Numerical Simulation of Impact Velocity on CFRP Aircraft Skin with Hat Shaped Stringer

R. Gayathri[1], G. Jims John Wessley[2]

[1]Aerospace Engineering, Karunya Institute of Technology and Sciences, Tamil Nadu, India. E-mail: joyaero.aero@gmail.com

[2]Aerospace Engineering, Karunya Institute of Technology and Sciences, Tamil Nadu, India. E-mail: jims_john@karunya.edu

Abstract

As a modern aircraft is made up of at least 50 percent of composite parts, the various attempts are tried to understand more about the behaviour of composites under the loads. The modern aircraft built of laminated composite can bear tension, compression, shear, combination of these loads and impact load. Among these loads, the impact load causes the severe damage and therefore, the impact on carbon fibre-reinforced plastic (CFRP) hat-stiffened composite panel that is used for high velocity aircraft structure was investigated. The dynamic behaviour of it was keenly monitored for two different velocities 150 as well as 250 m/s that are closer to cruise velocity of LEARJET 70 using spherical impactor. Post-processing results from LS dyna software was reasoned out by seeing the notable changes in the distribution of displacement, contact force and delamination zone were extracted.

Keywords: Spherical Impactor, Hat Stringer, Composite Plate, Delamination.

DOI: 10.47750/pnr.2022.13.S03.119

INTRODUCTION

At supersonic speeds, the recognition of impact failure is challenging and tedious task. The local and global failure mechanisms of composites such as tensile failure[1] in primary tows, deformation[1] in secondary tows, delamination, matrix cracking, shear plugging[1] and friction during penetration[1] are due to unexpected impact loading in manufacturing and service.

The characteristic study of tapered wing that can fly at a Mach number of 0.75 is done under uniformly distributed load and uniformly varying load. Based on the results, the necessity of adding stringer to the wing is understood [2]. Hat shaped and corrugated stringers are most popular nowadays but hat stringer is preferred because of its high structural integrity and simple product structure [1]. The most seen failure of hat-stringer composite panel under axial compressive load in the presence of test fixtures as well as without test fixtures are investigated and optimal design is obtained using MATLAB codes[3].

Structural idealization methods were incorporated to understand more about the induced damage due to drilling on laminated composites and its quantification method[4],[5]. The delamination process of the[6] composite bullet-proof material[6] was simulated using 7.62 X 39 mm rifle bullets penetrating laminates of different thicknesses[7]. The compressive preloading[8] of the various CFRP materials under low velocity impact[1] is investigated. The results revealed that the deflection[9] and energy absorption of composite plates increase equivalently with 80% preloading [10]. The necessity of patch repair parameters on functioning of the parent CFRP laminate plates was analysed based on the value of energy absorbed on [11] the delamination zone and it yielded an optimal design to resist impact failure[12]. The findings of scientific research study using high-velocity impact testing setup for woven-roving Glass Fibre composites was carried out to understand how the impactor shape, target thickness[13] and gas gun pressure affect the performance of composites [11].

MODELLING OF HAT STRINGER COMPOSITE PANEL

The hat stringer specification used by Rajkumar Rajamanickam[14] is considered in this study.

The fibre orientation and thickness of hat stiffened composite panel are highlighted in table below.

Table 1. Configuration of Hat Stringer Composite Panel

S. No	Parameters	Orientation/ Values
1.	Skin layup configuration (15 layers)	+45/-45/90/0/+60/-60/-15/-90/+15/-60/+60/0/90/-45/+45
2.	Stringer layup configuration (16 layers)	+45/-45/0/0/90/0/0/-15/+15/0/0/90/0/0/-45/+45
3.	Total thickness of skin	2.82 mm
4.	Total thickness of stringer	3.01 mm

The chosen plate with hat stringer configuration is made up of carbon fibre 270 GSM and epoxy resin GY257 using vacuum bag moulding method.

LS Dyna Modelling of CFRP Composite Skin

The values of 1 and 0 are set to indicate elastic and failed conditions. Based on the literatures, the history variables 1,2,3,4 and 5 are chosen to represent tensile fibre mode[15], compressive fibre mode[15], tensile failure [15]on matrix, compressive failure[15] on matrix [ed (i)] and max[ef(ip)] [efail] respectively.

