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Modelling and Analysis of Low Velocity Impact on Composite Laminate for Variable Parameters

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ABSTRACT:

There has been a predominant growth in the application of composite structures in the engineering fields, particularly in automobile and aerospace industries. This project is concentrated on the finite element analysis of the low-velocity impact on composite laminates of unidirectional Glass/Epoxy and Carbon/Epoxy material with different ply orientations. The modelling, meshing and simulations are performed using the Finite Element Package-Abaqus/Explicit. Parameters like deflection and contact force are studied under fixed boundary condition by varying the ply orientation in the models and maintained a constant angle between the consecutive plies in the plate. A good agreement is seen between the results of Glass/Epoxy and Carbon/Epoxy laminates and discussed.

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

I. INTRODUCTION

Composites are produced using various materials whose properties might be or might not be homogeneous or isotropic (like metals). Therefore, the utilization of composite material includes a wide selection of available materials such as fibers, 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.

Fiber- reinforced composite laminates are widely used in many engineering fields, owing to their high strength to-weight and stiffness-to-weight ratios. These structures are fabricated in required direction with adopting a tailoring property. They have been increasingly used in load-bearing structures such as aircraft and automobile industries. However, they are liable to damage due to low velocity impact loading during in service. This impact loading can cause extensive sub-surface damage that may not be visible on the surface but can lead to a significant reduction in the strength of composite laminates.

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.

Ghasemi Nejhad (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 is due toimproper handling and maintenance issues which include airframe part handling, transportation, storage and also accidental instrument drops.

The resistance to impact depends on several factors of the laminate such as stacking sequence, impacting object size, velocity and mass of the impactor. The dynamic behavior of the composite laminates is very complex due to their many concurrent phenomena under impact load. Fiber breakage, delamination, matrix cracking and plastic deformations due to contact are few effects, which should be considered when a structure made from composite material is impacted by a foreign body.

FRC laminates are widely used in aircraft and automobile industries, owing to their high strength-to-weight and stiffness-to-weight ratios. They are liable for damage due to low-velocity impact loading during service. Stresses are developed and deformation occurs in the case of a low-velocity impact. The impact and the damage are guided by three parameters that are ply orientation; Impact Energy (Mass, Velocity of the Impactor) and boundary conditions, the stress and deformation do not vary linearly with the impact energy and the other parameters, which are going to be studied in this project.

Now a day composite structures are used in many applications like aerospace, marine etc., because if its special properties like high strength to weight ratio and lightweight. Low impact velocity causes matrix cracking, delamination, fibre breakage and penetration. Impact on a composite structure damages the structures and reduces the strength and stability and damages are very difficult to detect by naked eye. Therefore, it is very important to predict the failure of the composite structure and also very difficult to understand the behaviour of composite structures. Cantwell. W.J, Morton J (1978).

In order to improve the composite structure, it is important to understand the dynamic behaviour and damage propagation under impact loads Mili F, Necib B (2001).From the experiments, low impact velocity on composite structures attains less reduction in their properties like tensile, compression and shear strengths by Sevkat (2009) and damages are mainly due to matrix failure and delamination, not by fibre failure by Mikkor (2006). In the cases of metals, impact energy absorbed by elastic region and plastic region;

