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Energy Absorption Characteristics of Sandwich Panels Due To Foreign Object Damage

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ABSTRACT

Foreign object damage (FOD) usually happens when objects are sucked into jet engines powering military or civil aircraft. Under extreme conditions, FOD can lead to severe structural damage. More commonly it produces locally impacted sites of the fan and compressor airfoils, reducing the fatigue life of these components. FOD is a prime cause for repair in aircraft engines. The present study deals with the impact of a projectile on solid and sandwich structures with different impact angles, the honeycomb core is generally used in between two face-sheet because of its advantage of weight reduction and high specific energy absorbing capability during impact. .The modeling of the sandwich panel is done using HYPER MESH and the analysis is carried out using explicit solver LS DYNA 971 R 8.0 and finally, a comparative analysis is carried out between solid and sandwich panel based on energy absorption and weight reduction of the structure.

Keyword: Foreign Object Damage, Specific Energy Absorption, Johnson-cook, Damage Parameter.

1. INTRODUCTION

FOD refers to Foreign Object Damage caused by objects ingested into turbine engines during take-off and landing, these impacts cause severe damage to parts of aero-engines. Foreign object damage (FOD) arises due to ingestion of small hard particles like small pebbles and sand particles in gas turbine engines. These ingested objects cause damage and lead to a reduction in strength after impacting stationary and rotating components of gas turbine engine. The velocities of the objects can reach 60 to 500 m/s depending on the engine specification. Due to non-contained engine fragments, there are horrified incidents where there is a loss of aircraft and valuable human lives. This foreign object debris has to be contained within the engine with the help of the casing. Many of the engine casing structures are made up of metals but in order to contain the debris, the thickness of the casing has to be increased which in turn increases the weight of the component which is not preferable in aerospace industries. In order to overcome this drawback, one of the alternative methods is the using of honeycomb structures in place of metallic casing structure. A typical sandwich structure consists of two thin, high strength face-sheets bonded to a thick and light. Face-sheets are strong when compared to the core which is relatively weak and flexible, but when they combined as a sandwich panel they produce a structure that is stiff, strong and lightweight.

1.1 LITERATURE SURVEY

In order to carry out the entitled the work an extensive literature survey was done by collecting and studying the number of relevant journals, articles and technical papers from the available resources.

The impact of debris induces small nicks on fan and compressor blades which, in turn, will act as stress raisers prone to crack initiation. The damage caused by FOD tends to compromise the mechanical balance of the rotating components and also alters the aerodynamic flow over the blade aerofoil. This results in high vibration or flutter which can promote crack propagation this was investigated by Xi Chen et.al [1]. A number of different approaches have been tried in order to simulate FOD in the laboratory. Early approaches often employed a quasi-static chisel indenter to introduce a notch in the leading edge of a blade or specimen by Hamrick et.al [2]. The validity of the Johnson-Cook constitutive relation and failure criterion at high strain rates was assessed by predicting the dynamic response of Ti-6Al-4V under high-speed ball impact at various velocities and angles. White light scanning was performed by Xuemei Wang and Jun Shi et.al [3]. The numerical simulations for studying the impact and penetration of thin plates by small fragment impactors were carried by Damodar et.al [4]. In these study threshold velocities for different combinations of pitch and yaw angles of the impactor were obtained for the impactor-target test. Conclusions drawn from such predictions contribute to improvements in the design of impact load on sandwich panel components and help in reducing the experimental effort associated with design.

1.2 METHODOLOGY

In order to study the impact behaviour of the projectile on honeycomb structures for energy absorbing characteristics during an impact event, the following methodology is adopted. Based on the study of available literature the process of energy absorption behaviour of thin walled structures is examined. For this case, the modeling of the core is done by using the available modelling and meshing tool HYPERMESH V12.0. Then the analysis is carried out by importing the model to available solver tool LS DYNA 971 R 8.0 solver. A number of impact analysis is also carried out on the sandwich panel structures by considering the sandwich structures with damage parameters taking into consideration. The projectile is impacted on the sandwich panel at different impact angles to understand energy absorbing characteristic of honeycomb sandwich panel and to study the structural behaviour of honeycomb structure during impact.

2. FINITE ELEMENT MODEL

The geometric model considered for the analysis is as shown in Fig-1 it consists of a plate and spherical shape projectile. The target plate is modelled as solid and sandwich panel having a plate thickness of 3.175mm into a specimen with the dimension of 25.4 mm × 25.4 mm. The projectile is spherical in shape with a diameter of 6.35 mm. The target specimen was aligned such that the projectile impacted on its flat surface at various incidence angles (i.e., normal or oblique impact).

