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The Impact Behaviour of Carbon Fiber-Epoxy Composite Leading Edge using Finite Element Method

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Abstract*: Composite material has been widely used in aircrafts due to its high strength to weight ratio that leads to weight saving of the aircrafts. Equally important, aircraft material should be tough i.e. it should have the ability to absorb high energy and thus resist fracture. The aircraft's wing design requires the material to have high toughness as parts of the wing especially its leading edge is subjected to impact loadings. Using finite element software of LS-DYNA, this research focuses on studying the impact behaviour of composite panels that represent the leading edges of wings when the panels are subjected to rigid sphere projectile. Three shapes of panels are used: flat, semi-circular and semi ellipse while panels can be of 2, 4 and 8 layers to vary its thickness. The panels are made of laminated composites with woven carbon fibres and the angle of orientations are $[0/90]_n$, $[0/45]_n$ and $[45/-45]_n$ where n will give the number of layer for the composite. The Mat-58 material type suitable for woven type fibre is used where failure criteria of Hashin is applied. It was found that the simulation results are in a very close agreement with the finding from experiments conducted earlier. Furthermore, the optimum stacking sequence was found to be the $[0/45]_2$ stacking sequences

***Index Terms*: Energy absorption, FEA Simulation, Impact loading, Leading edge.**

I. INTRODUCTION

Studies conducted on composite materials and structures applicable in aircraft and aerospace structures are numerous [1-5]. In aircraft structure, composite material has been applied in various parts including fuselage, wing and tail. The main reason for the applications of composite material here is its high specific strength and stiffness that provide weight saving to the aircraft. However, most of these parts require accurate structural analysis as they are subjected to variety of loads that may lead to failures such as yielding, buckling, fatigue, parametric instability and impact fracture [6-10]. As shown in Fig.1, one important part of a wing of an aircraft is leading edge, a section commonly hit by impact loading that may be a consequence of bird impact or hail impact. These impactors come as a projectile that can hit and penetrate the wing structure commonly made of laminated composites. As a consequence, delamination or even fracture may occur to the structure and thus reducing its load carrying capacity [11].

It is thus significant to investigate the influence of impact loading on curved panels resembling the leading edge at the design stage of the aircraft wings.

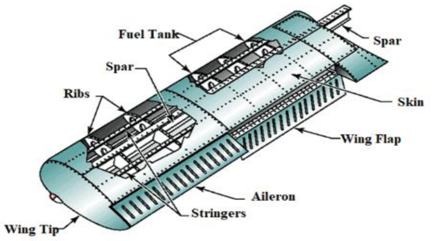

Fig. 1: An aircraft wing

The ability to resist impact load that may lead to fracture is characterised by the toughness of the structure. Toughness is a material property that give the amount of energy absorbed by the structure subjected to impact loading. For a leading edge of an aircraft to function well, it must be able to absorb a certain amount of kinetic energy i.e. it must have a minimum toughness. As such it is necessary to conduct impact test on all forms of leading edge to determine its toughness and parameters that affect the toughness.

Lo´pez-Puente et al [12] performed investigation on the breakage mechanisms of carbon/epoxy woven composite that occur during the penetration process of oblique ballistic impacts. The experimental works was successfully validated with numerical results. In a study, the curvature effect on the initiation of fracture of composite plates and shell was investigated [13]. Cylindrical shell structure was found to be affected more compared to flat plates. Furthermore, several FEM models have been developed to investigate the impact induced fracture of laminated composite structure [14-16]. Omar et al [17] conducted experimental study to investigate the effect of several parameters of curved panels such as curvature, thickness and angle of orientation on the impact behaviour of carbon fiber epoxy composite wing leading edge structure. The study discovered the significant effects that are actually provided by the parameters and the plots of the energy absorption per unit mass of structure against those parameters were given.

