Studies on Layering and Orientation of Foldcore Composites Subjected to Impacts

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ABSTRACT

The mechanical behaviour of sandwich structure with folded cores produced by folding Aluminium sheets to zigzag structures is evaluated under metal fragment impact loading. The impact performance under Transverse Low Velocity Impact with different layering and orientations of foldcore composites with subsequent damage assessment is addressed. For geometrical optimization, the influence was studied by impacting metal ball against the specimen fabricated with different geometrical core designations, number of layers and their arrangements over one another. Compression tests were performed before impact and after impact on the fabricated geometries for identifyingthe **Potential Stress Bearing Capacity** and the **Residual Stress Bearing Capacity** respectively of each selected geometric candidate (using Stress-Strain characteristics). To conclude the analysis, numerical model was developed using Finite Element (FE) package – CATIA V5 and the analysis was done using another FE package – Hyper Mesh 11.0. The results obtained from simulations were correlated with experimental data, for the effective study of the parameters and evaluation of damage patterns and energy absorption mechanisms in experiments.

Key Words: Foldcore Composites, Compression test, Layering &orientation, Hyper Mesh 11.0.

1. INTRODUCTION

One of the main design parameters of modern engineering and transport structuresfor aerospace and automotive applications is weight reduction. For this the sandwich design principle plays a key role, as it allows high weight-specific bending stiffness compared to a monolithic structure. A sandwich structure typically consists of two thin and stiff skins, separated by a lightweight core in between. The separation of two thin skin layers by a cellular core allows better weight-specific bending stiffness compared to monolithic structures.

Honeycomb structures are the classical core materials used for aircraft components.They have some major drawbacks like direct transmittance of impact loads, costly manufacturing and water accumulation in the closed cell configurations. To overcome these drawbacks, so as the use of these can be increased in structures, a new generation of core materials was developed in recent years, called Foldcores. The basic idea is to produce three-dimensional structures from a flat sheet of material in an origami-like manner by simple folding processes. The Foldcore possess open ventilation channels in one direction, solving the problem of closed cells in honey combs. Single or double curvature structures can be folded without generating internal stresses. Furthermore, the manufacturing processes cost can reduce the cost of such core structures as these can be manufactured continuously compared to expensive honeycomb cores that are manufactured discontinuously. Major advantage of Foldcores over honey comb structure is its capability to absorb energy by crushing itself on events of collision. Also ventability of the core is desired, i.e. the cells are not closed and water is not trapped and can escape.

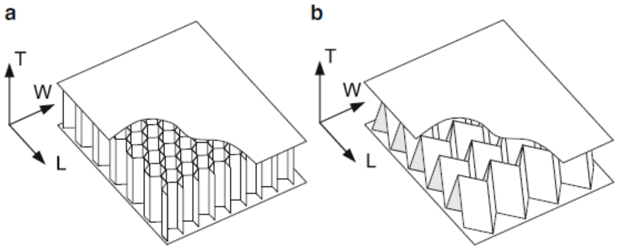

Fig.1. (a) Honeycomb Structure (b) Foldcore Structure

Objective of the subject study was to investigate the strength bearing capability of different foldcore geometries prior to and followed by Solid Fragment Impacts. Also this study considered the effect of layering and orientations in the composite.Regular foldcore geometries which are representative candidates from larger geometric families were selected and fabricated. The fabricated composites are subsequently subjected to controlled Transverse Low Velocity Impacts. The **Potential Stress Bearing Capacity** of each selected geometric candidate was compared with the **Residual Stress Bearing Capacity** left out in them after the impact. This case wise study, in the form of stress strain characteristics, could provide valuable insights into the impact energy absorptions and residual strength left out in different Foldcore configurations. The study lead to an evident selection of the geometric and layering pattern for enhanced energy absorption in an impact loading and residual strength left out after impact loading.

2. LITERATUER SURVEY

i. Sebastian Heimbs, "Foldcore Sandwich Structures and Their Impact Behaviour". 2013. In book: Dynamic Failure of Composite and Sandwich Structures, p.491-544.

