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Damage Analysis of Composite Stiffened Panels under Low Velocity Impact Loading for Aircraft Application

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ABSTRACT: Composite Materials have become a popular due to its high specific strength and high stiffness to weight ratio. They found extensive applications in automobile, aerospace, defence equipment's and other critical components. Composite plates are predominantly used as alternative materials to regular materials. In order to provide even better strength and resistance to deformation, stiffeners are attached to the composite plates thereby increasing the bending stiffness to a large extent. These stiffened panels have found principal application in aircraft wings, ship hulls and bridge decks. In this project, low velocity impact on composite plate and composite stiffened panel has been studied. Numerical models of composite plates and stiffened panels are impacted with different energies (4J, 9J, 16J) and are analysed by finite element software ABAQUS explicit and four different oblique impact angles 90◦, 60◦, 45◦and 30◦ are analysed. Different parameters such as displacement, contact force, energy absorbed were compared for both composite plates and stiffened panels. It was noted that stiffened panels offer more resistance to deformation and absorb more energy due to high stiffness.

KEYWORDS: Stiffened Panels, low-velocity impact, FE Model, ABAQUS Explicit.

I. INTRODUCTION

There has been a predominant growth in the application of composite structures in the engineering fields, particularly in automobile and aerospace industries. To catalogue few examples are the aircraft tail, the wings with tapered composite stiffeners, Monocoque F-1 formula racing car shells and bonnet, Wind turbine light weight blades and sports and recreational machines and many more. This project is concentrated on the finite element analysis of the low-velocity impact on composite panel and composite stiffened panel of unidirectional Glass/Epoxy material with different velocities. The modelling, meshing and simulations are performed using the Finite Element Package-ABAQUS/Explicit. Parameters like deflection and contact force are studied under all fixed boundary condition and two fixed boundary conditions.

Composites are produced using various materials whose properties might be or might not be homogeneous or isotropic (like metals). Therefore, the utilisation of composite material includes a wide selection of available materials such as fibres, reinforced concrete, metals, and fibres. However, it is primarily fibre reinforced composites that have been increasingly used for aero-space applications. These composites generally consist of layers of unidirectional or bidirectional fibres of high specific modules for the high structural applications required, particularly in military aircraft (mainly glass fibres, carbon fibres, Kevlar) which are fortified together by matrix type of material (e.g., epoxy resin). Laminated composites have multiple benefits over other conventional materials like metals: e.g., high specific rigidity and strength, excellent corrosion resistance and anisotropic properties that can be tailored to strength necessities. They are prone to low velocity impacts during their function in any respective application and thus a study on this specific parameter is essential. The stress developed due to the impact can cause certain deformation which shouldn't be a cause of failure of the machine, owing to this fundamental and significant trait, this study aims at impact analysis. Certainly, the coupling between stretching, twisting and bending made available by selecting appropriate stacking sequence in composite laminate permits aero elastic tailored structures.

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M. Salvetti (2018) studied the effects of experimental and numerically composite models with a low impact velocity on composites. Impactor mass effect varies impact energy and speed and laminate composite damage, experimental and numerical impact parameters, effect characterization and impact characterization, and impact response effects studied.Gupta, Madhu (2004) - Performed the experiments for the normal and oblique impact on single sheet steel and aluminium sheets and concluded how the relation between plate thickness and incident velocity can be determined under different parameters and additional work can be referred to. Different types of contact models and special algorithms have been dived to analysis the FRC structural response under low impact analyses.

GhasemiNejhad (2018) The impact performance and damage tolerance were assessed by instrumented drop weight impacts for woven carbon fibre reinforced thermoplastic composites. The effect of impact speed within the range of used speeds was found to be insignificant. The energy impact has had a considerable impact on the panel performance.Feli (2018) From parametric studies on the laminated box beam, the impactor slowed down when the velocity and the mass of the impactor increased, with a more normal deflection of the beam. There is no rebound of the impactor if the impactor speed and mass are big enough. The absorbed energy by box due to greater damage has been increased by increasing the speed and mass of the impactor

Homayoun (2019)The digital analysis describes that damage induced by the low velocity CFRP plate without drilling increases as the impact energy increases. The addition of stiffener to the composite plate significantly reduces the total damage to the composite plate and stops the impactor in a short time.