This study is to continue the work in [17] by applying finite element method in investigating the impact behaviour of carbon epoxy composite wing leading edge structure subjected to a solid low velocity projectile. Three shapes of leading edge panels were used: flat, semi-circular and semi ellipse while panels can be of

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2, 4 and 8 layers to vary its thickness. The study on the effect of radius of curvature of the panels on the impact behaviour of the panels was also conducted.

II. METHODOLOGY

The material properties of the carbon-epoxy composite used here are given in this section. The dimensions of the curved panels that represents wing leading edge of aircraft are specified. The FEM procedures of modelling and analysis using LS-DYNA [18], a software owned by Livermore Software Technology Corporation (LSTC) are also elaborated.

A. Materials

The leading edge of the wing in this study is made of carbon-epoxy composite. Carbon fibre in woven fabric form was used here and, in the experiment, [17] performed. Tensile test was conducted on such the fabricated carbon-epoxy specimen to get the stress-strain plot such as shown in Fig. 2. In the LS-DYNA software applied in this study, the material model used is Mat-58 that is suitable for laminated composite with unidirectional layers and woven fibres. The Mat-58 applied the Hashin's failure criteria while tolerating progressive failure analysis such that as the maximum effective strain is reached at certain elements, the specific elements are considered completely removed. For composites with woven fabrics and laminates such as in this study, the quadratic failure criteria are used such as:

Failure mode for tensile fibre ($\sigma_{11} > 0$):

$$\left(\frac{\sigma_{11}}{X_T}\right)^2 + \left(\frac{\sigma_{12}}{X_S}\right)^2 = 1 \qquad (1)$$

Failure mode for compressive fibre ($\sigma_{11} < 0$):

$$\left(\frac{\sigma_{11}}{X_C}\right)^2 + \left(\frac{\sigma_{12}}{X_S}\right)^2 = 1 \qquad (2)$$

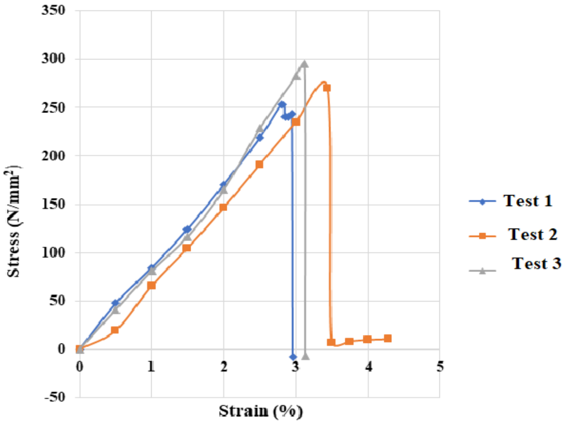


Fig. 2 : Stress-strain plot for the composite

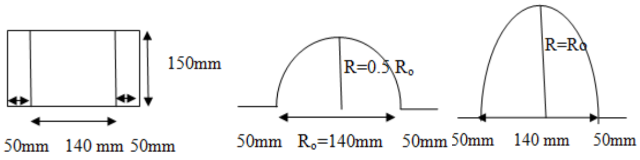
On the other hand, the impactor is made of steel with slight adjustment in the steel density property to complement the experimental values [17]. Table I gives the material properties of the composite and the steel impactor.

Table 1 Material properties of composite and steel impactor

Material	Young's modulus, E (GPa)	Poisson's ratio, *v*	Density (Kg/mm^3)
Composite	87.34	0.207	1.75(10^{-6})
Steel	207	0.3	2.389($^{-3}$)

B. The dimensions

Following the experimental work performed by the authors [17], the leading edge applied here is of three forms: flat, semi-circular and semi-ellipse such as shown in Fig. 3. The effect of thickness of composite is studied by varying the composite number of layer such as the composites may have 2, 4 and 6 layers where thickness per layer is 1 mm. Depending on the number of layers, the selected angles of orientation of the composites are $[0/90]_n$, $[45/-45]_n$ and $[0/45]_n$ where n will give the specified number of layers. In LS-DYNA, the leading edge panel was defined as SECTION_SHELL as Mat-58 can only take shell element. By doing so, the thickness for each layer and the angle of orientation associated with each layer can be specified. Furthermore, the radius of the impactor ball is 10 mm. The impactor was defined as SECTION_SOLID where the size of the steel impactor can be input.



