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Effect of stiffener on composite plate under low velocity impact

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Abstract : *Plate / panel structures of fiber reinforced laminated composites are being increasingly used in automotive engineering, aerospace structures, marine technology, electronic devices and other applications. To achieve better efficiency in terms of strength and overall weight, such plates are more often than not fitted with ribs / beams / stiffeners. It has been shown in literature that laminated composite plates are quite susceptible to damage when subjected to low velocity impact. Hence, the present paper is aimed at studying the effects of low velocity impact loads on laminated composite stiffened structures, particularly stiffened plates. The paper highlights a computational model to analyze the behavior of stiffened plates of such composite materials subjected to low velocity impact. The commercial explicit finite element software ANSYS/LS-Dyna has been used. The contact force is calculated in conjunction with the loading and unloading processes. The time history of the impact process such as target plate deflection, due to an impact force acting at the center of the plate, is obtained.*
Keywords*: Low velocity impact, composite material, Impact load*

I. Introduction

During the life of a structure, impacts by foreign objects can be expected to occur during manufacturing, service, and maintenance operations. An example of in-service impact occurs during the manufacturing process or during maintenance; tools can be dropped on the structure. In this case, impact velocities are small; but the mass of the projectile is larger. In composite structures, impacts create internal damage that often cannot be detected by visual inspection. This internal damage can cause severe reductions in strength and can grow under load. Therefore, the effects of foreign object impacts on composite structures must be understood, and proper measures should be taken in the design process to account for these expected events. Concerns about the effect of impacts on the performance of composite structures have been a factor in limiting the use of composite materials. Laminated composite plates are quite susceptible to damage when subjected to low velocity impact by a foreign object and plate structures, when stiffened, attain a greater strength with a small increase of weight. Composite stiffened pate structures are efficient from the point of view of higher strength, material economy as well as ease of construction. In addition to the light weightiness obtained from composites, the stiffened system itself provides much higher stiffness for a specified structural weight. In relation to above-mentioned advancement in the use of composite stiffened structures, analysis of these systems has become an important prerequisite prior to their design and construction. The behavior of composite structures subjected to low velocity impact has been studied by numerous researchers, including experimental, numerical and analytical works. **Caprino et al[1984]** used a simple model, based on energy considerations, which has been tested to predict the behavior of a composite plate subjected to low-velocity impact. To calculate the maximum contact force during impact a force displacement curve for the structure has been used, area under the curve is compared with kinetic energy of impactor to calculate maximum contact force. **Yigit and Christoforou [1995]** developed a more realistic linearized contact law based on elastic-plastic contact law including the permanent indentation effects. The contact law was derived by combining the classical Hertzian contact theory and elastic-plastic indentation theory for metallic bodies. **Vaziri et al[1996]** used a super finite element method that exhibits coarse-mesh accuracy to predict the transient response of laminated composite plates and cylindrical shells subjected to non-penetrating impact by projectiles. **Oguibe & Webb [1999]** investigated the impact response of a laminated composite square plate using the finite element technique. An approximate failure mode has been incorporated into the model by a combination of spring, gap and dashpot elements to account for the energy dissipated during the damage process. **Abrate [2001]** provided a detail review on various analytical models of impact on composite laminates. He classified impact models into four groups: energy balance models, spring-mass models, complete models and impact on infinite plate model. **Her & Liang[2004]** investigated, the composite laminate and shell structures subjected to low velocity impact are studied by the ANSYS/LSDYNA finite element software. The contact force is calculated by the modified Hertz contact law during and unloading processes. **Chunand & Kassegne[2005]** used the higher-order shear deformation theory is used to study the response of graphite/epoxy laminated composite non-prismatic folded plates subjected to impact loads. **Tiberkak et al [2006]** In this investigation, the fiber-reinforced composite plates, without damage, subject to low velocity impact was studied by the use of finite element analysis (FE). To analyze the response of the plate, a Newmark time integration algorithm was used. **Tiberkak et al[2008]** investigated, fiber-reinforced composite plates subjected to low velocity impact are studied by the use of finite element analysis. Mindlin□ s plate theory is implemented into the FE approach in which a 9-node Lagrangian element is considered. **Setoodeh et al[2009]** coupled a generalized layer wise finite element model with 3D elasticity theory, a finite element-based computer code for the analysis of thick composite laminates has been developed. Hertzian nonlinear contact law models for contact forces between the rigid projectile and the laminated plate has been used.

