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Ballistic performance of unidirectional glass fiber laminated composite plate under normal and oblique impact

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Abstract

In this paper, experimental and numerical analysis of perforation behaviour of laminated composite reinforced with unidirectional glass fiber have been presented due to impact by 52 g blunt projectile. The influence of oblique impact on the ballistic performance of laminated target has been studied by considering four impact angles (0°, 30°, 45° and 60°) and impact velocities in between 50-500 m/s. The experimental impact tests on laminated target with fiber orientation (0°/90°/90°/0°) is performed with pneumatic gun. Material characterization of GFRP is performed with experimentation. The variation of residual velocity, acceleration, energy absorption and damage pattern in the laminated composite plate is studied in detail. The numerical results in terms of residual velocities and damage pattern in the target are having good agreement with experimental results and many new interesting results are also generated especially in case of oblique impact.

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Keywords: Laminated GFRP composite; Impact load; Oblique impact; Finite Element analysis

1. Introduction

FRP laminates are widely used as structural component in aerospace, military, protective armor, marine, motorsports as well as in civil engineering on the account of their good specific strength, light weight and moduli. The ballistic impact load is one of the critical conditions that the composite structure may undergo during their service life, in which incidence angle of impacting projectile is variable. Therefore, the penetration and perforation resistance of laminated structural component under differently oriented projectile impact is one of the important parameters to insure. The numerical analyses of perforation in the composite plate due to transverse normal

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impact were reported in the literature [1-3], which were described in respect of nose shapes of projectile, stacking sequence and target thickness on perforation of target. Some experimental studies were conducted by researchers to access the energy absorption in glass fiber composite and probable influence of target thickness and incidence velocity [4], along with numerical simulation using ABAQUS [5]. Recently, Xie et al. [6] studied the influence of impact angle on the ballistic limit of CFRP composite plate and concluded that the ballistic limit of spherical projectile increased continuously with impact angle.

In the present work, perforation behaviour of GFRP composite plate under blunt projectile impact, normal to the target plate has been studied experimentally and numerically. The influences of impact angle and incidence velocity on perforation of the target plate have been studied, considering different impact angles (0°, 30°, 45° and 60°) and velocities (50-500 m/s). Material characterization of GFRP is also carried out. All the numerical simulation in the present study has been performed by using AUTODYN hydro code.

2. Numerical modeling

The numerical simulation of ballistic perforation of the laminated composite plate has been carried out using a commercial hydro code ANSYS/AUTODYN v14.5. The interaction between plate and projectile is defined by "gap interaction method" with gap size of 0.05 mm and frictionless contact. The target plate of size 140 mm × 140 mm × 3.3 mm and 52 g blunt projectile of diameter 19 mm have been modeled using three dimensional hexahedral eight noded elements to mesh the target and projectile. The size of the element at central impact region was 0.5 mm x 0.5 mm and it was increased gradually towards the target periphery as described in literature [7], see Fig. 1.

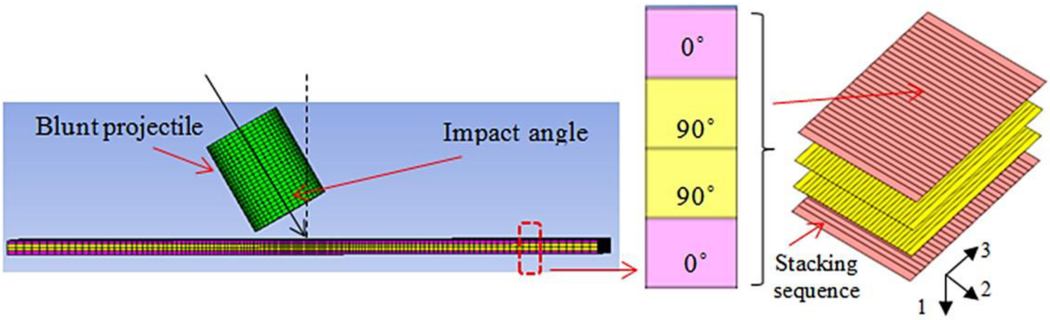

Fig. 1. Numerical model of laminated GFRP composite target and projectile

The failure initiation criteria and growth of damage in GFRP composite plate is based on the combination of material stress and strain. The global axis along *z*-direction or through thickness direction of composite plate was assigned the direction-11 while the *x* and *y* direction or in-plane axis of plate were assigned the direction-22 and 33 respectively in accordance with the requirement of AUTODYN. The modified version of Hashin's failure criteria [8] has been implemented in numerical model as below;

Failure along 11-plane,

$$e_{11f}^2 = \left(\frac{\sigma_{11}}{\sigma_{11f}}\right)^2 + \left(\frac{\sigma_{12}}{\sigma_{12f}}\right)^2 + \left(\frac{\sigma_{31}}{\sigma_{31f}}\right)^2 \geq 1 \tag{1}$$

Failure along 22-plane,

$$e_{22f}^2 = \left(\frac{\sigma_{22}}{\sigma_{22f}}\right)^2 + \left(\frac{\sigma_{12}}{\sigma_{12f}}\right)^2 + \left(\frac{\sigma_{23}}{\sigma_{23f}}\right)^2 \geq 1 \tag{2}$$