(a) (b) (c)

Fig. 3 The 3 forms of leading edge: (a) Flat plate (R = 0) (b) Semi-circular (R = 0.5R_0), (c) Semi-ellipse (R = R_0)

C. Boundary Conditions

The zero displacement occurring in all directions at the base of the leading edge panel was taken as the boundary condition of the structure. In LS-DYNA, the impactor is considered MAT_RIGID as it is set to be un-deformed.

D. Energy Absorption

Through finite element analysis (FEA), the graph of displacement against time, velocity against time and force against time can be determined. The he following formula is to calculate the energy absorbed, E :

$$E = \frac{1}{2} * m * \left(v_i^2 - v_f^2\right) \qquad (3)$$

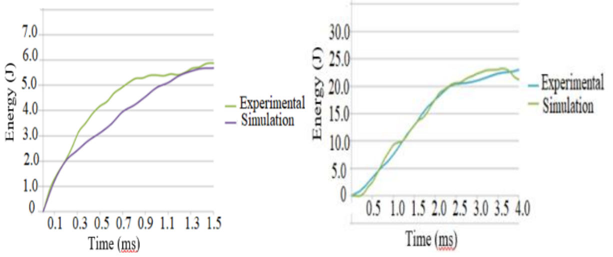
where m is the mass of the composite, v_i and v_f are the initial and final velocities of the ball.

III. RESULTS AND DISCUSSION

Here, the results from the FEA is first validated with results from the experiment performed earlier. Following that, the results on the impact behaviours of the three forms of the trailing edges with varying radius of curvature and thickness are elaborated.

A. Validation

The validations of the FEA works were conducted by comparing to the author's previous experimental study [17]. The validation is performed on composites with the following specifications: 1. Flat plate, R = 0 having 2-layer with angle of orientation, $[0^\circ/90^\circ]$ 2. Semi-circular plate, R = $0.5R_o$ having 4-layer with angle of orientation, $[0^\circ/90^\circ]_2$. While Fig. 4(a) shows a different numerical and experimental plots corresponds to flat leading edge due to inevitable problems of noise and vibration of machine at the time of experiment, for leading edge with semi-circular form in Fig. 4 (b), there is a good correlation in the graph of energy absorbed vs time corresponds to numerical and experimental work. The graph shows that increasing the impact time, the absorption of energy increases as well, in a non-linear fashion.



(a) (b)

Fig. 4 **:** Experimental validations for leading edges with (a) R = 0, 2 layers, [0/90] and (b) R = 0.5Ro, 4 layers, $[0/90]_2$

B. Impact behaviour of composite leading edge panels

The impact behaviour of composite subjected to low velocity impact is characterised by the deformation of the composite material until the point of fracturing. A material deforms as it absorbs increasing amount of energy while stress is created in the material. As the deformation is increased, stress is increased as well up to a certain level of energy absorbed, fracture starts to occur when the material cannot take the stress anymore. This is the point when the striker passes the specimen. Fig.5 shows the striker that passes the semi-circular, 2 layer specimen with [0/90] orientation angle. The amount of energy absorbed before fracturing, can be calculated using Equation (3) based on the graphs in Fig. 6. In Fig.6, the highest energy occurs at the beginning of the horizontal energy and velocity line that shows the specimen has been cut. In this case, the maximum energy absorbed is28.1042 J.

