DAMAGE CHARACTERIZATION OF COMPOSITE STIFFENED PANELS UNDER IMPACT LOADING IN AIRCRAFT APPLICATION

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ABSTRACT

Composite Materials have becomesa popular due to itshigh specificstrength 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.

INTRODUCTION

There has been a pre dominant growth in the application of composite structures in the engineering fields, particularly in automobile and aerospace industries. To catalogue few examples are the aircrafttail, the wingswithtapered composite stiffeners, Monocoque F-1 formula racing car shells and bonnet, Wind turbine light weightblades and sports and recreational machines and many more. This projectisconcentrated on the finiteelementanalysis of the low-velocity impact on composite panel and composite stiffened panel of unidirectional Glass/Epoxy materialwithdifferentvelocities. The modelling, meshing and simulations are performedusing the FiniteElement Package-ABAQUS/Explicit. Parameters like deflection and contact force are studiedunder all fixedboundary condition and twofixedboundary conditions.

Composites are produced using various materials whose properties mightbe or might not be homogeneous or isotropic (like metals). Therefore, the utilisation of composite material includes a wideselection of availablematerialssuch as fibres, reinforcedconcrete, metals, and fibres. However, itisprimarily fibre reinforced composites that have been increasinglyused for aero-space applications. These composites generallyconsist of layers of unidirectional or bidirectional fibres of high specific modules for the high structural applications required, particularly in militaryaircraft (mainly glass fibres, carbon fibres, Kevlar) which are fortifiedtogether by matrix type of material (e.g., epoxyresin). Laminated composites have multiple benefits over otherconventionalmaterials like metals: e.g., high specificrigidity and strength, excellent corrosion resistance and anisotropicpropertiesthat can betailored to strengthnecessities. They are prone to lowvelocity impacts duringtheirfunction in any respective application and thus a study on thisspecificparameteris essential. The stress developed due to the impact can cause certain deformationwhichshouldn'tbe a cause of failure of the machine, owing to thisfundamental and significant trait, thisstudyaims at impact analysis. Certainly, the couplingbetween stretching, twisting and bending made available by selectingappropriatestackingsequence in composite laminatepermitsaeroelastictailored structures.

M. Salvetti (2018) studied the effects of experimental and numerically composite modelswith a low impact velocity on composites. Impactor mass effect varies impact energy and speed and laminate composite damage, experimental and numerical impact parameters, effectcharacterization and impact characterization, and impact responseeffectsstudied.Gupta, Madhu (2004) - Performed the experiments for the normal and oblique impact on single sheetsteel and aluminium sheets and concluded how the relation between plate thickness and incident velocity can bedeterminedunderdifferentparameters and additionalwork can bereferred to. Different types of contact models and specialalgorithms have been dived to analysis the FRC structural responseunderlow impact analyses.

GhasemiNejhad and Parvizi-Majidi (1990)-The impact performance and damage tolerancewereassessed by instrumented drop weight impacts for wovencarbon fibre reinforcedthermoplastic composites. The effect of impact speed within the range of used speeds wasfound to beinsignificant. The energy impact has had a considerable impact on the panel performance.HomayounHadavinia and Fatih Dogan(2011)- Analysised and describesthat damage induced by the lowvelocity CFRP plate withoutdrillingincreases as the impact energyincreases. The addition of stiffener to the composite plate significantlyreduces the total damage to the composite plate and stops the impactor in a short time. Fromparametricstudies 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 absorbedenergy by box due to greater damage has been increased by increasing the speed and mass of the impactor.

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Orifici (2020) Experimental and numerical investigations wereconductedinto the damage growth and collapse behavior of composite blade-stiffened structures. Four panel types weretested, In the numericalanalysis of the undamaged panels, collapse waspredictedusing a plyfailuredegradation model. The numericalapproach gave close correlationwithexperimentalresults. Yaoyao (2020) studied the buckling and post-buckling performance of composite stiffened panels withsub-stiffening structure subject to compression. The bucklingresponse of the composite stiffened panel is first predicted and verified by experimental data availablefrom the literature. Thensub-stiffeners are introducedinto the composite stiffened panel. Concludedthatresults show the introduction of sub-stiffeners to composite T-stiffened panel causes a significantimprovement of bucklingload.