Orifici (2020) Experimental and numerical investigations were conducted into the damage growth and collapse behavior of composite blade-stiffened structures. Four panel types were tested, In the numerical analysis of the undamaged panels, collapse was predicted using a ply failure degradation model. The numerical approach gave close correlation with experimental results.

Impact damage is a major consideration of aircraft composite structure design and maintenance. Damage to airframe structure caused by low velocity impact is because of both operational as well as maintenance activities. There are usually few incidents of low velocity impact (LVI) damage in the operating environment and most can be attributed to birds hitting on aircraft and hailstone strikes. The major causes of LVI damage isdue toimproper handling and maintenance issues which include airframe part handling, transportation, storage and also accidental instrument drops.

II. FINITE ELEMNT MODELLING

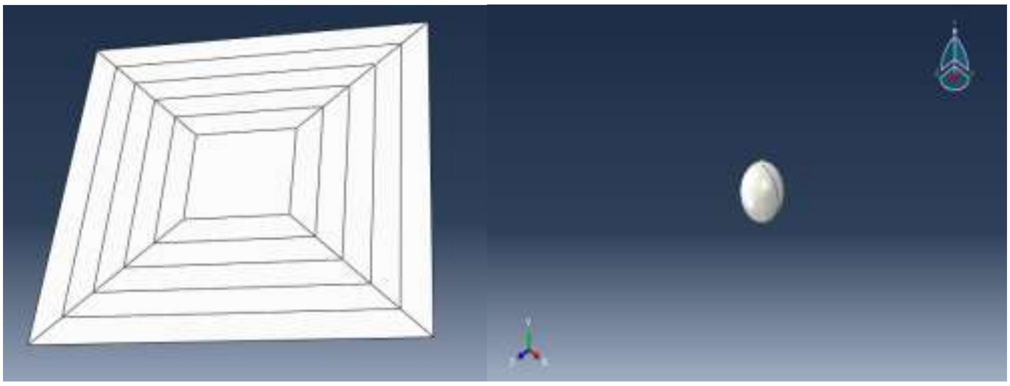

Fig 1: Finite element model of composite plate and the impactor.

The specimen consists of glass fibre reinforced composite layers. According to ASTM principles for low impact testing, the dimension of each layer is taken as 100×150mm having thickness of 0.3mm. The composite panels used were oriented with angles of 0˚, -45, +45, 90˚. For composite panel, the orientation of fibres is $[+45^\circ/0^\circ/-45^\circ/90]_S$ and for stiffened composite panel, skin has layup of $[+45^\circ/0^\circ/-45^\circ/90]_S$ andstiffeners also consists of 8 layers and has layup of $[+45^\circ/0^\circ/-45^\circ/90]_S$.

Plates are modelled. The Plates are modelled as 3D Deformable solid of extrusion type. The dimensions of plates are 100mm x 150mm and having thickness of 0.3 mm as shown in Figure. Each composite plate is oriented indifferent directions. The composite plates have orientations -45/0/45/90. This is taken from ASTM standards.

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There are three types of elements in modelling; they are solid, continuum shell and conventional shell element. Solid is a three-dimensional body and it is applicable to the objects with significant dimensions in the entire three axes, which means only shell elements have to be used. We have two options here, continuum shell and conventional shell given in Fig 3.

The Indenter can either be a solid element or a rigid shell element. Since our main emphasis is on the characteristics of the laminate, to reduce the complexity of the problem, the indenter is considered to be a spherical rigid shell. However, assigning a reference point at the centre of the sphere and assigning mass to it makes it a proper indenter.