Fig.5: Deformation of the semi-circular, 2 Layers, [0/90] specimen

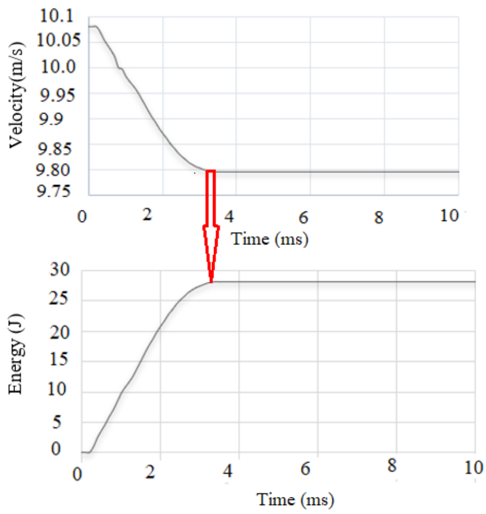


Fig. 6: The velocity and energy absorbed in the deformation of the semi-circular, 2 layers specimen

Increasing the thickness to 8 layers of the semi-circular specimen with $[0/90]_4$ stacking sequence, the deformation process can be seen in Fig. 7 and Fig.8. From Fig. 8, it can be seen that it takes longer time of 3.9 s for the striker to fully penetrate the specimen. The velocity becomes constant at 9.797 m/s where the energy absorbed can be calculated as 31.28889 J.

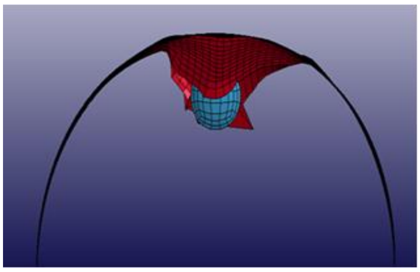


Fig. 7: Deformation of semicircular, 8 layers, [0/90]4 specimen

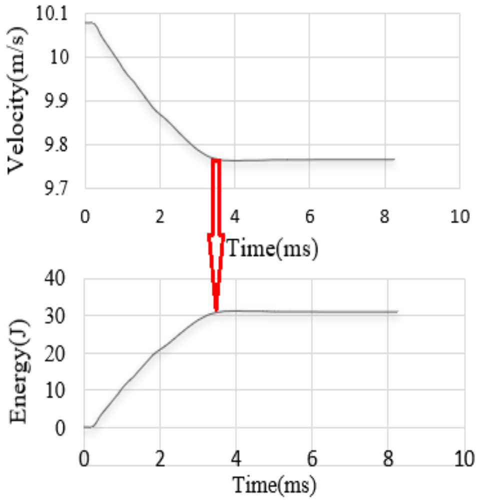


Fig. 8 The velocity and energy absorbed in the deformation of the semi-circular, 4 layers specimen

C. The radius of curvature effect

This study is to investigate the influence of radius of curvature of the leading edge panels on the impact behaviour of the panel. The radius of the leading edge was varied from 0 to 140 mm. The thickness and stacking sequence are fixed at 4 layers and $[0/90]_2$ respectively. Table II shows the energy absorbed per unit mass by specimens having varying radius of curvature while Fig. 9 gives the effect of radius of curvature of the leading edge on the specific energy absorbed.

Table II**:** Influence of radius of curvature of leading edge specimen on its energy absorption

Radius (mm)	Energy (J)	Specific energy (J/Kg)
0	2.67	20.6
35	10.95	71.2
70	23.09	132.7
105	20.7	100.48
140	17.1	71.8

From **Figure 9**, conclusion can be made that the increase of radius of curvature will also increase the specific energy. The maximum point occurs at radius, R = 70 mm and the specific energy starts to reduce following the maximum point. The highest energy per unit mass for 4 layers composite is 132.7 J/Kg.

D. The influence of panel thickness

This study is to investigate the effect of thickness of the leading edge panels on the impact behaviour of the panel. In this study, thickness of leading edge panels were varied while the stacking sequence of $[0/90]_n$ with R = 70 mm was used. In tabular form, the effect of panel thickness on the energy and specific energy absorbed can be seen in Table III. It shows that even though the energy absorbed is increased as the thickness is increased, the specific energy is decreased. This makes sense because the mass increases doubly moving from 2 to 4 and to 8 layers while the energy increases at lower rate compared to the rate thickness is increased. Fig. 10 shows clearly that specific energy decreases with the increase of the thickness of the specimen.

