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Dynamic response of laminated GFRP composite under low velocity impact: Experimental and Numerical study

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Abstract

This paper presents experimental and numerical study of dynamic response of laminated glass fiber reinforced polymer (GFRP) composite plate due to blunt projectile impact considering incidence velocity lower than the ballistic limit. The experimentation of impact tests were performed with pneumatic gun which was used to propel a 52 g cylindrical steel projectile of diameter 19 mm on the laminated composite plate $(0°/90°)_5$ of size 140 mm × 140 mm × 3.12 mm. A three dimensional Finite Element model has also been presented in ANSYS/AUTODYN, a commercial hydro code, considering shock effect of impact in material modeling. The numerical results were validated with actual results. The time histories of velocity and acceleration of projectile along with the deflection, resistance force, energy absorption and damage pattern in the target plate have been studied. The numerical predictions of damage in the target and velocity history of the projectile show good correlation with the actual results.

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1. Introduction

Fiber reinforced polymer composites are extensively used in structural applications like making of external body of light weight automobiles, swimming pools and racing bikes due to their virtues of high stiffness, light weight and ease of manufacturing [1-2]. Nevertheless, these materials are prone to damage under impact because of their low

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ductility. Therefore, the needs of impact analysis of FRP materials attract the researchers in this field. Some significant studies concerning impact behaviour of FRP composite have been discussed here in brief.

Some experimental investigations addressing impact behaviour of composite plate using falling drop weight were reported in literature. Aslan et al. [3] studied experimentally the behaviour of E-glass/epoxy laminate under low energy impact using different masses of indenter and the indentation in laminate was discussed. It was concluded that the delamination in the target plate increased with the span size of plate. The effect of diameter of indenter on delamination in the target plate was studied by Icten et al. [4] and it was concluded that the induced damage in the target was more in case of impact by bigger indenter. Mishra and Nayak [5] studied analytically the deflection, stresses and contact force variation in the composite target due to low velocity impact by considering nonlinear Hertizian contact low. It was reported that the contact force increased with impact velocity. Some numerical approach to study low velocity impact phenomenon in the composite plate was also reported in the literatures. Tiberkak et al. [6] studied numerically the effect of impactor mass and incidence velocity on contact force and stress variation in the composite target. It was found that the peak of contact force increases with impactor mass and velocity. Another numerical study of in this regard was performed by Malik et al. [7] by using ABAQUS and impact energy absorption in target plate was discussed. Whereas, the damage in carbon /epoxy composite plate was studied by Zhang et al. [8], with ABAQUS software and it was concluded that the delamination and matrix crack were predominant cause of failure.

The available literatures indicate that the low velocity impact on composite plate was performed by falling weight, in which mass of indenter was kept high with limited velocity of impact. Thus, there is a need of study of FRP composite plate due to impact in which a long range of incidence velocity of projectile ranging up to the ballistic limit should be considered. In the present study, the dynamic response of composite plate due to projectile impact has been presented with experimentation and finite element analysis, in which the projectile velocity ranges up to the ballistic limit.

2. Numerical modeling

The numerical simulation of impact behaviour of laminated composite plate has been carried out using ANSYS/AUTODYN v14.5, a commercial hydro code. The GFRP composite plates of dimension 140 mm × 140 mm × 3.12 mm and 52 g cylindrical blunt steel projectile of diameter 19 mm have been modeled using Lagrangian process and hexahedron brick element. Frictionless contact is defined between the target and the projectile using "gap interaction method" [9] with a gap size of 0.03 mm. A mesh division of 70 × 70 has been used for the quarter plate, which shows good convergence in the numerical results with those obtained from experimentation. The details of numerical model and pictorial representation are available in literature [10].

3. Material modeling and characterization

The target plate as a deformable body is modeled with orthotropic constitutive relations in combination of nonlinear volumetric response that incorporates shock of impact. The failure model is based on material stress/strain criteria, available in AUTODYN code. All the details of material modeling and the constitutive relations are described in previous work [11]. The elastic properties of glass fiber lamina were obtained through tensile tests of GFRP laminate in universal testing machine (UTM), Civil Engineering Department, IIT Roorkee, India. The specimen dimension, manufacturing and testing procedure were followed according to ASTM D3039/D3039M. The material properties of GFRP laminate were obtained as required in the material model presented by Hayhurst et al. [12]. Three strain gauges were applied on the surface of specimens; one along longitudinal, second along transverse and third along the thickness. Most of the time strain gauges get broken in mid of the tests and unable to predict tensile failure strength and that's why failure strength was taken from UTM reading. The stress strain curves obtained from strain gauges give accuracy in the elastic modulus and Poison's ratio calculation. Hence, the plots of stress-strain and longitudinal versus lateral strain have been taken from strain gauges, Fig. 1. The material properties of GFRP composite as calculated from tensile test are listed in Table 1.