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Investigation of high velocity impact of cylindrical projectile on sandwich panels with fiber–metal laminates skins and polyurethane core

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ABSTRACT

In this study, the high velocity impact response of sandwich specimens with FML skins and polyurethane foam was investigated by experimental and numerical approaches. Impact tests were performed using a helium gas gun to identify deformation mechanisms and to check accuracy of finite element model. The 3D finite element code, LS-DYNA was used to model impact of cylindrical projectile with clamped boundary condition. Parametric studies were carried out incorporating different core densities, initial velocities of projectile and layer's stacking sequence. The results show the facesheets have major contribution on energy absorption of the sandwich specimens. Also, increasing core density does not significantly change absorbing energy in comparison with the effects of other parameters. Comparison of different layer sequences of skins indicated that these panels have benefits of both composite sandwiches and metal sandwiches, simultaneously. Examining damaged specimens demonstrated the cracks in front and back facesheet develop in different patterns. Circumferential crack was made in front facesheet, and radial crack was made in back facesheet.

1. Introduction

Sandwich panels are widely used in aircraft industries, train structures, containers and building structures due to their high stiffness and strength to weight ratio [21]. During their service life, these structures may be subjected to high velocity impacts by low-mass fragments resulting from the effects of disintegrating machineries [36]. These impacts constitute a high risk for such panels, because the mechanical properties are reduced after impacts. Therefore, vulnerability of composite skins under localized impact loads results in having skins replaced with alternative materials [1].

Fiber Metal Laminates (FMLs) are a new kind of hybrid composites. These composites resist very well against impact loads with their low crack growth rate and high-energy absorption [34]. In fact, FMLs combine plastic behavior and durability of metals with extreme fracture and fatigue properties of fiber-reinforced composites [26]. FMLs are multi-layer materials consisting of metal alloys and fiber-reinforced composite plies. Over the past few years, aerospace manufacturers have been interested in GLass Aluminium REinforeced (GLARE) which is made up of aluminum and glass/epoxy layers. A kind of GLARE has been used to manufacture upper fuselage of Airbus A380 [2].

Although there is an extensive research on low velocity response of sandwich structure, limited works has focused on high velocity impact response of sandwich panels [18]. Moreover, high velocity impact is a wave propagation controlled phenomenon, and its behavior does not depend on boundary conditions and dimensions of specimens [2,18]. Therefore, conclusions obtained from static or low-velocity impact tests cannot be applied to high velocity processes. Thus, it is necessary to study high velocity response of sandwich structures.

The following describes some recent researches on high velocity behavior of sandwich structures. Villanueva et al. investigated experimentally ballistic limit of aluminum core sandwich structures with plain composite and FML skins [23]. They showed these novel structures have excellent energy absorption under high-velocity impact conditions. Ivaez group studied the high-velocity response of sandwich structures with foam core and E-glass fiber/polyester skins [18]. They implemented Hou failure criteria in a VUMAT subroutine to model progressive failure of facesheets. Skvortsov et al. offered an analytical model based on the energy-balance principle to estimate the ballistic limit of sandwich panels [30]. The predicted energy of panels was close to results obtained from intermediate-velocity impacts. Kepler et al. performed high-velocity tests on sandwich structures with GFRP skins and Divinycell H80 core [19]. They offered a lumped spring-mass model to obtain force history. They modeled sandwich structure by concentric springs with shear spring connectors. For modeling of