The excerpt titled "Dynamic Failure of Composite and Sandwich Structures" focused on the foldcore sandwich structures and their impact performance. These structures are produced by folding a flat sheet of material to three-dimensional zigzag structures in an origami-like manner. The cell wall material of Foldcore could be of cardboard, plastics, metals or composites. Based on static and dynamic tests, the mechanical properties under compression and shear loads are assessed here. The hard body steel impactors and rubber fragments impact performance under low and high velocity impact with different projectiles and subsequent damage assessment is addressed. Overview on numerical modelling for Foldcore sandwich analyses is also included. In the end, an overview on present and potential applications of Foldcore sandwich structures is given. The impact performance on the composite Foldcore structures is evaluated. Foldcore structures have open cells for proper ventilation which results in better mechanical properties and high strengths including long life span. Different materials can be used for making the cores in three-dimensional geometries. The stiff zigzag structure even acts like a delamination stopper. In addition to single core structure, a dual core configuration was also investigated. Dynamic finite element simulations with LS-Dyna resulted as an effective tool for model development of complicated shapes. The results correlated well with the experimental data allowing better parametric study.

ii. V. Balasubramani and S. RajendraBoopathy, "Prediction of residual tensile strength of laminated composite plates after low velocity impact", 2014. In book: Journal of Agricultural and Biological Science, Mar 2014, Vol. 9, Issue 3, p.320.

Laminated composite materials have advantage of high stiffness to low weight ratio and also high strength to low weight ratio and therefore are used widely in aerospace and transportation industries. In this paper Foldcores are subjected to low-velocity impact due to birds, hail,rain and from dropped tools used during manufacture or maintenance. Low velocity impact damages mostly internal parts and is invisible, but minimizes the residual strength of structure. In this study, the residual tensile strength of three stacking sequences of Glass Fibre Reinforced Plastic (GFRP) composites is determined after lowvelocity impact experimentally using different threshold energy. A model was selected based on linear elastic fracture mechanics for predicting residual strength of impacted GFRP composites. Experimental results showed the reliability of the model in the field of low velocity impact and its usefulness determined the residual tensile strength. The correlation between the analytical and experimental results was done and compared. The determination of residual strength in impacted laminates is very useful for predicting product-life cycle of the composite.

iii. Yan Ying, Lou Chang, Cheng Chuan Xian, Zhang Yi Ning and Yang Xu, "Investigation of impact residual strength of woven and non-woven composites", 2014, In book:, ICCM'13Proceedings.

The residual mechanical properties of different carbon fibres were evaluated after drop weight impact damage. Results from all tests when compared, showed the residual mechanical properties of woven fabric lamina better than unidirectional lamina reinforced composites. The relationship between energy and mechanical degradation was established. A numerical model by Caprino was made for validation of results obtained for woven carbon composites

iv. A. Manes, F. Serpellini, M. Pagani, M. Saponara, M. Giglio, "Perforation and penetration of aluminium target plates by armour piercing bullets", 2013. In book: International Journal of Impact Engineering, P. 69.

This paper discusses the Experimental, analytical and numerical simulations which were performed to study the ballistic resistance of 6061-T6 aluminium plates subjected to normal impact of small calibre armour piercing bullets. Bullets made of steel and having core of tungstenwere used. The bullets were impacted at different velocities resulting in deep penetration to complete perforation of plate. For numerical simulations, LSDYNA and ABAQUS solvers were used. Ballistic results and deformations of the platesin analytical models followed a cavity expansion approach. The capability of the models to reproduce the physical features of the phenomena was also discussed. For the residual stress patterns on the plate's surface, X ray diffraction measurements were performed both before and after the tests and the experimental measurements are compared with the numerical model results. The work focused on monolithic plates, the results and discussion were of interest for the design of optimized multilayer armour shields. This paper showed that when a hard bullet subjected to deformable sabot impacts against a ductile material like aluminium, the sabot behaviour (driven by deformation and friction) tends to arrest the whole bullet itself.

v. C hang Qi, Shu Yang, Dong Wang, and Li-Jun Yang, "Ballistic Resistance of Honeycomb Sandwich Panels under In-Plane High Velocity Impact", 2013. In book: The Scientific World Journal, Vol. 2013.