In this paper, the spherical impactor was considered and its effect on composite plate and plate with the stringer are noted to understand the nature of delamination failure. Spherical impactor diameter and mass are 11.1 mm and 11.1 g respectively.

The top surface of plate is hit by hemispherical impactor at 150 m/s, the indentation in zone of delamination and the distribution of x-stress and its maximum value are shown in figure below.

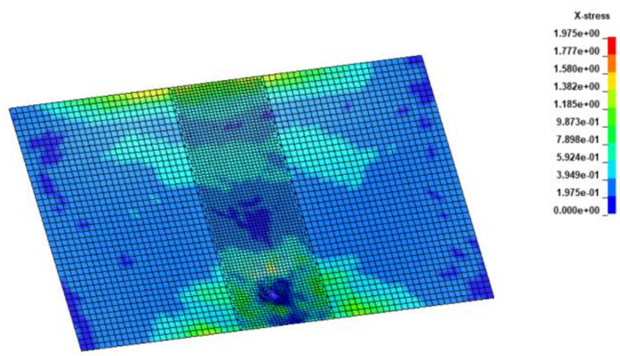

Fig. 1; The Distribution of x Stress

The x stress value is maximum along x-direction and it is seen close to edges. The x-stress keeps on decreasing from the edges to the centre of the plate. The maximum x-stress value is 1975 MPa from this simulation. The x and y distance of delamination is 21mm and 24 mm.

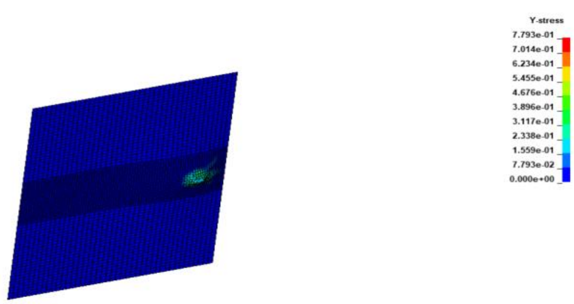

Fig. 2; The Distribution of y Stress

The maximum y-stress value is 779.3 MPa and it is found at the delamination area. In the remaining area, zero stress is noted.

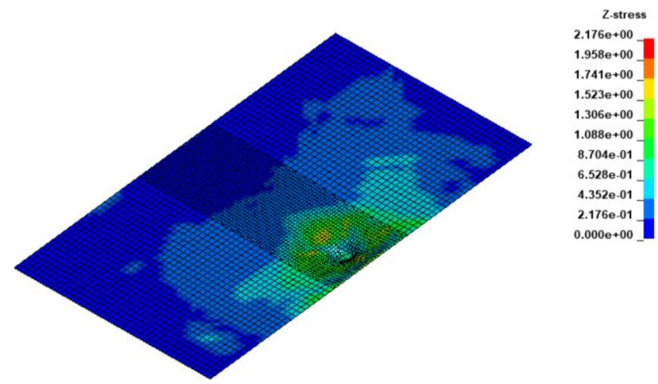

Fig. 3; The Distribution of z Stress

At the top surface of plate, the observed maximum z-stress value is 2176 MPa and its value decreases from impact location to the opposite edge. In comparison with x stress and y stress, z stress is the largest value.

LS Dyna Modelling of CFRP Skin with Hat Shaped Stringer for Impact Velocity of 150 m/s

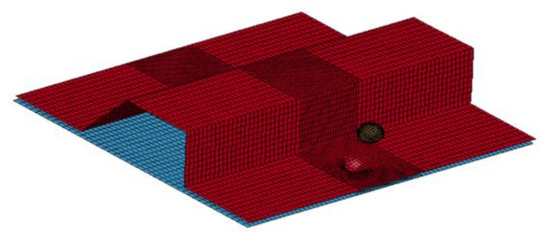

Fig. 4; CFRP Skin with Hat Shaped Stringer

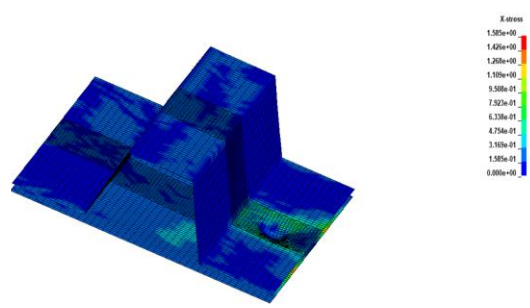

Fig. 5; The Distribution of x Stress

The maximum x stress value is 1585 MPa. Based on rule of thumb, the length of delamination (x, y) is (27,30) mm.