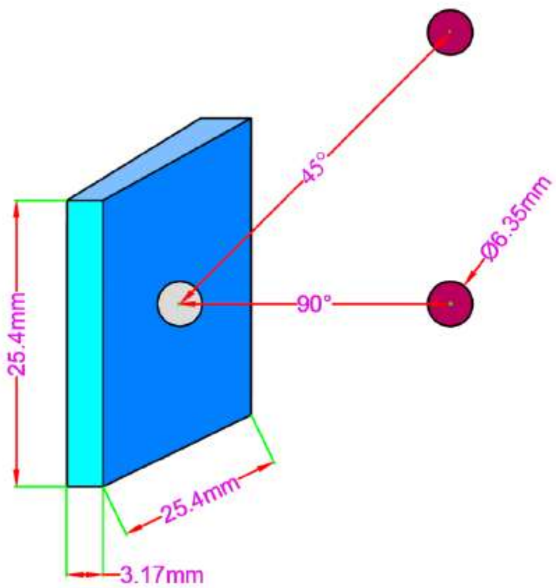


Fig 1: Geometric model of solid plate and spherical projectile with normal and oblique angle

A three-dimensional, numerical model representative of the FOD testing was modeled using Hyper-mesh and analysis is carried out using the explicit finite element code LS DYNA. The eight-node brick hexahedral elements were used in the simulation. Fig-2 shows a typical finite element mesh created for the target and the spherical projectile. The movement of the target along was constrained in all direction along the sides of the plate. The impact velocities in the present study were 182.88 and 243.84 m/s, and two impact angles of 90 and 45 were used.

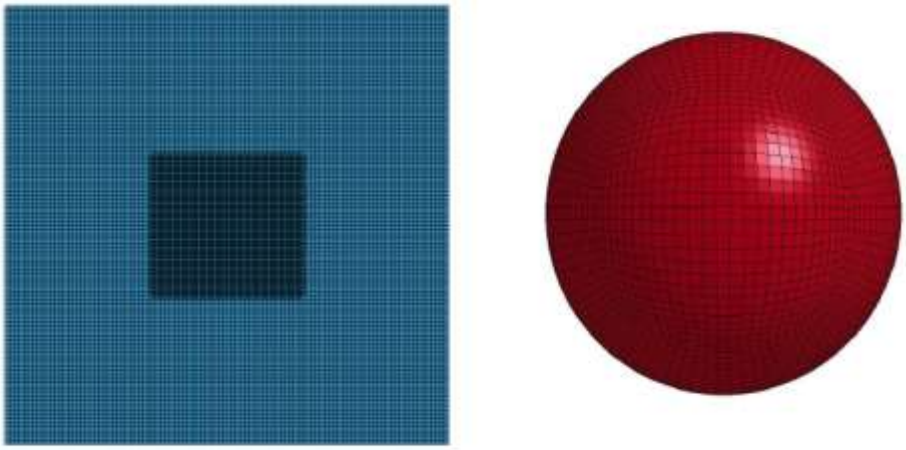


Fig-2 Meshed model of target plate and spherical projectile

3. MATERIAL PROPERTIES

*MAT_JOHNSON_COOK and *MAT_ELASTIC material model is used for the target plate and spherical projectile with material as Ti-6Al-4V and alumina. The mechanical properties of the target and the projectile are as shown in Table-1 and Table-2 respectively.

Table 1: Properties of Ti-6Al-4V target

Density	4650.22 kg/m^3
Young's modulus	110.316 GPa
Poission's ratio	0.31
Plastic strain to failure	0.22
Yield stress	1.00663 GPa
Tangent modulus	1.59269 GPa

Table-2 : Properties of Alumina projectile

Density	7750.373 kg/m^3
Young's modulus	193.053 GPa
Plastic strain to failure	0.56
Poisson's ratio	0.305
Yield stress	339.222 MPa
Tangent modulus	165 MPa

3.1 Johnson cook material model

*MAT_JOHNSON_COOK is especially used as a material model in case of high strain rate conditions and the same is considered as the material modeling for the target. The parameters used in the study are as shown in Table-3.