Impact damage is a major consideration of aircraft composite structure design and maintenance. Damage to airframe structure caused by lowvelocity impact isbecause of bothoperational as well as maintenance activities. There are usually few incidents of lowvelocity impact (LVI) damage in the operating environment and most can beattributed to birdshitting on aircraft and hailstone strikes. The major causes of LVI damage isdue toimproper handling and maintenance issueswhichincludeairframepart handling, transportation, storageand alsoaccidental instrument drops.

Application ofSTIFFENED PANELS

The stiffened panel is one of the mostprimary parts of airframesystemswithlow and higherintensity of loadings. These panels containmainlytwo basic parts : Longitudinal (stiffeners/stringers) as reinforcingmembers and skin. Stiffened panels withbondedstiffeners are widelyused in aerospace and othereminent engineering applications where the structural weight of the material and strengthis the major concern. Stiffeners in a stiffened panel enable highlydirectionalloads to besustained and introduce multiple loadpathsthat can protectagainst crack growthundertensileloads, compressive loads and damagegiven in Fig 1.

Fig.1: STIFFENED PAELS

COMPOSITE DAMAGE MODEL

Composite laminatesubjected to impact load, itundergoes fibre damage at the interface as well as bending moment of the panel. In case of pure bending, tensile and compressive stresses exist. Actuallybendingphenomenaalsoincludesshear stress. In bendingtensile and compressive stresses existwithin the layer or fibre and shear stress existbetween the two laminas. Tensile and compressive stress actsalong the length of the fibre. But shear stress acts tangent to the surface of the layers. Composite materials are strong in tension and compression but weak in shear. Becauseepoxyholds the bond betweentwolayerswhose bonding strengthislow for shearstress.

When the object hits the composite panel, initially the impactor comes in contact with the outermost skin of the composite lamina. When a body withsome mass ismovingwith a velocity, it has kineticenergy. As soon as the body hits the composite panel, kineticenergygetstransferredfrom impactor body to composite panel. At the interface fibre damage take place due to impact.
An impactor having mass m and movingwithvelocity(v1), then the kineticenergy or impact energy (Ki) can beexpressed by

$$K_i = \frac{1}{2} m v_1^2 \qquad (1)$$

Energy transferred (K_t) from impactor to composite plate is

$$K_t = \frac{1}{2} m v_1^2 - \frac{1}{2} m (v_i(t))^2 \qquad (2)$$

Velocity of the impactor,

$$v_i(t) = v_1 - \frac{1}{m} \int_0^t F_{exp}\, dt \qquad (3)$$

F_{exp}= Experimental impact force (N)

t = Time (s)

Failure Modes : Intra ply damage

Intra ply damage isbecause of tensilefailure of fibres whenthey are subjected to axial loading or breakage of fibres whentheygetrupturedbetween impactor and composite panel surface. Whentensile stress in the fibre exceeds the tensilestrength of the composite fibre, it breaks intopieces. The intra ply damage isresults in fibre rupture.

Micro buckling in fibreiscaused due to compression forces however rupture of fibres is due to tensile forces. Fibre pull out happenswhen the bondbetween matrix and fibre isfeeble. This causes the fibre to bedrawn out of the matrix subsequentlydebondingmechanismoccurs. If in case the bondingbetween matrix and fibre isfirmthen, therewouldn'tbe fibre debonding or fibre pull out given in Fig2.

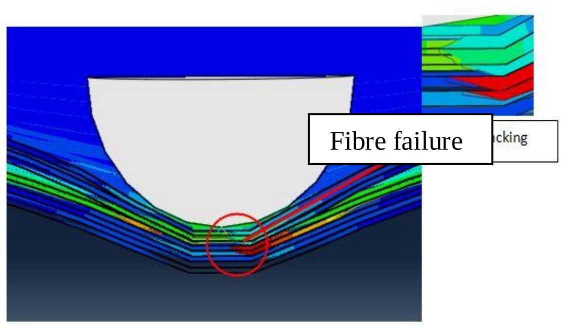

Fig.2 : Fibre Failure in panel

FINITE ELEMENT MODEL

The specimenconsists of glass fibre reinforced composite layers. According to ASTM principles for low impact testing, the dimension of each layer istaken as 100×150mm havingthickness of 0.3mm. The composite panels usedwereorientedwith 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 $[+45˚/0˚/-45˚/90]_S$andstiffenersalsoconsists of 8 layers and has layup of $[+45˚/0˚/-45˚/90]_S$.