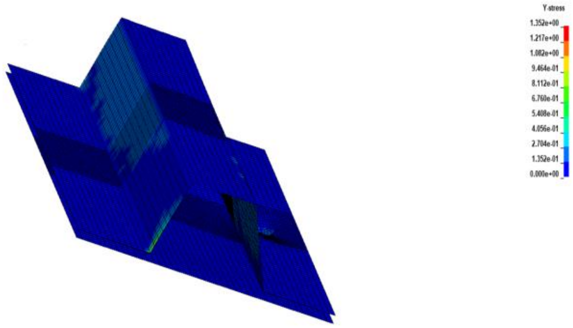

Fig. 6; The Distribution of y Stress

The maximum y stress value is 1352 MPa and it is noted near the edge of web on the opposite side of impact.

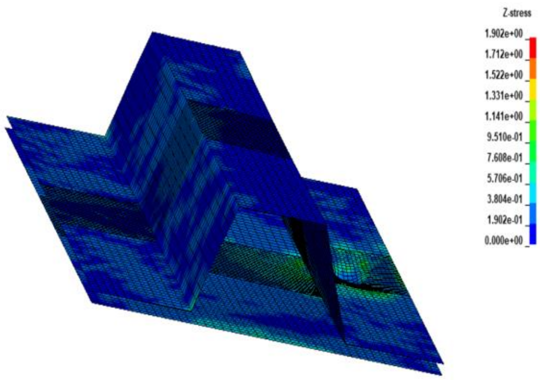

Fig. 7; The Distribution of z Stress

The maximum z stress value is 1902 MPa and it is located near the impact. Its magnitude is higher at the bottom flange of hat stringer than the top flange.

The ten nodes are picked randomly and the resultant velocity plot at these nodes is shown in fig below.

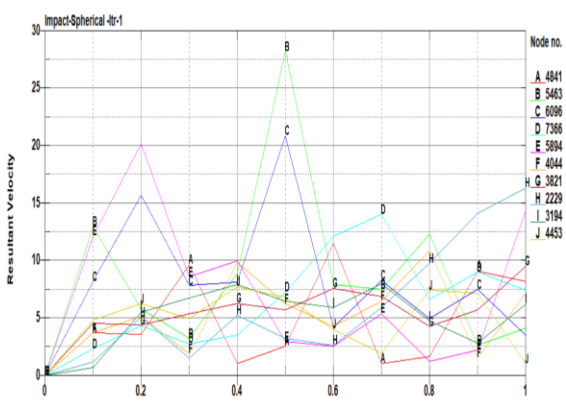

Fig. 8; The Resultant Velocity

The resultant acceleration with time for the same ten nodes chosen above is shown in fig below.