In the above literature response of composite plate was analyzed by different method. In the present investigation, an explicit finite element software ANSYS/LS-DYNA has been used to calculate the transient response of the impact on stiffened composite laminated square plate. A modified Hertzian contact law for loading and unloading processes during the impact period has been adopted to calculate the contact force. For validation purpose numerical results has been compared with existing result of **Her&Liang[2004]**.

The objective of this paper is to study the influence of stiffener in composite plate with clamped and simply supported boundary condition on the impact response of the composite structures. Contact force and center deflection are presented for different parameters with different number of stiffener and boundary conditions using the software ANSYS/LS-dyna.

II. Composite Material Model in ANSYS/LS-DYNA

The commercial explicit nonlinear finite element software ANSYS/LS-DYNA has been used throughout this study. LS-DYNA has been used to analyze energy absorption and contact force history during low velocity impact projectile on composite laminate target plates. LS-DYNA is a general purpose transient dynamic finite element program, specializes in contact related problems such as impact and other dynamic loading. ANSYS adapts the LS-DYNA as the solver for the impact problems.

To solve the impact problems by ANSYS/LS-DYNA, meshing of plate is identified the number the element selected in x and y direction. An appropriate shell element 'thin_shell_163' selected for defining number of node in an element. Mesh geometry of plate in ANSYS/ LS-DYNA can be seen in the figure.1 the material properties for the impactor and target object can be a rigid body, and composite material. The most common material model in ANSYS/LS-dyna is Plastic kinematic is used. Initial and boundary conditions specified the initial conditions for the impactor such as impact velocity, acceleration; boundary conditions for the target object such as clamped or simple support composite plate. Contact conditions defined the type of contact and friction coefficient, there are different types of contact can be chosen to accurately represent the physical model, among them surface to surface (STS),automatic single surface and node to surface (NTS) are the most common use. However for a composite material structures impacted by solid impactor, assumptions in the input data such as damping and dynamic coefficient of friction make it difficult to get more accurate result. In this way, the modelling of stiffened composite plate is sufficient to study the response of composite plate under impact loading.