The Johnson–Cook (J–C) constitutive relation and fracture criterion were selected as the material model for the target. The Johnson–Cook(J–C) constitutive relation scan describe the behaviour of material subjected to large strains, high strain rates, and high temperatures, sand can be expressed as

$$\sigma_e = (A + B\varepsilon_e^n)\left(1 + C\, ln\frac{\dot{\varepsilon}_e}{\dot{\varepsilon}_0}\right)(1 - T^{*m}) \quad (1)$$

Where A ,B ,C , *n* and *m* are material constants, σ_e is the equivalent von Mises stress, *e* is the equivalent plastic strain; $\dot{\varepsilon}_e$ is a dimensionless strain rate,˙ is a user-defined reference strain rate. The Johnson–Cook fracture criterion is based on damage evolution, where the damage *D* of a material element is expressed as

$$D = \frac{\varepsilon_{pe}}{\varepsilon_f} \tag{2}$$

Where ε_{pe} is the increment of equivalent plastic strain that occurs during san integration cycle and ε_f is the fracture strain. Failure is assumed to occur by element erosion when *D* equals unity. The fracture strain depends on stress triaxiality, strain rate and temperature, and sis given by

$$\varepsilon_f = \left(D_1 + D_2 exp(-D_3\sigma^*)\right)(1 + D_4 ln\dot{\varepsilon})(1{+}D_5T^*) \tag{3}$$

Where *D*1 to *D*5 are material constants, σ^* is the stress triaxiality ratio

Table-3 Parameters of Ti-6Al-4V target

A	B	C	M	T_m	T_r
1380	948	0.005	1	1800	293
D_1	D_2	D_3	D_4	D_5	
-0.09	0.27	0.48	0.014	3.87	

The hexagonal and circular core is 3mm in height and the above and below face plates are 0.0875mm each. The thickness of the core is 1.5mm.The adhesive bonding between the face sheet and the core is modelled as *CONTACT_TIEBREAK_NODES_TO_SURFACE and failure is defined in terms of shear and tensile stresses.

$$\left(\frac{\sigma_n}{\sigma_{nf}}\right)^2 + \left(\frac{\sigma_s}{\sigma_{sf}}\right)^2 \geq 1 \tag{4}$$

Where σ_{nf} and σ_{sf} are tensile and shear failure stress respectively.

4. FINITE ELEMENT ANALYSIS

Initially, the projectile is impacted on a flat solid plate to obtain the energy absorption of the target during impact. In the next stage, the flat target is replaced by the honeycomb structures made with a hexagonal structure and circular structures. The modeling of these honeycomb structures are in such a way that the total mass of the both the honeycomb structures are nearly equal and the dimension of the target plate, as well as the material model of the projectile, are kept same.

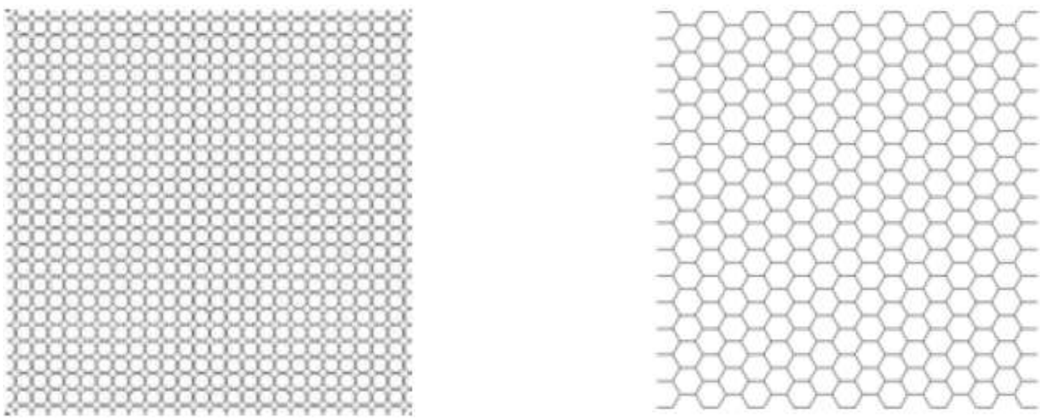
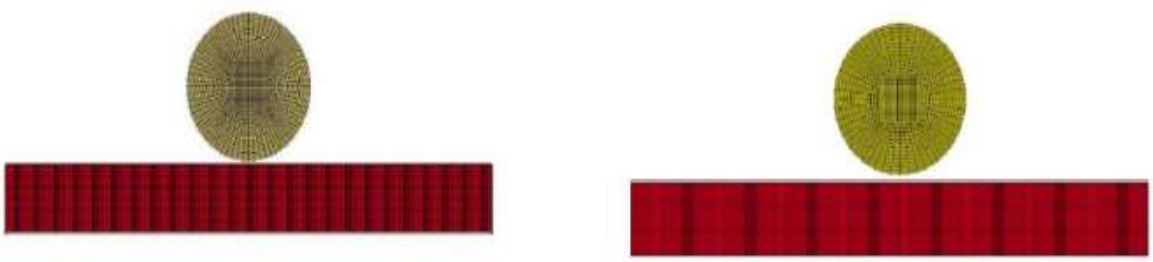