Table III: The effect of thickness on the specific energy

Thickness	Energy (J)	Specific Energy(J/Kg)
2 layers	20.07	230.69
4 layers	23.09	132.7
8 layers	31.08	89.31

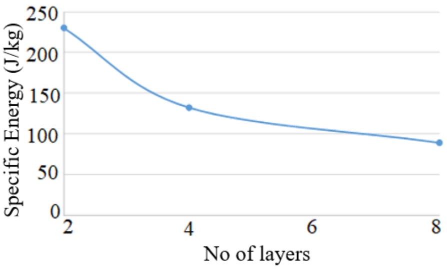


Fig. 10: Specific Energy Vs Thickness

Comparing to the experimental results [17], the energy absorption trend obtained through FEA is similar where the energy absorbed was increased with the increase of thickness.

E. Influence of Stacking Sequence

The effect of stacking sequence of the leading edge panels on the impact behaviour of the panels is given here. Since the radius of curvature for the highest energy absorption is R = 70 mm, the FEA computations for different stacking sequences are taken for model with R = 70 mm. Table IV shows the change of energy absorption capability of the leading edge panels with fibre orientation while Fig. 11 shows the plots of energy per unit mass against thickness of the leading edge panel. It can be seen from the plots that the highest energy absorbed is provided by the [0°/45°] configuration and followed by the [45°/-45°] and [0°/90°] stacking sequences.

Table IV**:** The change of Energy Absorption Capability with Angle of Orientation

Thickness	**Fiber orientation**	**Energy (J)**	**Specific energy (J/Kg)**
2 layers	[0º/90º]	20.07	230.7
	[45º/-45º]	22.6	259.8
	[0º/45º]	21.5	247.13
4 layers	[0º/90º	23.2	133
	[45º/-45º]	27.4	157.5
	[0º/45º]	38.17	219.36
8 layers	[0º/90º]	31.3	89.9
	[45º/-45º]	40.4	116.1
	[0º/45º]	45.2	129.88

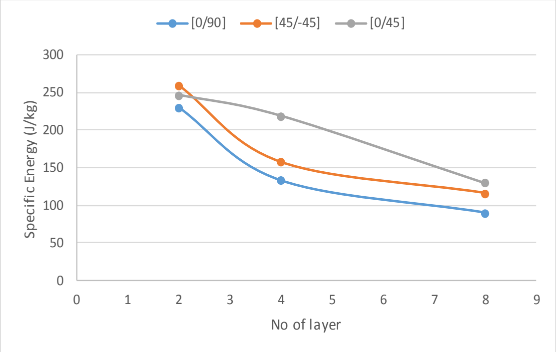


Fig.11: The effect of thickness on specific energy of the leading edge panels

IV. CONCLUSIONS

The impact behaviour of laminated composite panels exerted by steel ball impactor was studied numerically using the LS-DYNA FEM software. The composite panels can be of three forms i.e. the flat, the semi-circular and the semi-ellipse panels were representing the leading edge of aircraft. Material type Mat-58 in LS-DYNA was employed. Validations of the numerical work were successfully conducted based on experiment results for semi-circular panel having 4 layers with $[0^o/90^o]_2$

orientation. Following that, several studies were performed to investigate the influences of panel thicknesses, angle of orientation and radius of curvature on the impact behaviour of the composite panels. It was found that panel with R = 70 mm gives the highest energy absorbtion. Thus the radius, R = 70 mm is the optimum radius of curvature for the range of specimen tested in this investigation. For the same curvature with different thickness, the plots of the energy per unit mass against thickness shows the reduction in specific energy absorption as the thickness is increased. Lastly, for the effect of angle of orientation, it can be said that the optimum stacking sequence is found to be for the combination of [0º/45º] stacking sequences