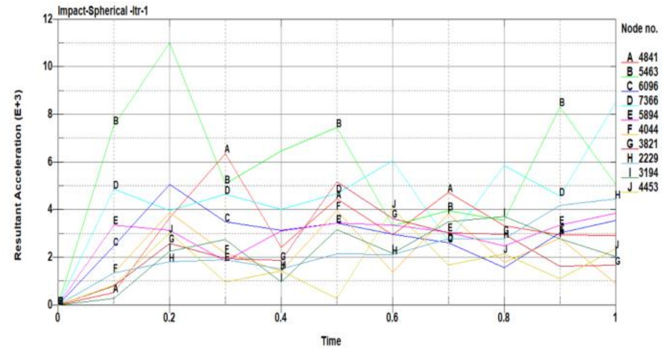

Fig. 9; The Resultant Acceleration

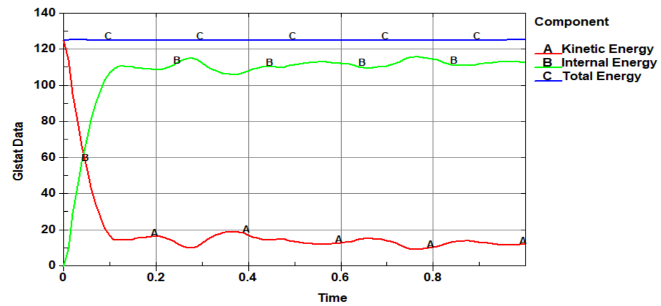

Fig. 10; Energy Plot for Impact Velocity of 150 m/s

The internal energy absorbed reaches the value of 116 kJ. The kinetic energy falls to 18.95 kJ from 125.26 kJ. Since the impactor comes back to the plate, the kinetic energy is a non-zero value.

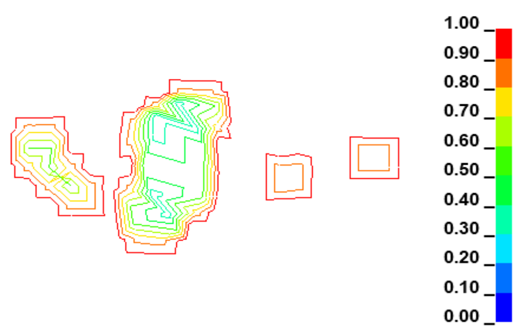

Fig. 11; Contour of History Variable 1

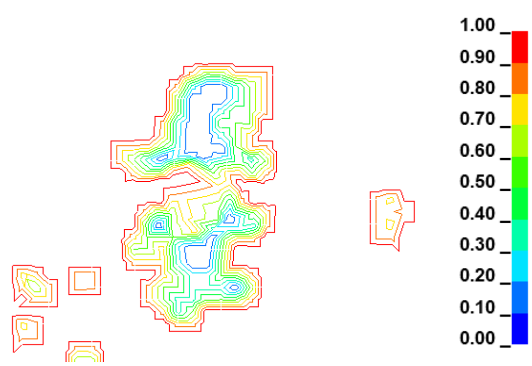

Fig. 12; Contour of History Variable 2

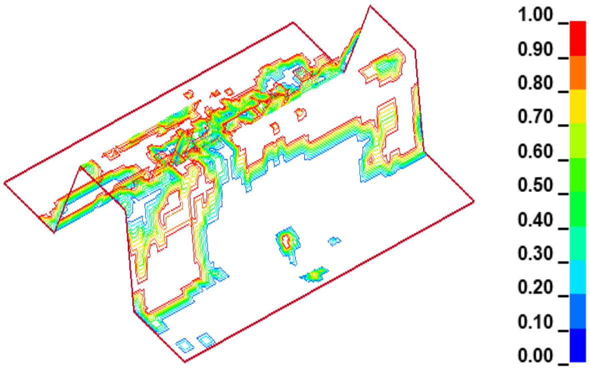

Fig. 13; Contour of History Variable 3

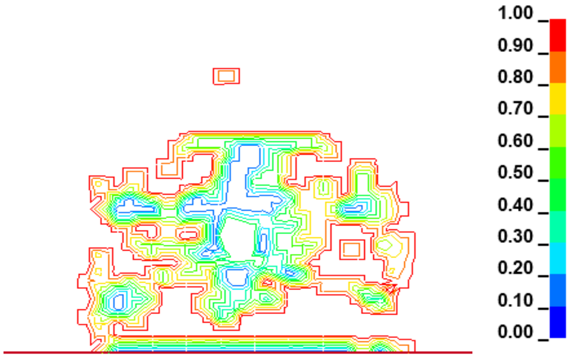

Fig. 14; Contour of History Variable 4

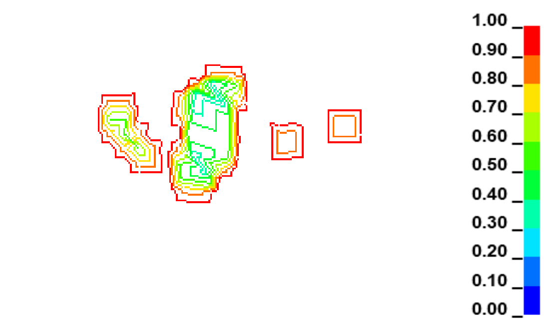

Fig. 15; Contours of History Variable 5

All fringes are taken at impact location. Zero indicates failure and 1 indicates elastic fringe.