Plates are modelled. The Plates are modelled as 3D Deformablesolid of extrusion type. The dimensions of plates are 100mm x 150mm and havingthickness of 0.3 mm as shown in Figure. Each composite plate isorientedindifferent directions. The composite plates have orientations -45/0/45/90. This istakenfrom ASTM standards. There are three types of elements in modelling;they are solid, continuum shell and conventionalshellelement. Solid is a three-dimensional body and itis applicable to the objectswithsignificant dimensions in the entirethree axes, whichmeansonlyshellelements have to beused. We have two options here, continuum shell and conventionalshellgiven in Fig3.

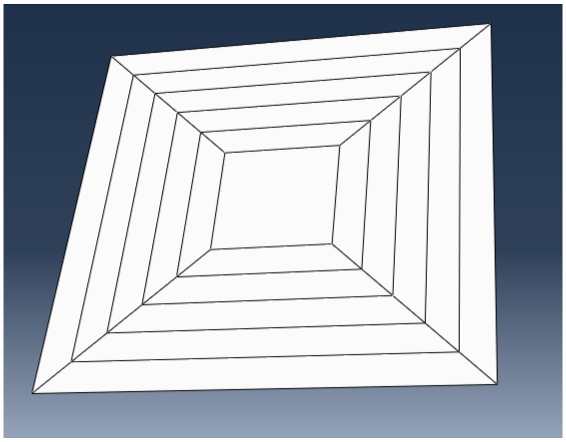

Fig. 3. Composite laminate

IMPACTOR

The Indenter can eitherbe a solidelement or a rigidshellelement. Sinceour main emphasisis on the characteristics of the laminate, to reduce the complexity of the problem, the indenter isconsidered to be a sphericalrigidshell. However, assigning a reference point at the centre of the sphere and assigning mass to itmakesit a proper indenter.

Sinceitis a rigid body, itdoes not undergoanydeformation. It alsodoes not absorbanyenergy or contact force. Hence the wholeenergy and force ittransmittedinto the laminate. In modelling a two-dimensionalenclosedsemicircleisdesigned and itisrotated about its axis in 360 degreeswhichresults in the sphere, then in the geometry a point iscreated at the centre of the sphere. This centre isthenconvertedinto a reference point in the interaction portgiven in Fig4.

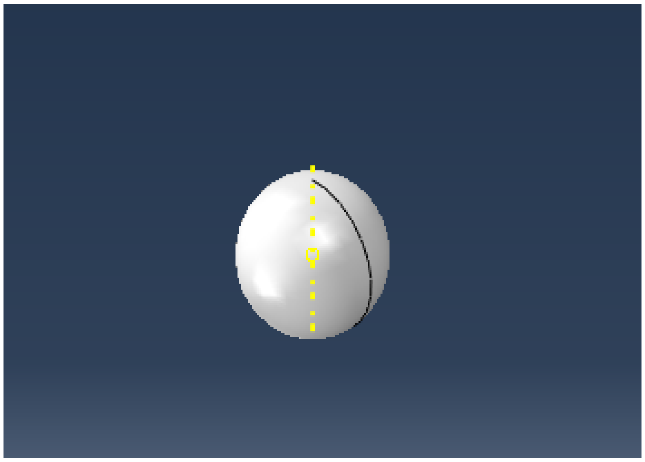

Fig. 4 Rigid Impactor of Mass 3kg

MATERIAL PROPERTIES

Glass fibre reinforcedepoxyisused as a principal material. The mechanicalproperties of Glassfibre islistedbelow.

Table 1- Materialproperties 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;

ASSEMBLY

Afterassigningmaterialproperties, the instances are created as dependent instances so as to makeindividual part assembly possible. Assemblyisdone by placing the layers one over the other. The I-section stiffened panels are created by eightlayers of Glass fibre reinforcedepoxy plates with an orientation of [+45˚/0˚/-45˚/90˚] s. Theseeightlayers 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.

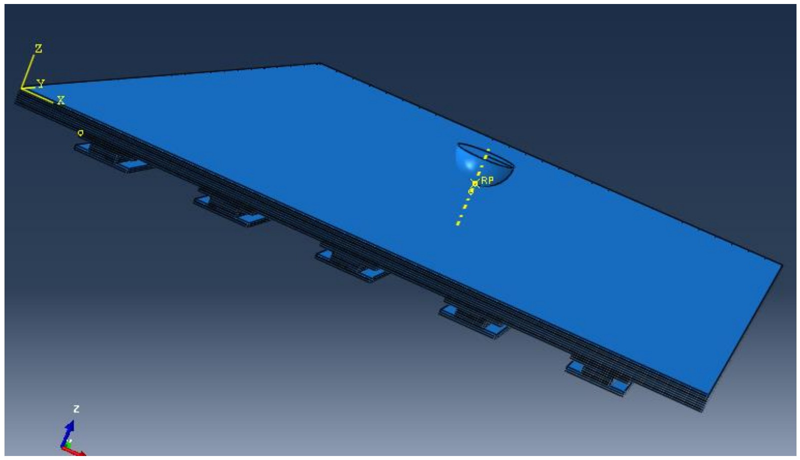

Fig5. Assembled composite stiffened panel with I-section stiffeners

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 withoutstiffeners.

