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Ballistic analysis of fiber metal laminates impacted by flat and conical impactors

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ABSTRACT

In the present study, the ballistic limit of GLARE is investigated experimentally and numerically. Ballistic tests were conducted using one stage gas gun. In the experimental part, the ballistic limit of GLARE was determined. The effect of aluminum lamina thickness and the nose shape of projectile on the ballistic limit were also investigated. The experimental results show that the ballistic limit of GLARE impacted by a flat projectile is higher than in the case of a conical nose projectile, and that by decreasing the aluminum laminate thickness from 0.5 mm to 0.3 mm, the Specific Perforation Energy (SPE) is increased. In the numerical section, the penetration process was simulated using LS–DYNA software. The validation of the finite element model was done by experimental results. The effects of various involved parameters such as laminate thickness, mass and radii of impactor were also investigated. The numerical results prove the efficiency of GLARE over bare aluminum laminate with equal thickness, due to the lower deflection and higher SPE. Furthermore, the less the mass of the impactor or the greater the diameter of the flat projectile, the greater the ballistic limit of GLARE. Reasonable agreement is concluded between the numerical and experimental results.

1. Introduction

Fiber Metal Laminates (FMLs) are hybrid composites consisting of alternating layers of metal-alloy sheets and fiber reinforced epoxy prepreg, which is usually regarded as a family of highly damage-tolerant materials with a high weight-saving potential. In the mid 1970s, researchers at the Delft University of Technology (DUT) discovered that putting fibers in the bond layer between metal layers can improve the metal's fatigue properties by bridging cracks to keep them from growing [1]. The development of the family of highly fatigue-resistant FMLs, ARALL (Aramid Reinforced ALuminum Laminate) and GLARE (Glass Laminate Aluminum Reinforced Epoxy) started in the 80s at the DUT [1–5]. Based on fiber orientation in prepreg and grades of aluminum-alloy sheets, GLAREs are categorized in six standard classes which are shown in Table 1. Some major advantages of GLARE are: high specific strength, high tolerance to fatigue, impact, corrosion, explosion and fire condition, formability, durability, reparability, etc. [4].

Impact failures are the main form of damage in aerospace structures which are subjected to low or high velocity impact due to bird strike, ice from propellers, runway debris, etc. [4]. It has been demonstrated that GLARE enhances energy absorption and increases the ballistic limit in comparison to the metal or composite from which it is made [4,6]. There are several studies of Fiber Metal Laminates subjected to impact loads [3,4,6–17]. Vlot [2–4,6,15,16] studied the impact properties of GLARE, Composite laminate and monolithic aluminum targets. Abdollah and Cantwell [8,18] investigated the ballistic limit of FMLs based on 2024-O and 2024-T3 aluminum alloy skins impacted by spherical projectiles. Their studies show that the specific perforation energy of the target with 2024-T3 aluminum alloy skin is higher. Hoo fat et al. [11] investigated the ballistic limit of GLARE experimentally and analytically. Their research shows that the bending and membrane deformation accounts for 84–92% of the total energy and only 2–9% of the total energy dissipated by delamination. Compston et al. [8] studied the high velocity impact of GLARE impacted by flat and spherical projectiles. The ballistic limit of GLARE impacted by a flat impactor is higher than with a spherical impactor, whereas the reverse result are observed for bare aluminum targets. Sadighi et al. [10,12–14] investigated the impact resistance of fiber metal laminates. They found that GLARE has a better performance in impact loading in comparison to all other types of FMLs. Furthermore, aluminum alloy 2024T3 can be the best candidate among other types of alloys due to its ductility and stiffness. Ghalami

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Table 1
Mechanical properties of aluminum 1050 [10].

Property	Value
Density, $\rho\left(\frac{kg}{m^3}\right)$	2700
Elastic modulus, E(GPa)	72
Yield stress, S_Y(MPa)	170
Tangent modulus, E_t(GPa)	0.84
Poisson ratio, v	0.32
Failure strain, ε_f	0.24

Table 2
Mechanical properties of unidirectional glass/epoxy [10].