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REFERENCES

1. Lapcik, L., Ruszala, M.J.A, Vasina, M., Lapcikova, B. & Greenwood, R.W. (2016) Hollow spheres as nanocomposite fillers for aerospace and automotive composite materials applications. Composites Part B: Engineering, Volume 106, 74-80.
2. Wang, X., Xia, P. & Masarati, P. 2019. Active aeroelastic control of aircraft wings with piezo-composite. Journal of Sound and Vibration, 455, 1-19.
3. Eken, S. 2019. Free vibration analysis of composite aircraft wings modeled as thin-walled beams with NACA airfoil sections. Thin-Walled Structures, 139, 362-371.
4. Azammi, A.M.N., Sapuan, S.M., Ishak, M.R., Sultan, M.T.H. 2018. Conceptual design of automobile engine rubber mounting composite using TRIZ-Morphological chart-analytic network process technique. Defence Technology, 14(4), 268-277.
5. Alkateb, M., Sapuan, S.M., Leman, Z., Jawaid, M., Ishak, M.R. 2018. Quasi-static crush behaviour of environmentally friendly kenaf/wool epoxy composites elliptical tube. Journal of Mechanical Engineering and Sciences. 12(2), 3671-3688.
6. Talreja, R. & Phan, N. 2019. Assessment of damage toleranceapproachesfor composite aircraft with focus on barely visible impact damage. Composite Structures, 219, 1-7.
7. Tuo, H., Lu, Z., Ma, X., Zhang, C. & Chen, S. 2019. An experimental and numerical investigation on low-velocity impact damage and compression-after-impact behavior of composite laminates. Composites Part B: Engineering, 167, 329-341.
8. Reddy, T.S., Mogulanna, K., Reddy, K.G., Reddy, P.R.S. & Madhu, V. 2019. Effect of thickness on behaviour of E-glass/epoxy composite laminates under low velocity impact. Procedia Structural Integrity, 14, 265-272.
9. Carrillo, J.G., Gonzalez-Canche, N.G., Flores-Johnson, E.A. & Cortes, P. 2019. Low velocity impact response of fibre metal laminates based on aramid fibre reinforced polypropylene. Composite Structures, 220, 708-716.
10. Kounain, M.A., Khan, Z., Al-Sulaiman, F., Merah, N. 2016. Low Velocity Impact Damage Analysis in Plain Weave Woven GFRP Laminates Through Optical and SEM Microscopy. International Journal of Recent Technology and Engineering, 4(6), 29-39.
11. Chandekar, G.S., Thatte, B.S. & Kelkar, A.D. 2010, On the behavior of fiberglass epoxy composites under low velocity impact loading. Advances in Mechanical Engineering, 2010,1-11
12. Lopez-Puente, J., Zaera, R., &Navarro, C. 2008. Experimental and numerical analysis of normal and oblique ballistic impacts on thin carbon/epoxy woven laminates. Composites, 39, 374-387.
13. Lin, H.J., & Lee, Y.J. 1990. Impact-Induced Fracture in Laminated Plates and Shells. Journal of Composite Materials, 24, 1179-1199.
14. Hassan, M.A., Naderi, S. & Bushro, A.R. 2014. Low-velocity impact damage of woven fabric composites: Finite element simulation and experimental verification. Journal of Materials and Design, 53, 706-719.
15. Johnson, A.F., & Holzapfel, M. 2003. Modelling soft body impact on composite structures. Composite Structure, 61, 103–13.
16. Her, S.C., & Yu C.L. 2004. The finite element analysis of composite laminates and shell structures subjected to low velocity impact. Composite Structures, 66, 277–285.
17. Nurihan O, Yulfian A, Ali JSM. Experimental Study of Impact on Carbon Fiber-Epoxy Composite Wing Leading Edge Structure. Applied Mechanics and Materials. 2014; 493: 672-677. Livermore Software Technology Corporation (LSTC). LS-DYNA 971 KEYWORD USER'S MANUAL, Livermore, CA, USA. 2009.

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