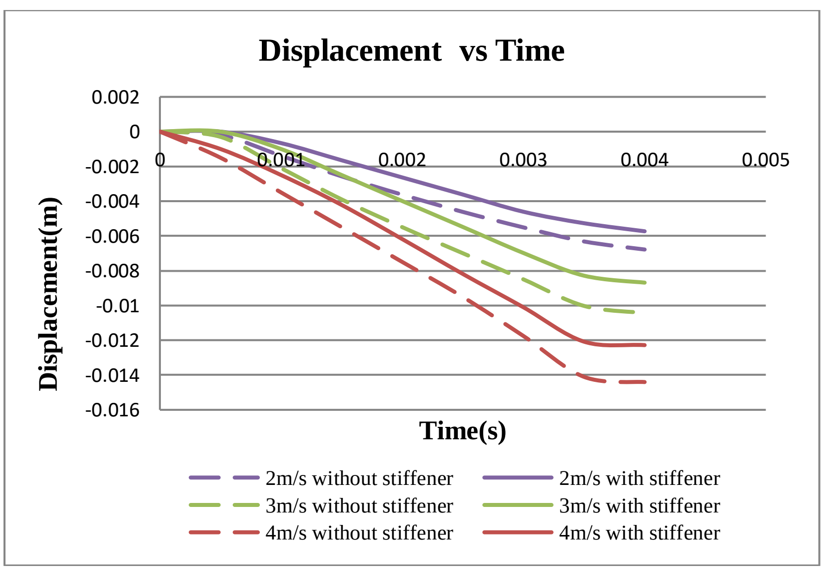

Fig6.Displacement Vs Time graph for all sidesfixed

As the impactor touches the composite panel the deflection 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 Impact

Simulation of different impact angles including 90◦, 60◦, 45◦and 30◦ withsame impact energy(16J) wascarried 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

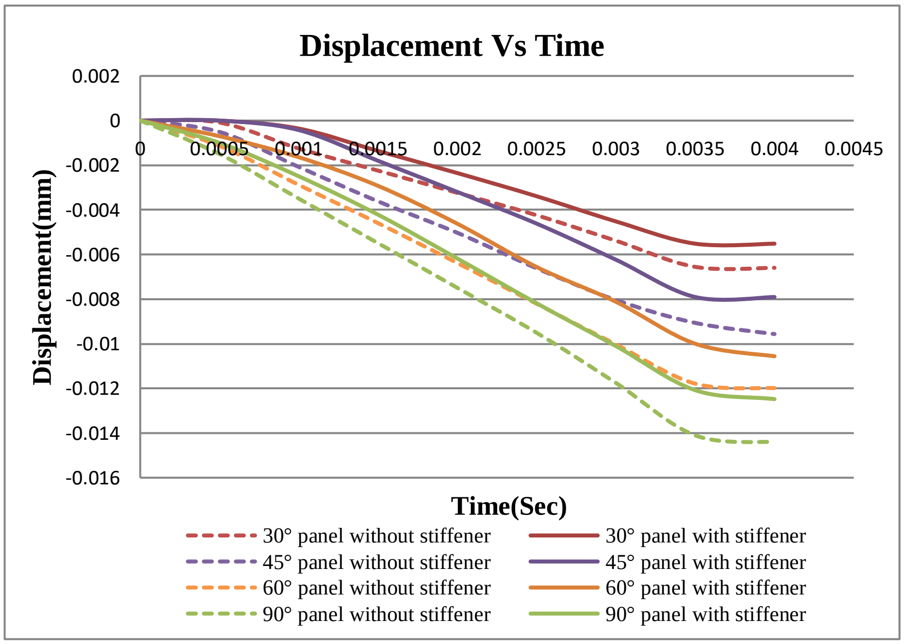

Fig. 7Displacement Vs Time graph for different impact angles

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.

CONCLUSIONS

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 withstifferneroffers 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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