Fig-3: Model of the honeycomb structures

Circular Hexagonal



t=0msec

t=0.03msec

t=0.06msec

Fig4: Impact on sandwich structure with normal angle of 90^0

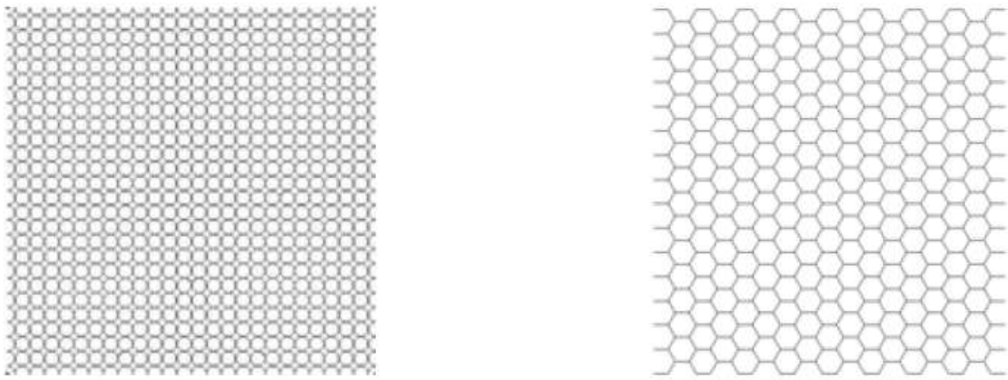
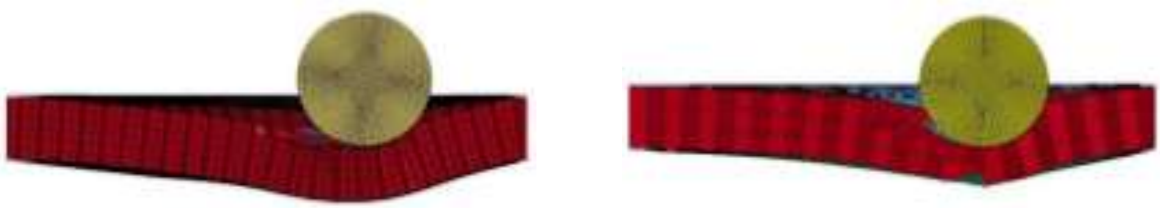


Fig-5: Model of the honeycomb structures

Circular Hexagonal

t=0msec

t=0.03msec



t=0.06msec

Fig-6: Impact on sandwich structure with normal angle of 45^0

5. COMPARATIVE ANALYSIS BETWEEN SOLID AND HONEYCOMB SANDWICH PANELS

Based on the analysis results the kinetic energy and internal energy of the sandwich structure and solid plate are tabulated and these are as shown in Fig-4 and Fig-6.