In this paper, the dynamic results for in-plane projectile impact were studied on Honeycomb Sandwich Panels (HSPs) using HypermeshFE package. The sandwich panel are in three different unit cell configurations (regular, rectangular-shaped, and re-entrant hexagons) made of aluminium alloy as face-sheets and an aluminium honeycomb core. The ballistic resistances for different core configurations of HSPs were analysed. The HSP with the re-entrant auxetic honeycomb core showed the best ballistic resistance, due to the negative Poisson's ratio effect of the core. After that, the parametric studies were carried out to clarify the influences of macroscopic (face-sheet and core thicknesses, core relative density) and mesoscopic (unit cell angle and size) parameters on the ballistic responses of the auxetic HSPs. Numerical results showed that the perforation resistant capabilities of the auxetic HSPs increases as the values of the macroscopic parameters increases. However, the mesoscopic parameters affect those nonmonotonic effects on the panels' ballistic capacities. It was found that the blunter projectiles result in higher ballistic limits of the auxetic HSPs.

vi. Sebastian Heimbs, "Impact on sandwich structures with folded core", 2011. In book: Dynamic Failure of Composite and Sandwich Structures, p. 141-144.

The mechanical behaviour of Foldcore sandwich structures is evaluated under compression, shear and impact loads. The foldcores made of woven aramid fibres showed ductile behaviour, carbon foldcores showed brittle nature and absorbed energy by crushing, resulting in extremely high weight-specific stiffness and strength properties. The impact damage under low and high velocity impact loads were highly localized. Along with single-core structures, a dual-core configuration with two foldcores was also investigated, showing the potential of two-phase energy absorption behaviour. Impact simulations withLS-DYNA were developed along with experimental result. The structure being too complex took too much time for simulation but the FE package worked as an efficient tool and the results obtained correlated well with test data, allowing for efficient parameter studies of damage patterns and energy absorption mechanisms in virtual tests.

vii. PierrickGu´egan, Ramzi Othman, Daniel LeBreton, Franck Pasco, Nicolas Swiergiel and Pascal Thevenet, "Experimental investigation of rubber ball impacts on aluminium plates", 2010. In book: International Journal of Crashworthiness, Vol. 15, Issue 4, p. 391–399.

In this paper, the mechanical behaviour of foldcore structures for advanced sandwich composites under flatwise compression load using a virtual testing approach was presented. Here the dynamic compression test simulations solver PAM-CRASH and LSDYNA were compared to experimental data of two different folded core structures made of aramid paper and Carbon Fibre-Reinforced Plastic (CFRP). The focus of the investigations was the constitutive modelling of the cell wall material, the consideration of imperfections and the representation of cell wall buckling, folding or crushing phenomena. The consistent numerical result shows that this can be an efficient approach for the determination of the effective mechanical properties and a cell geometry optimization of folded core structures.

viii. S. Heimbs, P. Middendorf, C. Hampf, F. Hähnel, K. Wolf , "Aircraft sandwich structures with folded core under impact load", 2008. In book: International Journal of Crashworthiness, Vol. 15, Issue. 4, p. 343-355.

Folded structures have gained interest in the aerospace and transportation industries as a promising sandwich core structure. In this paper, the mechanical behavior of folded core made of carbon fiber-reinforced plastic (CFRP) under low velocity impact loads was investigated experimentally and numerically. Initially, the core properties under compressive and transverse shear loads were characterized for the validation of the simulation models. Low velocity impact tests under various energy levels with respect to evaluated damage of face and core were discussed and finally it was simulated with LSDYNA. These simulations were used to investigate the influence of different parameters on the impact behaviour numerically.

ix. S. Heimbs, P. Middendorf, S. Kilchert, A. F. Johnson, M. Maier, "Experimental and Numerical Analysis of Composite Folded Sandwich Core Structures Under Compression", 2008. In book: Appl Compos Matter, p. 363–377.

In this paper, the mechanical behaviour of foldcore structures for advanced sandwich composites under flatwise compression load using a virtual testing approach was presented. Here the dynamic compression test simulations use solvers PAM-CRASH and LSDYNA tovalidate with experimental data. Different Foldcore structures made of aramid paper and Carbon Fibre Reinforced Plastics (CFRP) where considered. The focus of investigation was on constitutive modelling of cell wall material, consideration of imperfections, representation of cell wall buckling and considering folding or crushing phenomena.

x.Matti J. Loikkanen, Murat Buyuk, Cing-Dao (Steve) Kan, "A computational and experimental analysis of ballistic impact to sheet metal aircraft structures", 2007.