Since it is a rigid body, it does not undergo any deformation. It also does not absorb any energy or contact force. Hence the whole energy and force it transmitted into the laminate. In modelling a two-dimensional enclosed semicircle is designed and it is rotated about its axis in 360 degrees which results in the sphere, then in the geometry a point is created at the centre of the sphere. This centre is then converted into a reference point in the interaction port given in Fig 4.

Glass fibre reinforced epoxy is used as a principal material. The mechanical properties of Glassfibre are listed below.

Table 1- Material properties for glass fibre

Properties	**Glass/Epoxy**
Density	1600 kg/m3;
Elastic Constants	E1=152 GPa; E2=8.71GPa E3 =8.71 Gpa; E2=E3 G12=G13= G23 =3.35 Gpa; υ12= υ13= υ3=0.3;
Strength [Mpa]	Xt=1930; Xc=962; Yt=41.4;Yc=276; S12= S13= S23=82.1;

After assigning material properties, the instances are created as dependent instances so as to make individual part assembly possible. Assembly is done by placing the layers one over the other. The I-section stiffened panels are created by eight layers of Glass fibre reinforced epoxy plates with an orientation of [+45˚/0˚/-45˚/90˚] s. These eight layers are united to form a single I-section beam. A total of five I-section stiffeners are attached at the bottom of the eighth panel as shown in the fig.5.

III. RESULTS AND DISCUSSIONS

The simulations are performed and the results are obtained in two phases, in the first stage the normal impact simulations are performed and then the better performing material is tested for oblique impact

Normal Impact: Following are the results of maximum deflection and contact force developed under the impact. The models are analyzed by Finite Element Method. Deflection and contact force are observed from the results of the Epoxy glass fiber composite panel.

For velocity 4 m/s : The simulation were carried out for All sides fixed- Panel with stiffeners and without stiffeners.

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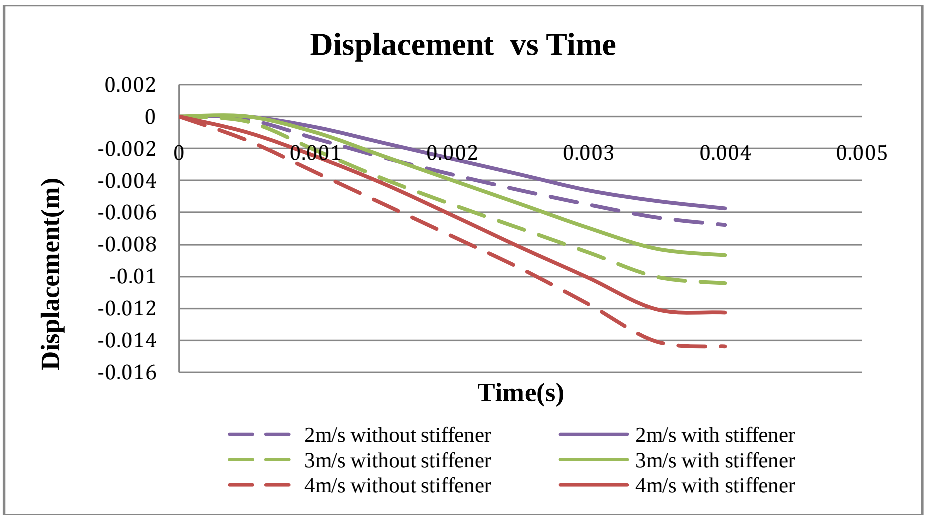

As the impactor touches the composite panel thedeflection of panel starts increasing with respect to time as shown in displacement vs. Time graph. It is observed that the deflection of composite.

Oblique Velocity: ImpactSimulation of different impact angles including 90◦, 60◦, 45◦and 30◦ with same impact energy (16J) was carried out to assess the influence of impact angles, damage behaviour of composite panel and composite stiffened panel as shown in Fig. 6.

When the impactor hits the composite panel with an angle, velocity can be resolved into two components. One is normal to the composite panel surface and another component is tangent to the composite surface. Normal velocity component results into deflection and tangential component results into shear force. Shear force causes delamination in the composite panel.