II. FINITE ELEMNT MODELLING

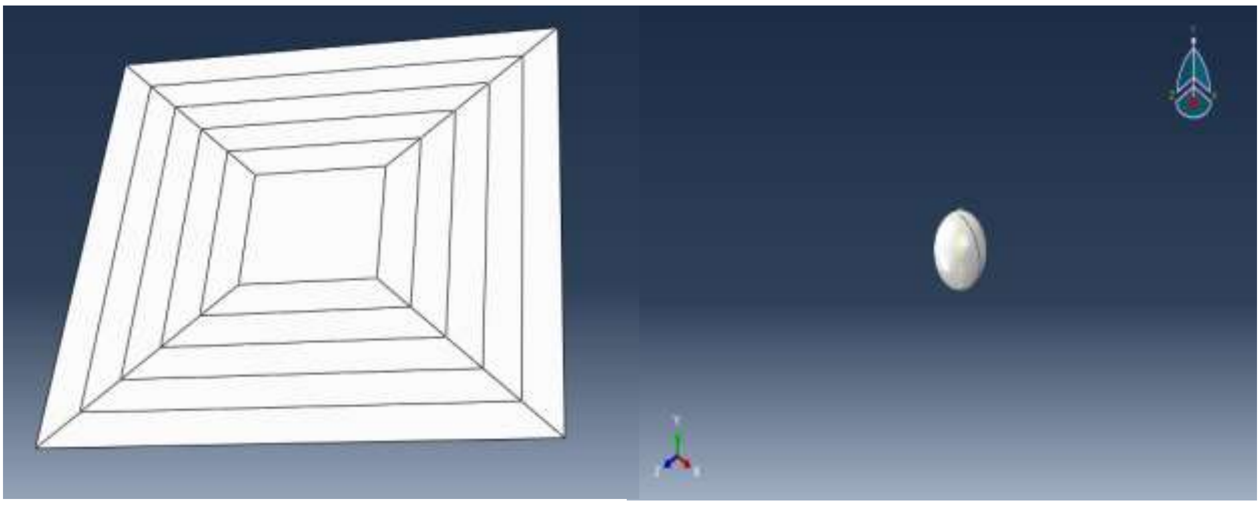

Fig 1: Finite element model of composite plate and the impactor.

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 $[+45˚/0˚/-45˚/90]_S$ and for stiffened composite panel, skin has layup of $[+45˚/0˚/-45˚/90]_S$ andstiffeners also consists of 8 layers and has layup of $[+45˚/0˚/-45˚/90]_S$.

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. 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 1.

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 1.

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/m^3;
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.

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 analysed 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 was carried out for All sides fixed- Panel with stiffeners and without stiffeners.

NORMAL IMPACT

Following are the results of maximum deflection and contact force developed under the impact of the models mentioned in Table1 analysed by Finite Element Method.

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.

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 are 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.

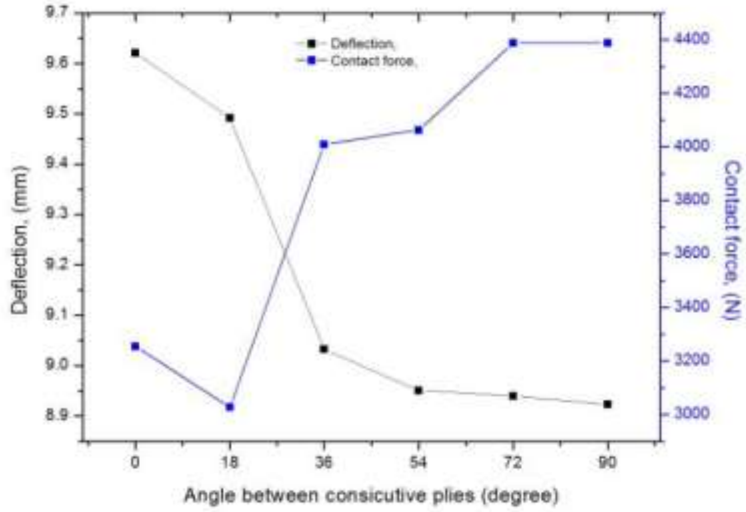

Fig. 2 Deflection and Contact Force vs. Angle between consecutive plies of carbon fiber composite laminate.

THE EFFECT ON CONTACT FORCE

Maximum contact force developed due to impact loading has the more significance in damage initiation. The results of maximum contact force of the impactor versus angle of consecutive plies in the plate is plotted with fixed boundary condition for different oblique angles are presented, shows that increasing in consecutive angle in plies under oblique impact, the contact force is initially decreases at 0 degree then increases in 18 degree and observed same in successive change for next consecutive layer. It observed that increasing contact force in the consecutive plies at normal impact loading condition.