In this paper, the ballistic resistance of 2024-T3 and 2024-T351 alloy aluminium flat plates to aircraft engine fragments was evaluated experimentally. For getting the ballistic speed limit of a spherical steel bullet, gas and powder gun tests were performed. The impactor represents the engine fragment with a diameter of 0.5 inch. The rectangular flat aluminium specimens were prepared as 12 x 12 inch and with three different thickness combinations of 1/16", 1/8" and ¼". A normal impact scenario was considered in terms of orientation of the specimens to the impacting projectile. A numerical model was constructed using Johnson-Cook (J-C) material model considering the thermo-viscoelastic behaviour with an accumulated damage and an equation of state model. LS Dyna was used for impact simulation and the ballistic limit comparisons for the failure mechanisms were validated. Experimental damage characteristics were used for identifying the essential failure parameters in the material model.

sandwich structure as it allows the moisture to pass through the openings and resulting in increased mechanical strength, lessened corrosion and increased structure life span. Previous papers have used the same kind of core geometries only by changing the material for fabrication. In the present study considering the existing primitive geometries, there optimization is done by changing the angles and dimensions of the core and core layer placement orientations are investigated by arranging two layers one over the other using aluminium metal for core fabrication and GFRP for face sheets.

3. METHODOLOGY

In the present study, **Metal fragment impact load** is considered. Metal balls were used as the fragment to hit the composite.

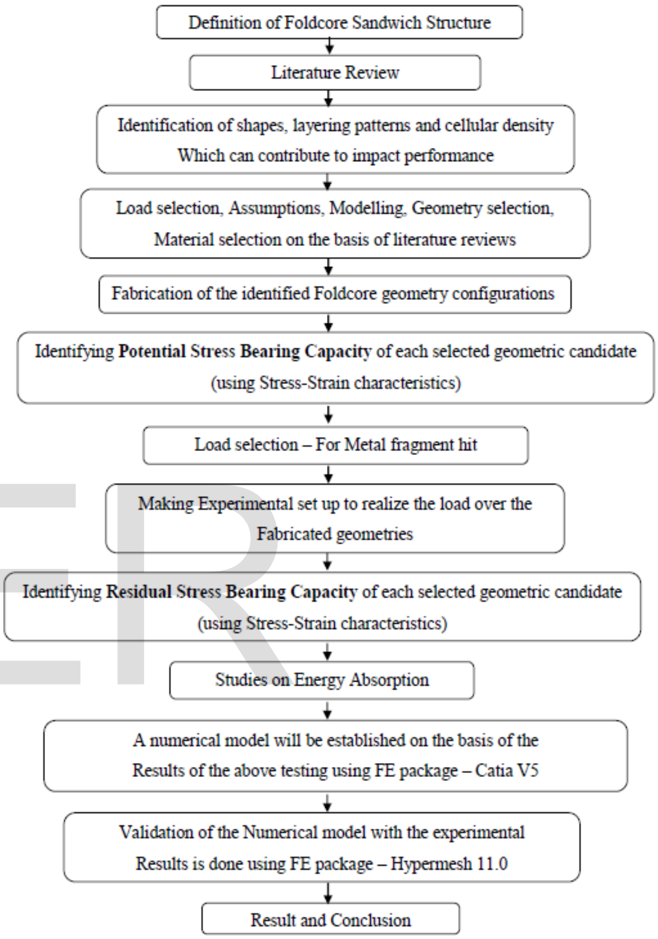

Fig 10. Flow chart for conduct of present study

Reciprocating Air Compressor was used for hitting the metal ball at high velocity. **Potential Stress Bearing Capacity** (prior to impact) **and ResidualStress Bearing Capacity** (following impact) are calculated in the form of Stress Strain characteristics. The same is analysed for concluding enhanced impact behaviour. For simulation, numerical models were created in the FE package Catia V5 and imported to Hypermesh 11.0 for validation where the results obtained from the experiments were validated for selected cases.