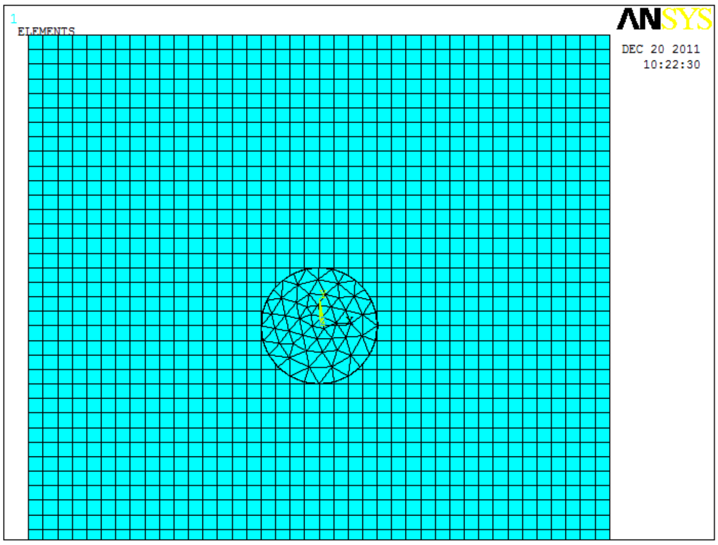

Figure.1. Mesh geometry of plate and impactor

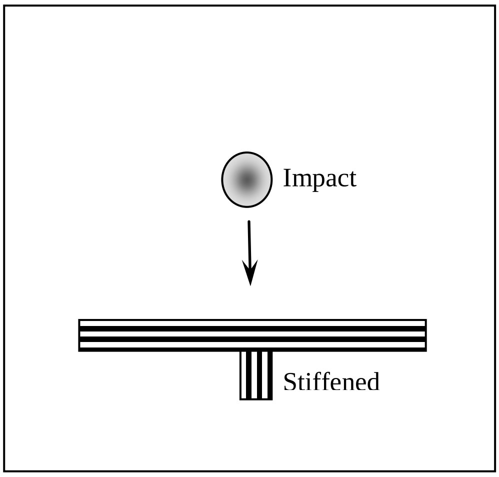

Figure.2. Composite Laminate and Impactor before impact

For the validation of result in ANSYS/LS-DYNA software in composite structure, the T300/934 $[0/45/45/90]_{2s}$ graphite/epoxy composite laminate subjected to low velocity impact has been taken from the result of **Her& Liang[2004]** . The length, width and thickness of the laminate are 76.2, 76.2 and 2.54 mm, respectively. The material properties of the composite lamina are listed in Table.1 Impactor velocity; radius and density are 25.4 m/s, 6.35 mm and 2800 kg/m3, respectively same as Her&Liang[2004].

Table.1: Material properties of T300/934

E_{xx}(GPa)	E_{yy}(GPa)	G_{xy}(GPa)	ν_{xy}	ν_{yz}	Density (kg/m3)
145.54	9.997	5.689	0.3	0.3	1535.7

As shown from the figure.3, the numerical results obtained by ANSYS/LS-DYNA can converge to the solution of Her&Liang [2004].

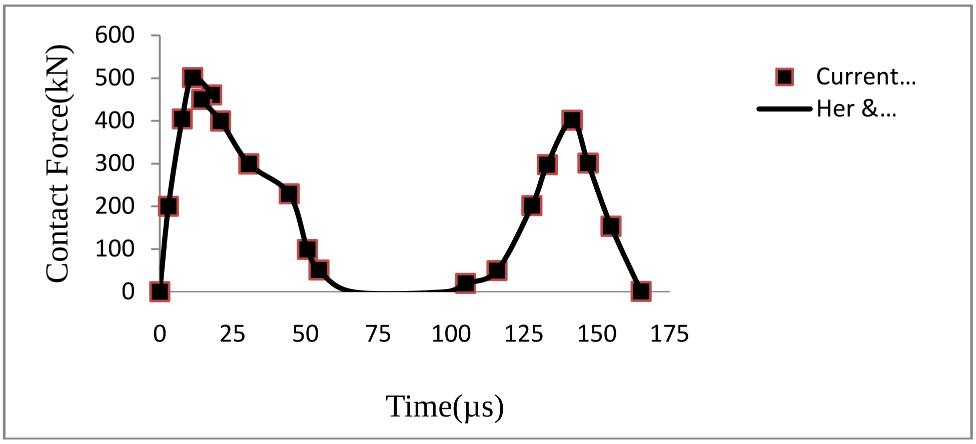

Figure.3. Contact Force vs time

Effect of stiffener on contact force and central displacement:

The stiffener in the plate also plays an important role in the impact responses. The effect of plate stiffener on contact force, the plate central displacement in the figure 4, 5, 6 and 7.With the same amount of impact energy, the stiffened plate has almost same contact force and smaller displacement produced under same impact. Properties of stiffener are same as the properties of composite plate as given in Table.1 and height and width are 10mm x 8mm and thickness of the stiffener is taken same as thickness of plate.