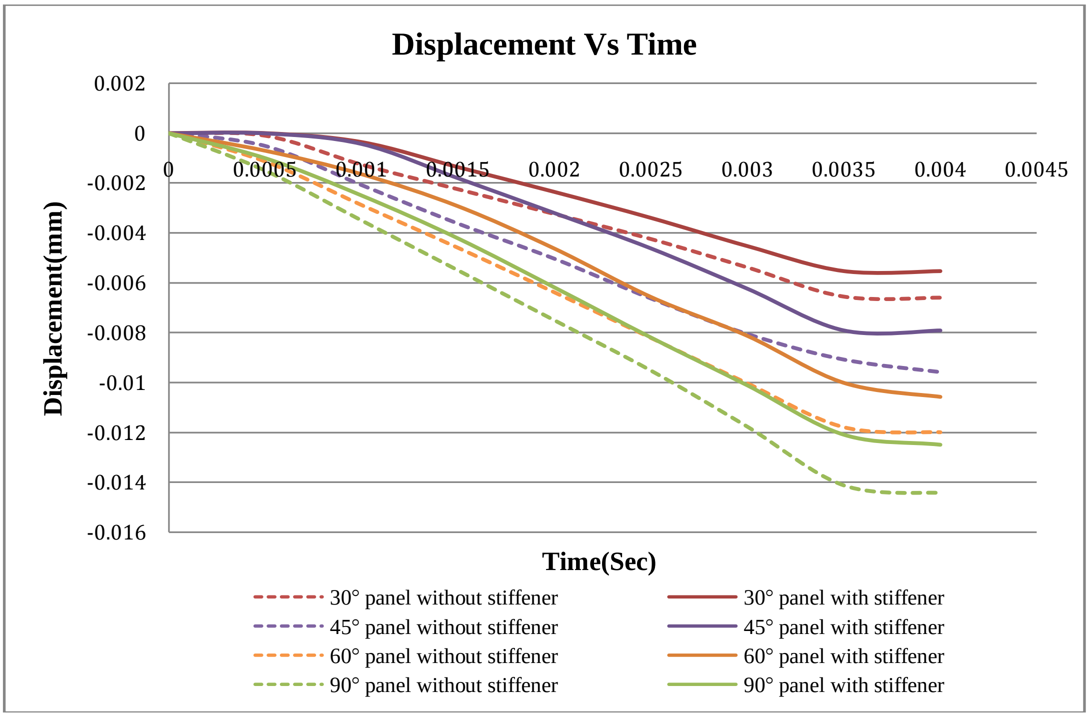

Fig. 7 Displacement Vs Time graph for different impact angles

In Fig.7 the deflectioniscomparedbetween composite panel and composite stiffened panel for different orientations of 300, 450 and 600. As itisobserved in Figure, the deflection of composite panel withoutstiffeneris more whencomparedwith composite panel withstiffener in oblique lowvelocity impact also. As the impact angle changes from 300 to 900 the deflection of the composite panel isincreasing. As the impact angle increases normal component of the velocityincreaseswhichresults in more deflection.

IV. CONCLUSION

Comparative results are plotted for displacement, energy and contact force of panel withstiffener and withoutstiffener. Deflection in composite panel withoutstiffeneris more whencomparedwith composite panel withstiffener. Composite panel withoutstiffener can easilydelaminatewhencomparedwith composite panel withstiffener. Composite panel withstiffeneroffers more stiffnessduringbendingthan composite panel withoutstiffener. So contact force in composite panel withstiffenersis more than composite panel withoutstiffeners. That energy absorption in composite panel withstiffenersis more than the composite panel withoutstiffeners. Finiteelementanalysisisalsodone for oblique impact with 30°, 45°, 60°, and 90° angles. It isobservedthat as the angle of obliquityincrease, the parameters like contact force, energyabsorbed, deflectionincreases for both composite panel and composite stiffened panel and 90° impact isdangerous condition.

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