In Fig. 2 the deflection is compared between composite panel and composite stiffened panel for different orientations of 30^0, 45^0 and 60^0. As it is observed in Figure, the deflection of composite

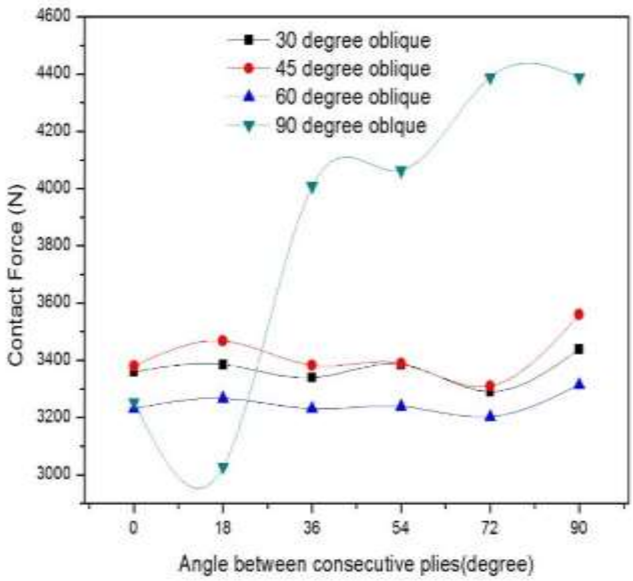

Fig. 3 Contact Force vs Angle between consecutive plies for different Oblique impact angles

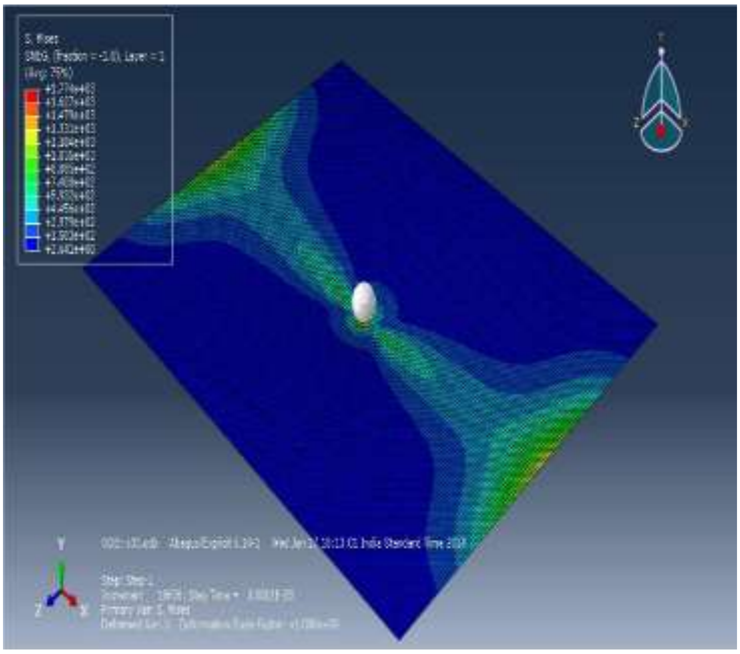

Fig.4 Stress contour under normal impact of 13.5J and fixed boundary conditions

The results of stress versus angle of consecutive plies in the plate is plotted with fixed boundary condition for different oblique angles are presented in Fig 3. The increasing in consecutive angle under oblique impact the stress developed in the plate is reduces initially then increases significantly and in consecutive ply angle 18 degree less stress is observed.

In the case of normal impact angle similar behaviour is observed in Fig. 4 The amount of stress developed in the plate is less for oblique compare to normal impact angle due to presence of plies orientation and type of impact angle.

CONCLUSION

Abaqus /Explicit were efficiently used to model the composite laminate and the indenter. The numericalmodel was simulated and measured the material datain order to predict the impact behaviour for the consecutive staking sequences, deformation and the contact force developed in various laminates under normal impact for considering unidirectional Glass/Epoxy and Carbon/Epoxy material with different ply orientations. The relation between the consecutive ply angle and the maximum deflection is studied. A good agreement is seen between the results of Glass/Epoxy and Carbon/Epoxy laminates and discussed. The parametric study with varying impact energy and boundary conditions is helpful to understand the response of composite laminate under low-velocity impact.

A new oblique contact model is developed using Abaqus/ Explicit. In this report it is discussed about the deformation, stress developed and contact force in the various laminates with consecutive ply angle under both normal and oblique low impact velocity. The relation between consecutive ply orientation, contact force, deflection and stress are developed in the plate due to low velocity impact are studied.

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