4. GEOMETRY SELECTION

Selected geometric patterns and layering orientations are as under:

1. Triangular core group of Foldcores

1. Single Core: CO
2. Parallel core arrangement: C1
3. Node to Node arrangement: C2
4. Perpendicular Arrangement: C3

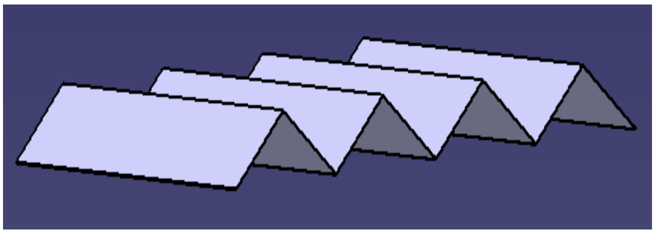

Fig2.Single Core: CO

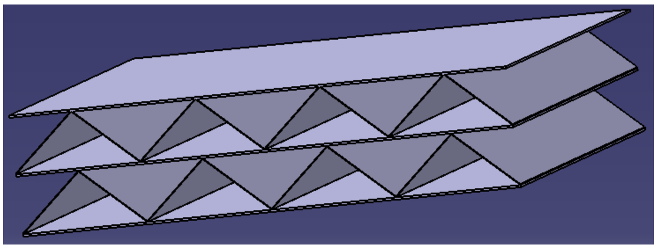

Fig3.Parallel core arrangement: C1

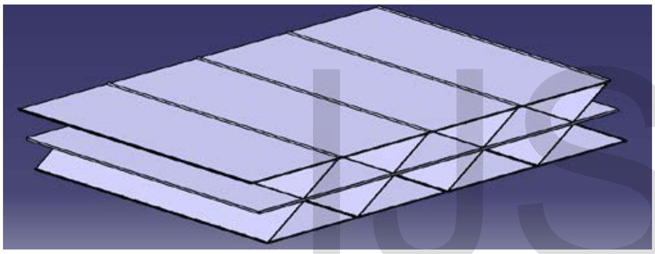

Fig4.Node to node arrangement: C2

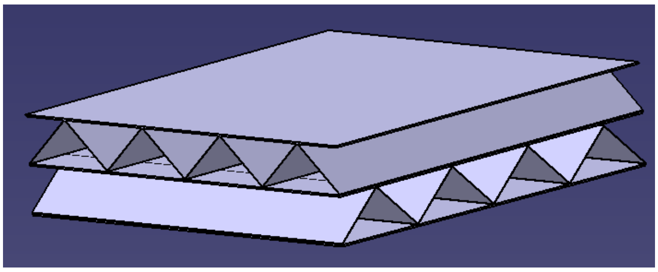

Fig5.Perpendicular arrangement: C3

2. Stepped core group of Fold Cores

1. Single Core: SO
2. Parallel core arrangement: S1
3. Node to Node arrangement: S2
4. Perpendicular Arrangement: S3

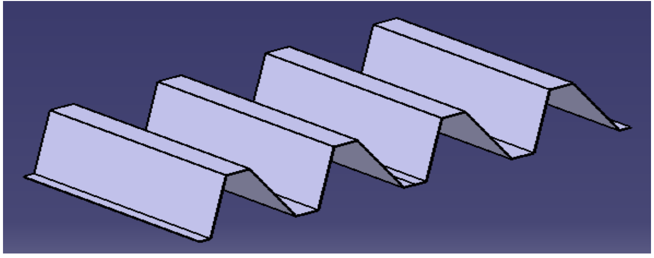

Fig6.Single core: SO

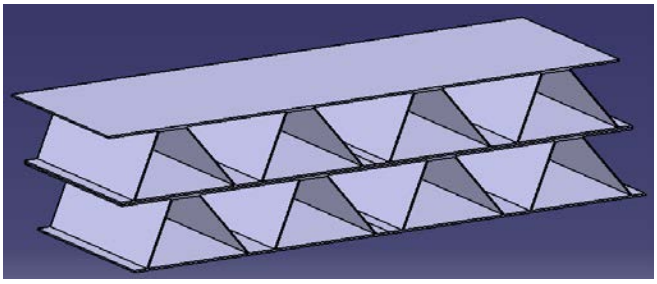

Fig7.Parallel core arrangement: S1

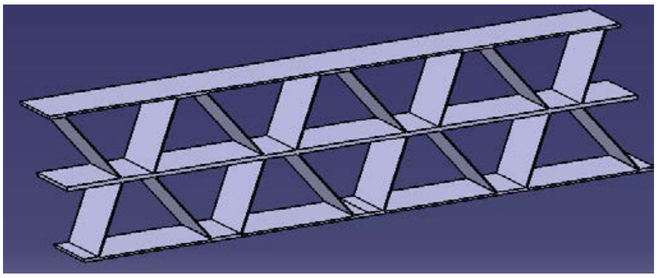

Fig8.Node to node arrangement: S2

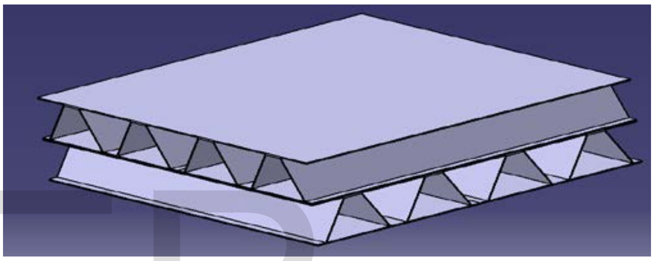

Fig9.Perpendicular arrangement: S3

In the present study Foldcores are fabricated of Aluminium and face sheets are made of Glass Fibre Reinforced Plastic (GFRP). Core and Skin are bonded using resin adhesives.

5. IMPACT REALIZATION

Distinction of LVI and HVI is based on the relation of impact velocity to wave speed in thickness direction of the target structure. If the above relation is higher than the failure strain of the material in thickness direction, then the incident is called High Velocity Impact (HVI), with local damage occurring before a globalstructural deformation is generated.High velocity impact tests with steel cubes are documented in the literature for CFRPFoldcore sandwich plates and aramid paper Foldcore sandwich. The steel cubes are considered to simulate the impact of debris, screws, screw nuts or small stones. Additional protective layers areinvestigated to prevent the sandwich structure from progressive impact damage.The test apparatus used in the present project study was set up considering all the parameters from literature reviews. The specimenwas simply supported at the edges to allow for bending deformation under impact load.The impact angle of the steel cube was 90^0, i.e. perpendicular to the surface.The velocity necessary to achieve full penetration is generally referred to as the ballistic limit.

The scope of the Impact testing covered three characteristic load cases:

(1) The impactor bounces back from the outer skin

(2) The impactor penetrates the outer skin and gets stuck in the core

(3) The impactor penetrates the whole sandwich structure.