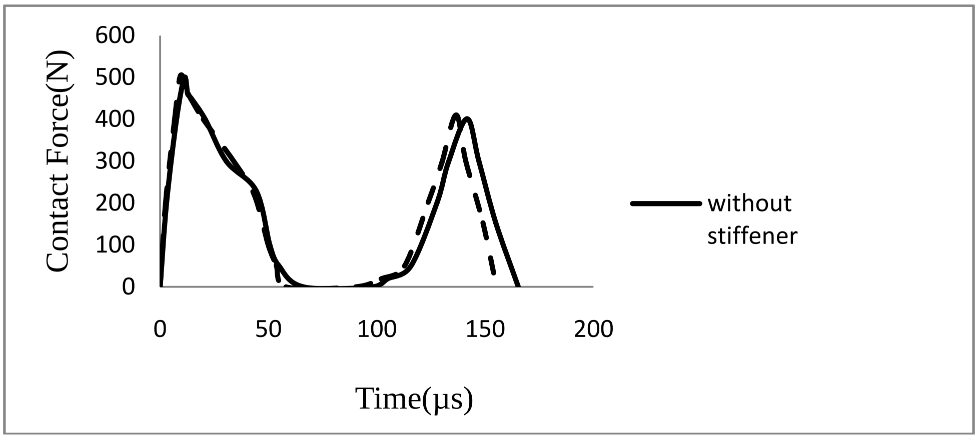

Figure.4. Comparison of contact force vs time with stiffened and non stiffened composite plate for all edge clamped boundary conditions

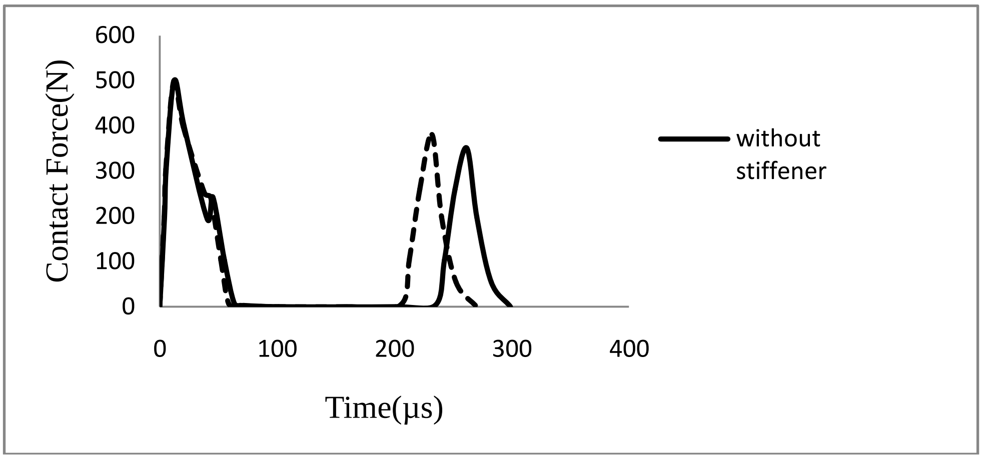

Figure.5. Comparison of contact force vs time with stiffened and non stiffened composite plate for all edge simply supported boundary conditions

Some interesting observation can be made by considering the impact duration in comparable arrangements for both elastic and elastic-plastic deformation. **Gong & Lam[1999]** Apparently the plastic deformation does not have significant effect on impact duration for low velocity impact. Effect of plastic deformation has not been taken in to consideration in this analysis. The duration of impact between two bodies occurs a very short period of time within a few seconds. Transient response of impact is investigated by ignoring the gravity effect and contact friction during impact period.

From the observation of the figure.4 and figure.5 the contact force history of composite plate with and without stiffener are different and maximum contact force in both the plate are almost the same and second peak of maximum contact force occurs earlier in case of composite plate with stiffener in comparison with composite plate without stiffener for simply supported as well as clamped edge boundary conditions. In case of simply supported boundary condition change in contact force duration is less than the change in contact force duration for clamped edge condition on adding stiffener on the composite plate and loading and unloading profile remains the same in both case.