Property	Value
Density, $\rho\left(\frac{kg}{m^3}\right)$	1550
Longitudinal modulus, E_{11}(GPa)	36
Transverse modulus, E_{22}(GPa)	5
Through-thickness modulus, E_{33}(GPa)	5
Shear modulus G_{12}(GPa)	2.7
Shear modulus, G_{13}(GPa)	2.7
Shear modulus, G_{23}(GPa)	1.92
Poisson ratio, υ_{12}	0.25
Poisson ratio, υ_{13}	0.25
Poisson ratio, υ_{23}	0.301
Longitudinal tensile strength, X_t(MPa)	465
Longitudinal tensile strength, Y_t(MPa)	5.6
In-plane shear strength, Y_c(MPa)	5.6
Ultimate tensile strain, ε_f	0.013
Ultimate shear strain, γ_f	0.12

Table 3
Mechanical properties of the projectile [10].

Property	Value
Density, $\rho\left(\frac{kg}{m^3}\right)$	7800
Elastic modulus, E(GPa)	210
Poisson ratio, v	0.3

and Sadighi [10] studied the ballistic response of sandwich panels with fiber metal laminates skin and polyurethane core in experimental and numerical investigations. They indicated that face-sheets have a greater contribution on energy absorption compared to sandwich specimens. Their results also indicate that in the comparison of different layer sequences of skins, the panels with FML skins have benefits with respect to both composite sandwiches and metal sandwiches.

In the present paper, the ballistic impact of GLARE5 is investigated experimentally and numerically. The impact perforation tests were conducted using one stage light helium gas gun at room temperature with targets secured in a square clamp. The numerical analysis was carried out by LS-DYNA commercial software. In both experimental and numerical analysis, the ballistic limits of GLARE5 are determined and the influences of parameters such as laminate thickness, impactor mass and diameter are explored. As mentioned earlier, there are few studies regarding impactor nose shape effect on ballistic limit in the literature. Hence, two sets of impactors with flat and conical nose shapes were selected and their effects are investigated.

2. Experimental procedures

2.1. Specimens and fabrication

The experimental part of this research consists of the fabrication of samples and the performance of ballistic tests. As mentioned earlier, GLARE is made of glass/epoxy laminates and aluminum layers. In this study, 1050 aluminum alloy with 0.3 and 0.5 mm thickness is used as facing layers. Unidirectional E-glass fibers and epoxy resin are used for preparation of the glass/epoxy laminates. The specimens were manufactured by the hand lay-up method. To achieve the desirable adhesion between aluminum layers and glass/epoxy laminates, the specimens were pretreated according to the ASTM D2651 [19]. The curing process is carried out at room temperature under 5 bar pressure for 12 h.

2.2. Mechanical properties

The mechanical properties of aluminum 1050 and unidirectional glass/epoxy are provided in Tables 1 and 2 respectively. To investigate the effect of projectile nose shape on the ballistic limit, two types of projectiles with flat and conical nose are used as impactors. The projectiles are made of steel and their mechanical properties are given in Table 3.

2.3. Ballistic experiments

The ballistic impact tests were conducted using one stage light helium gas gun at room temperature which is illustrated in Fig. 1.

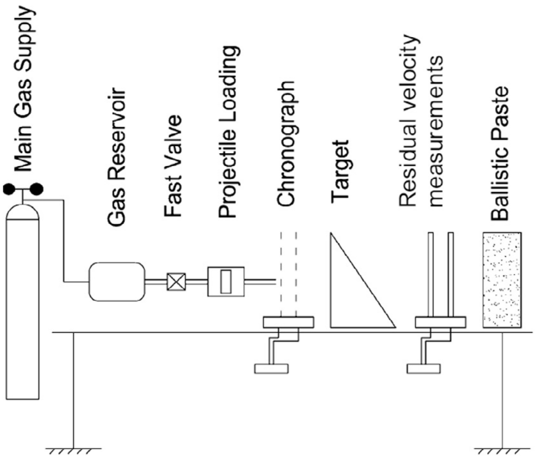

Fig. 1. Schematic illustration of gas gun [20].

The ballistic limit is the minimum impactor velocity which leads to complete perforation [21]. Several tests should be performed to determine the ballistic limit. The ballistic limit is acquired according to the following formula

$$V_{ballistic} = \sqrt{V_{initial}^2 - V_{residual}^2} \tag{1}$$

where $V_{initial}$ and $V_{residual}$ are the projectile velocity before and after impact [7]. The flat nose shape and GLARE5 were chosen as impactor and target for the first group of experiments. The impactor and target specifications are shown in Tables 4 and 5, respectively.

After performing several experiments, the ballistic limit was determined as $V_{ballistic}$ = 97 m/s.

Table 4
Impactor specifications.

Parameter	Value
Diameter (mm)	8.9
Length (mm)	30
Mass (g)	14.8