LS Dyna Modelling of CFRP Skin with Hat Shaped Stringer for Impact Velocity of 250 m/s

The effect of applying impact load at 250 m/s is discussed here.

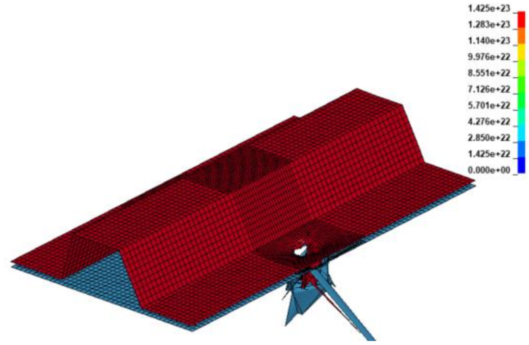

Fig. 16; The Distribution of x Stress

The maximum x stress value is 1407 MPa. Delamination length (x, y) is (30, 40) mm.

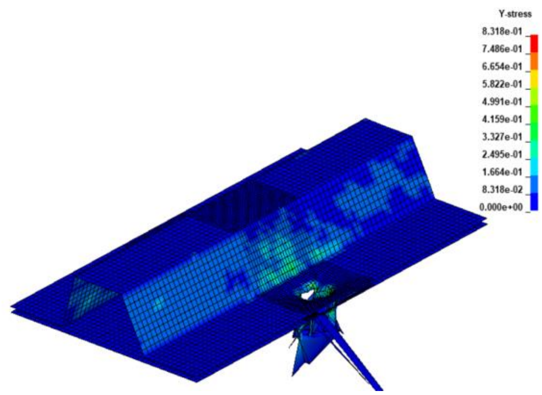

Fig. 17; The Distribution of y Stress

The maximum Y-stress value is 0.8209 MPa and it is noted near the location where the impactor hits.

On the other side of stringer, the effect is comparatively low.

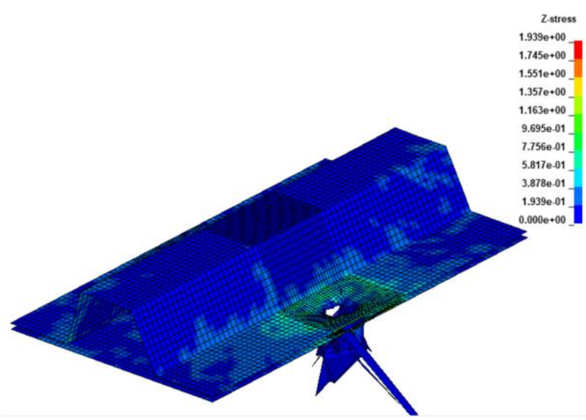

Fig. 18; The Distribution of y Stress

The maximum stress is located at the bottom surface of plate.

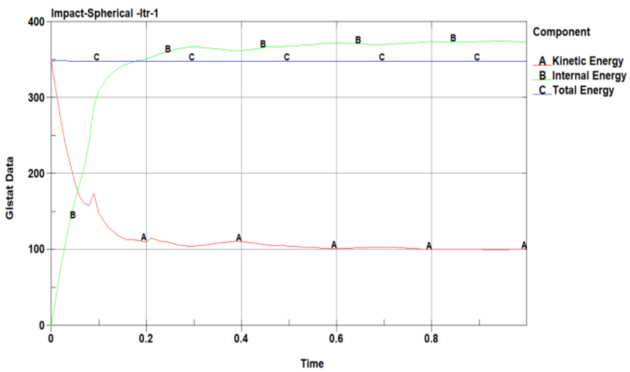

Fig. 19; Energy Plot

The internal energy absorbed is 373.5 kJ.