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projectile contact force, they used four shape functions including constant force, triangular force, sine series and combination of sine and triangular force. They showed, triangular and combined force results have good correlation with experimental data. Hoo Fatt and Sirivolu presented an analytical method to predict residual velocity of a hemispherical-nose projectile impacting on composite sandwich panel [14]. The model predictions of residual velocities were in good agreement with experimental data. Velmurugan et al. studied the response of sandwich panel to projectile impact in velocity range of 30–100 m/s [33]. The ballistic limit of WRM/epoxy/foam sandwich panels was more than ballistic limit of CSM/epoxy/foam sandwich panels. Hassan and Cantwell investigated perforation resistance of sandwich structures with different foam cores [12]. They indicated perforation resistance of sandwich panels closely related to Mode II work of fracture of the foam material. W. Hou and co-workers studied ballistic performance of metallic sandwich structures, and investigated experimentally effects of several key parameters on energy absorption of panels [16]. D.W. Zhou analyzed experimentally and numerically ballistic perforation of monolithic steel sheets, two layer sheets, and light weight sandwich panels [38]. The results reveals that layered plates absorb more energy than monolithic plates of the same material and total thickness.

In the previous works, mechanical properties and low velocity impact behavior [22,25,27] of fiber–metal laminates were studied. In this paper, the high velocity impact response of sandwich panels with FML skins and rigid polyurethane foam is investigated by experiments and numerical simulation. Crack patterns and failure modes of facesheets of sandwich panels are examined, and the results of impact tests are used to verify the numerical model of LS-DYNA. Then, the finite element models are employed to study the process of perforation. Parametric studies are performed incorporating different core densities, initial velocities of projectile and layer's stacking sequence. Influence of the parameters are investigated on energy absorption of sandwich panel and deflections of the facesheets.

2. Experimental procedures

2.1. Specimens manufacturing

The materials used for manufacturing of specimens were aluminum 1050 sheets with 0.5 mm thickness, unidirectional glass fiber (E-glass), polyurethane (PUR) foam (40 $\mathrm{g/cm^3}$) and epoxy resin (Epolam 2002, with hardener Epolam 2002). The specimens were fabricated using hand lay-up method followed by pressurizing them during the curing process. Applying pressure resulted in reduction of voids and removal of excess resin. Therefore, residual voids were very small and negligible [22]. Before fabrication, dust and oil of aluminum plies were cleaned by acetone. Also, aluminum layers were prepared according to (p2) etches method to make stronger bonding between aluminum and composite layers [17]. The layer configuration of facesheet laminates was Al/0/90/90/0/Al.

2.2. High velocity impact tests

High velocity impact tests were performed using helium gas gun. The gas gun was made of a pressure vessel of 200 bar capacity, a high speed firing valve (400 ms) and a hollow steel barrel with 4 m long. The inside diameters of barrels were 9, 10 mm. Fig. 1 shows the gas gun in our laboratory. Initial and residual velocity were measured by photoelectric and paper-break systems, respectively. The various initial velocities were produced by changing projectile location in the barrel. The sandwich specimens were clamped along all sides in a fixture with 10 cm × 10 cm opening.


(a)

(b)

Fig. 1. The high velocity impact test device of Composite Lab. (a) Photograph of pressure chamber and firing valve the device. (b) Photograph of the capture chamber and fixture of the device.

Table 1
Mechanical properties of aluminum sheets [29].

Property	Value
Density, ρ ($\mathrm{kg/m^3}$)	2700
Elastic modulus, E (MPa)	72,000
Yield stress, σ_y (MPa)	170
Tangent modulus, E_t (MPa)	840
Poisson ratio, ν	32
Failure strain, ϵ_p	0.24

The mechanical specification of aluminum layers and glass epoxy are given in Tables 1 and 2 [3,24,29]. The projectiles were flat-ended cylindrical. Other specifications of projectiles are given in Table 3.

3. Numerical analysis

3.1. Geometry modeling

The commercial finite element code of LS-DYNA V9.71 was employed for impact simulation. LS-DYNA is a non-linear dynamic modeling software that benefits explicit formulation [11]. LS-DYNA is able to simulate impact response of FMLs [3,28]. The numerical model consists of a projectile with initial velocity and a sandwich panel with FML skins and PUR core as target. The model geometry was created by the pre-processor ETA Femb and LS-PREPOST. To include out-plane stress components, the model was meshed with 8-node reduced integration solid element. A biased mesh was