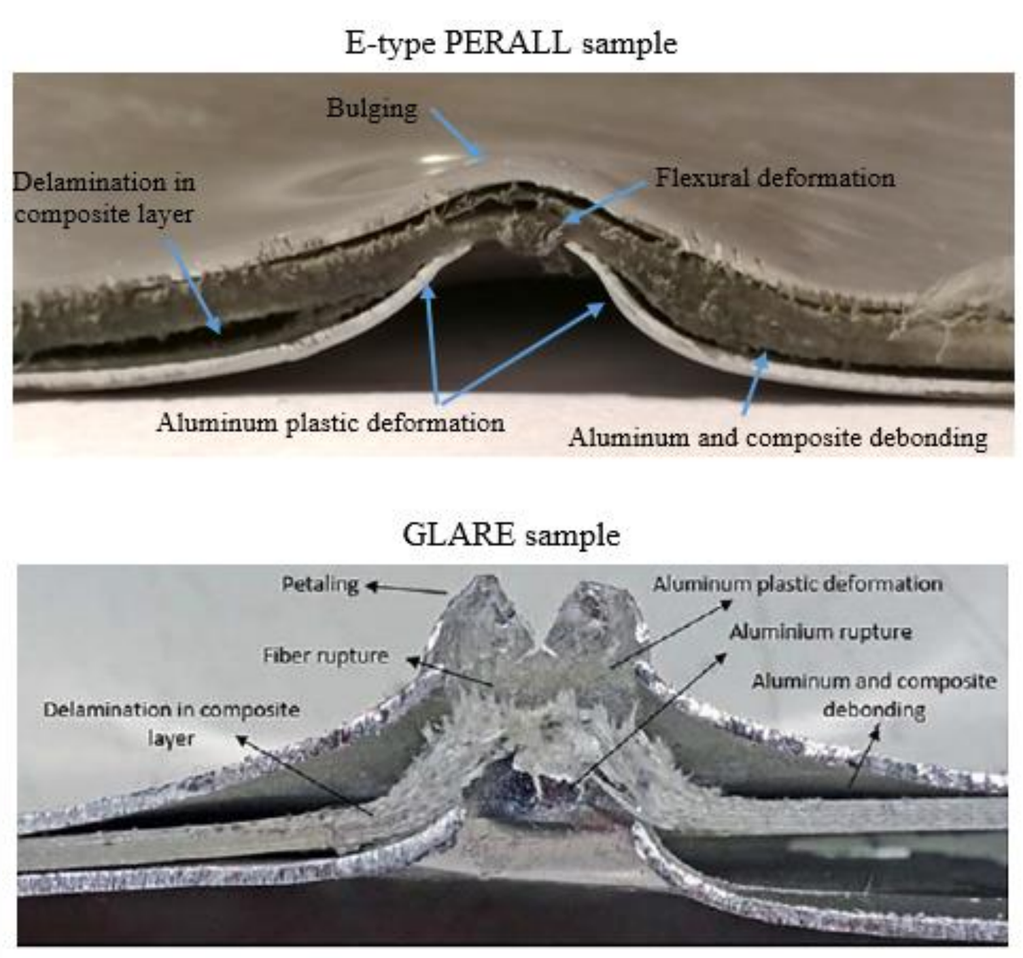

Fig. 3. Damage mechanisms in FML samples subjected to impact test with spherical projectile

Conclusion

FML specimens based on UHMWPE composite and aluminum alloy layers were prepared and subjected to impact tests. Using a spherical projectile, the increase in the thickness of the composite core prevents full penetration of the projectile and reduces the damage to the rear surface. In the tests with a conical projectile, the modes of damage includes plugging and petaling for the aluminum layer; and fiber breakage, splitting and delamination for the composite core. Compared with the GLARE laminate, PERALL samples with less thickness and less weight have much stronger impact resistance.

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