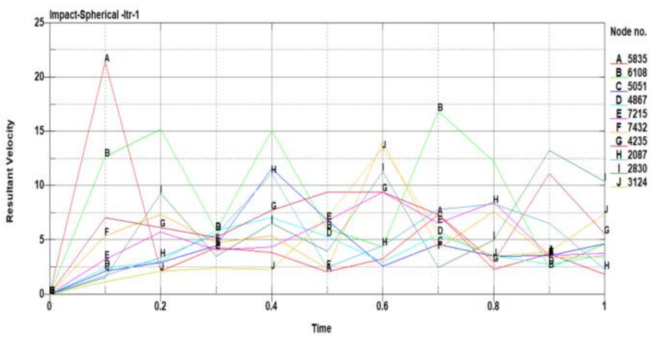

Fig. 20; The Resultant Velocity Plot

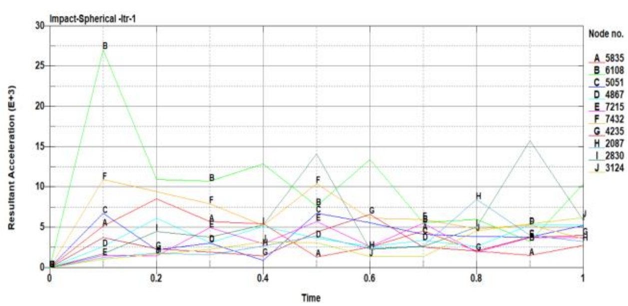

Fig. 21; The Resultant Acceleration Plot

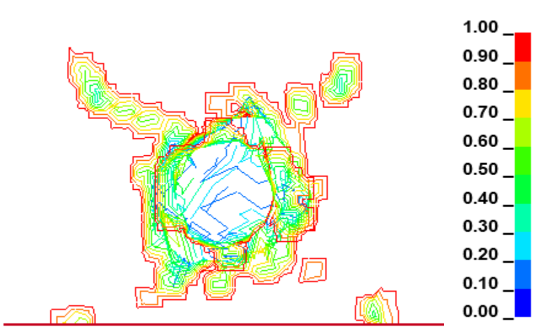

Fig. 22; Contours of History Variable 1

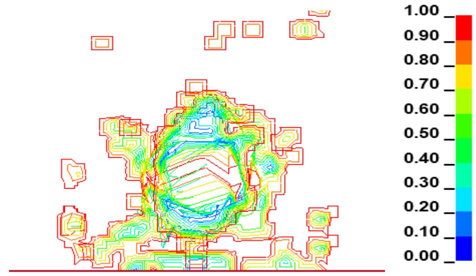

Fig. 23; Contours of History Variable 2

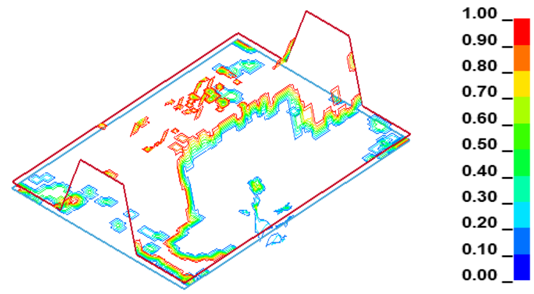

Fig. 24; Contours of History Variable 3

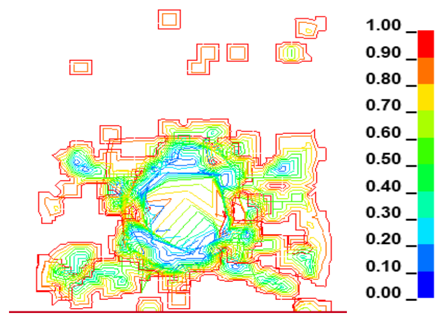

Fig. 25; Contours of History Variable 4

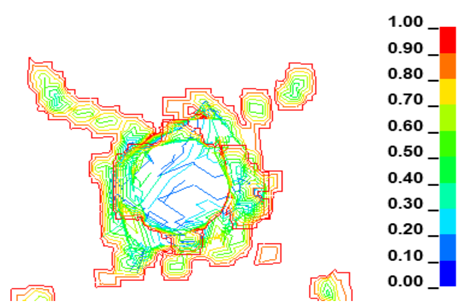

Fig. 26; Contours of History Variable 5

All fringes are taken at impact location to display failure and elastic conditions.

Conclusion

It is concluded that stiffeners increase the structural integrity. As more internal energy is absorbed, the induced damage at impact velocity of 250 m/s is more than 150 m/s. The peak values in resultant velocity and acceleration plot show the unhealthy structure. The history plots help to identify fringes that are failed due to high velocity impact.