Chart1: Kinetic energy of projectile with impact angle of 90^0

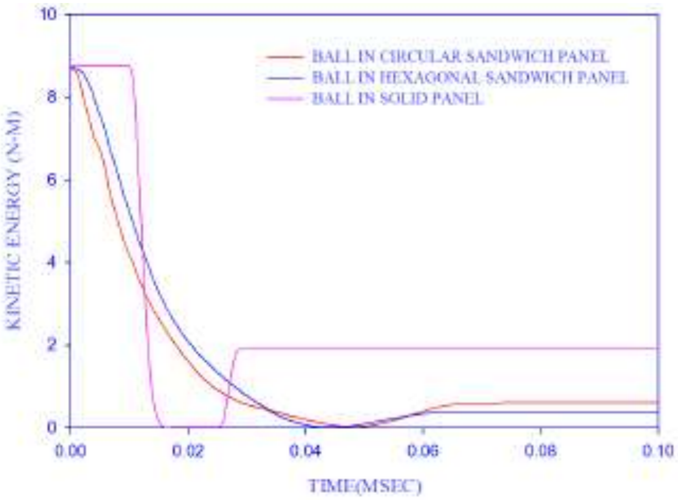


Chart 2: Kinetic energy of projectile with impact angle of 45^0

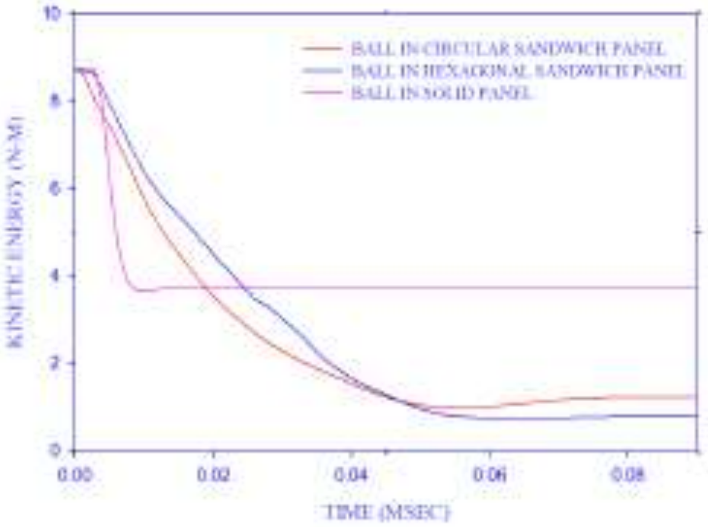


Chart-3: Internal energy of target plate with impact angle of 90^0

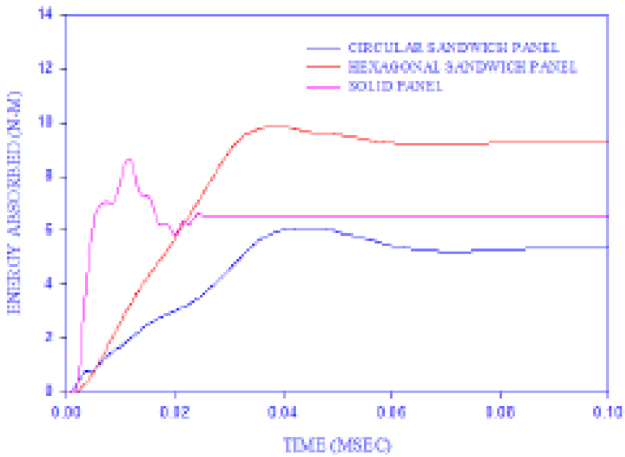
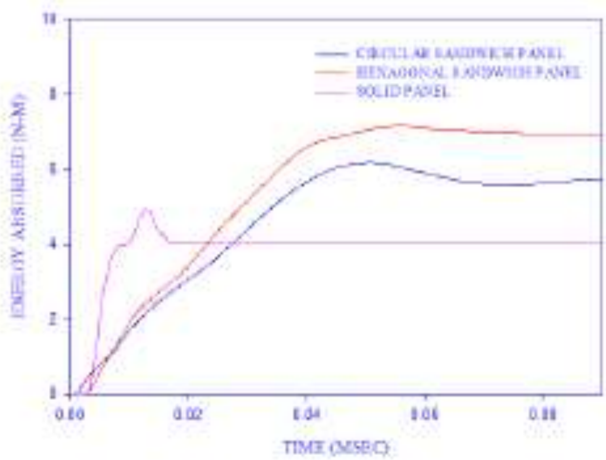


Chart-4 : Internal energy of target plate with impact angle of 45^0



By combining all the results including solid, hexagonal and circular honeycomb structures, the specific energy absorption of the each one is calculated and the values are as shown in the Table-4.

TABLE4 : SPECIFIC ENERGY ABSORPTION COMPARISON

Target	Energy absorbed (J)		Weight (gm)	Specific energy absorbed (J/gm)	
	90^0	45^0		90^0	45^0
Solid metallic	8.4	4.8	9.07	0.92	0.52
Hexagonal	9.7	7.7	2.36	4.11	3.26
Circular	5.8	6.2	2.74	2.11	2.26

CONCLUSION

This analysis is studied by using an alternate geometry. The alternate geometry is considered to be flat solid panel and honeycomb panel. The honeycomb technology is considered for the analysis since it has good weight reduction capability than solid panels. Further, the honeycomb structure with the hexagonal and circular shapes core with the nearly same amount of weight is employed. These two structures showed the best results for energy absorption compared to the solid structure. Hence the honeycomb sandwich panel showed good containment capability and the higher specific energy absorption behaviour compared to the solid panel.

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