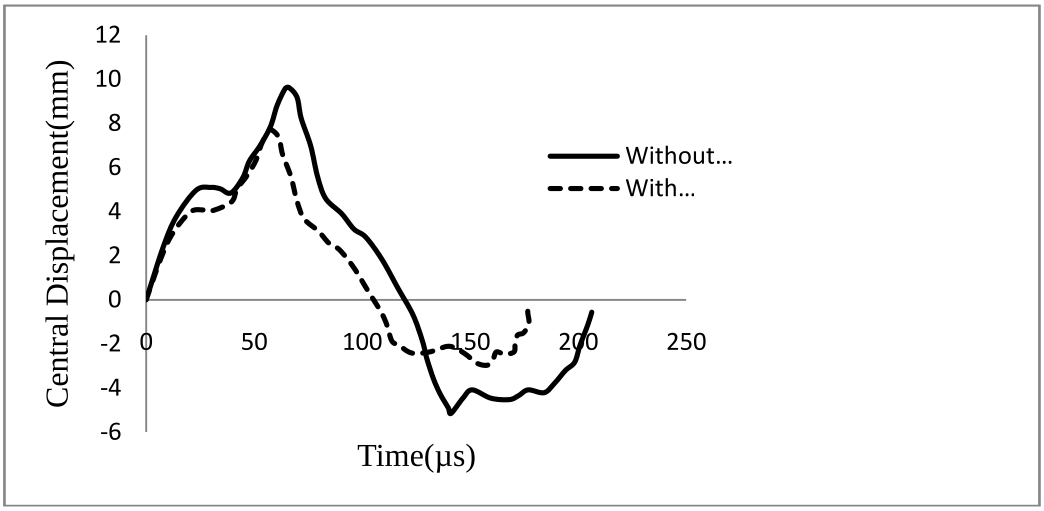

Figure.6 Comparison of central displacement vs time curve for composite plate with and without stiffener for all edge clamped boundary conditions

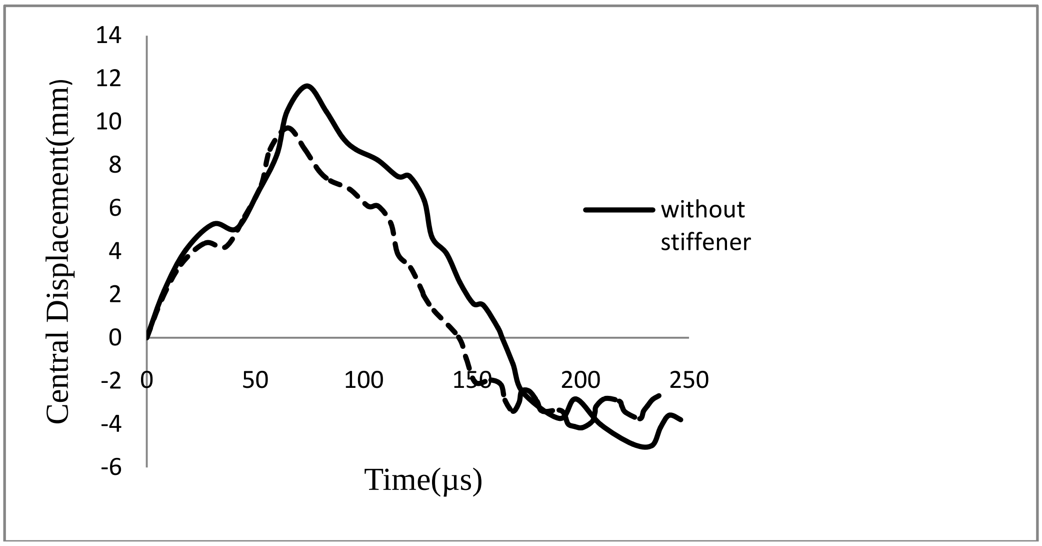

Figure.7 Comparison of central displacement vs time curve for composite plate with and without stiffener for all edge simply supported boundary conditions

From the observation of figure.6 and figure.7 the maximum central displacement of stiffened composite plate is less in comparison with plate without stiffener. Central displacement goes to maximum of stiffened plate and return back to its initial position earlier as compared to the composite plate without stiffener; this shows the increase in the stiffness of the plate because of stiffener. Profile of the central displacement in composite plate with and without stiffener is almost same. During the negative displacement of the stiffened composite plate, displacements profile is different in both simply supported and clamped edge boundary conditions. The central displacement in simply supported plate is greater as compared to clamped edge plate.

III. Conclusion:

Analysis shows the effect of stiffener on response of composite plate. In particular the displacement and contact force curve with respect to time were investigated, as the stiffness of the composite plate and contact force variation with time were analyzed without failure of composite structure with and without stiffener. Effect of number of stiffener, stacking sequence of laminate and velocity of impactor can be analyzed for future work.

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