REFERENCES

G. Minak, M. Fotouhi, and M. Ahmadi, "Low-velocity impact on laminates". Elsevier, 2016. doi: 10.1016/b978-0-08-100080-9.00006-3.

S. Heimbs, S. Heller, P. Middendorf, F. Hähnel, and J. Weiße, "Low velocity impact on CFRP plates with compressive preload: Test and modelling," Int. J. Impact Eng., vol. 36, no. 10–11, pp. 1182–1193, 2009, doi: 10.1016/j.ijimpeng.2009.04.006.

P. K. Rakesh, V. Sharma, I. Singh, and D. Kumar, "Delamination in Fiber Reinforced Plastics: A Finite Element Approach," Engineering, vol. 03, no. 05, pp. 549–554, 2011, doi: 10.4236/eng.2011.35064.

J. Zhou, B. Liao, Y. Shi, Y. Zuo, H. Tuo, and L. Jia, "Low-velocity impact behavior and residual tensile strength of CFRP laminates," Compos. Part B Eng., vol. 161, no. September 2018, pp. 300–313, 2019, doi: 10.1016/j.compositesb.2018.10.090.

R. Rajamanickam, "Study of delamination of composite hat skin stringer interface failure".

G. Jims John Wessley, A. Gaith Franklin, and S. J. Vijay, "Fabrication and mechanical characterization of stir cast AA6063-Borosilicate-Fly Ash hybrid metal matrix composites," Int. J. Eng. Technol., vol. 7, no. 3, pp. 101–105, 2018, doi: 10.14419/ijet.v7i3.6.14949.

J. D. Winkel and D. F. Adams, "Instrumented drop weight impact testing of cross-ply and fabric composites," Composites, vol. 16, no. 4, pp. 268–278, 1985, doi: 10.1016/0010-4361(85)90279-4.

S. N. A. Safri, M. T. H. Sultan, N. Yidris, and F. Mustapha, "Low velocity and high velocity impact test on composite materials – A review," Int. J. Eng. Sci., vol. 3, no. 9, pp. 50–60, 2014, doi: 10.1177/1464420711409985.

G. lin Mo, Q. wen Ma, Y. xi Jin, W. min Yan, Z. xin Li, and Z. lin Wu, "Delamination process in cross-ply UHMWPE laminates under ballistic penetration," Def. Technol., vol. 17, no. 1, pp. 278–286, 2021, doi: 10.1016/j.dt.2020.05.001.

K. Giasin et al., "Effect of Fibre Orientation on Impact Damage Resistance of S2/FM94 Glass Fibre Composites for Aerospace Applications: An Experimental Evaluation and Numerical Validation," Polymers (Basel). vol. 14, no. 1, 2022, doi: 10.3390/polym14010095.

Y. Mo, D. Ge, and B. He, "Experiment and optimization of the hat-stringer-stiffened composite panels under axial compression," Compos. Part B Eng., vol. 84, pp. 285–293, 2016, doi: 10.1016/j.compositesb.2015.08.039.

R. Kaur, "Spars and Stringers- Function and Designing," Int. J. Aerosp. Mech. Eng., vol. 1, no. 1, pp. 58–61, 2014.

B. M. Icten, B. G. Kiral, and M. E. Deniz, "Impactor diameter effect on low velocity impact response of woven glass epoxy composite plates," Compos. Part B Eng., vol. 50, pp. 325–332, 2013, doi: 10.1016/j.compositesb.2013.02.024.

Y. Tie, Y. Hou, C. Li, X. Zhou, T. Sapanathan, and M. Rachik, "An insight into the low-velocity impact behavior of patch-repaired CFRP laminates using numerical and experimental approaches," Compos. Struct., vol. 190, no. December 2017, pp. 179–188, 2018, doi: 10.1016/j.compstruct.2018.01.075.

W. Xu, L. Liu, and W. Xu, "Experiments and Finite Element Simulations of Composite Laminates Following Low Velocity On-Edge Impact Damage," Polymers (Basel). vol. 14, no. 9, 2022, doi: 10.3390/polym14091744.