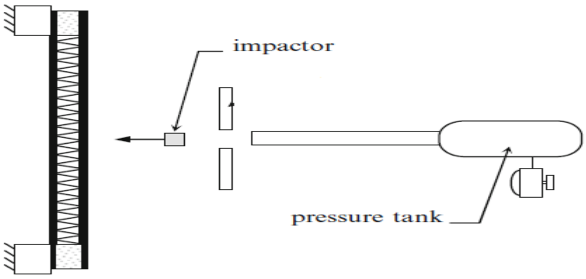

Fig 10. Impact Setup

Fig11. CO after hitting withanenergy of10.625 J

Fig12.C1 after hitting with anenergy of.625 J

Fig13. C2 after hitting withanenergy of10.625 J

Fig14. C3 after hitting withanenergy of10.625 J

Fig15.SO after hitting withanenergy of10.625 J

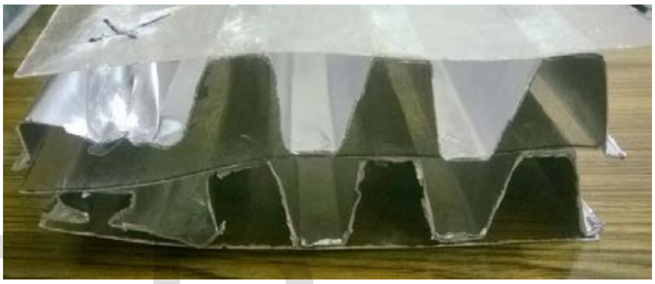

Fig16.S1 after hitting withanenergy of10.625 J

Fig17.S2 after hitting withanenergy of 10.625 J

Fig 18.S3 after hitting withanenergy of10.625 J

The impact hit performed on the configurations were compared and the configurations C2 and S2 resist to impact better in comparison to the other configurations. Delamination occurs in between the skin and the core and part of the skin materialand of the Foldcore were teared out by the impactor. The middle layer was penetrated bythe ball and pierced out completely. The large-scale skin/core debonding at the backsidewas visible in this cross-section.Overall, this is complex failure behaviour with different failure modes,posing high demands on the numerical models. This indicates the potential for an improved impact damage resistance of the multi-core concept with a further optimisation of the choice of middle layer designation and orientation of folded core.

6. COMPRESSION TESTING

In Strength of Materials rhetoric, the resultant compressive strength is a major indicative parameter for identifying the impact withstanding capacities of any structure or composite. If the material compresses and shortens under load, it is said to be in compression. Compressive strength can be measured on materials, components and structures under controlled loading using a Universal Testing Machine. It can be measured by plotting applied force against deformation in the testing machine. Some materials fracture at their compressive strength limit; others deform irreversibly, so a given amount of deformation may be considered as the limit for compressive load.

In the present project study, the compression tests on the structures were performed as:
1. Before impact test compression i.e. Potential
2. After impact test compression i.e. Residue

The compression test was done for the force value of forces at 0.1kn, 0.2kn, 0.3kn, 0.4kn and 0.5kn respectively.

Compression test results were plotted in the form of Stress Strain curves for both primitive geometries i.e. Triangular and Stepped core (C0 and S0). Subsequently stress strain chara for other geometries are obtained using simulations in Hypermesh 11.0. The Potential and Residual stress leftovers for C1, C2, C3, S1, S2 and S3 are thus obtained and validated by relating C0 and S0 simulation and experimentation result.

When complete C group is compared, the geometry which entirely absorbed impact energy of 10.625 J and still leaving the maximum residual strength was “C2”geometry i.e. node to node geometrical arrangement of cores. Hence Node to Node arrangement (shown in Red) is having an edge over all other considered geometries in C group in resisting impacts.

When complete S group is compared, the geometry which entirely absorbed impact energy of 10.625 J and still leaving substantial residual strength was “S2” geometry i.e. Node to Node geometrical arrangement of cores. Hence Node to Node arrangement is having an edge over all other considered geometries in S Group also in resisting impacts but when compared with C group, C2 geometry showed the maximum residual strength.

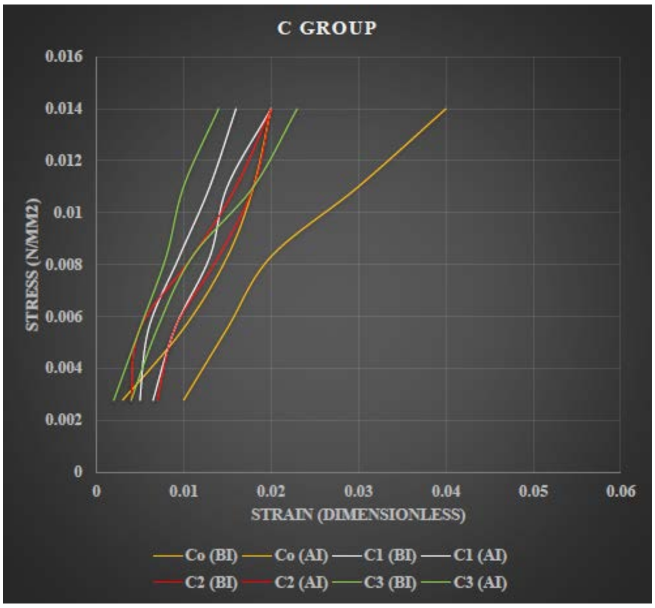

Fig 19. Comparison of Stress Strain chara for before impact and after impact Fold Core composites for C0 geometry.

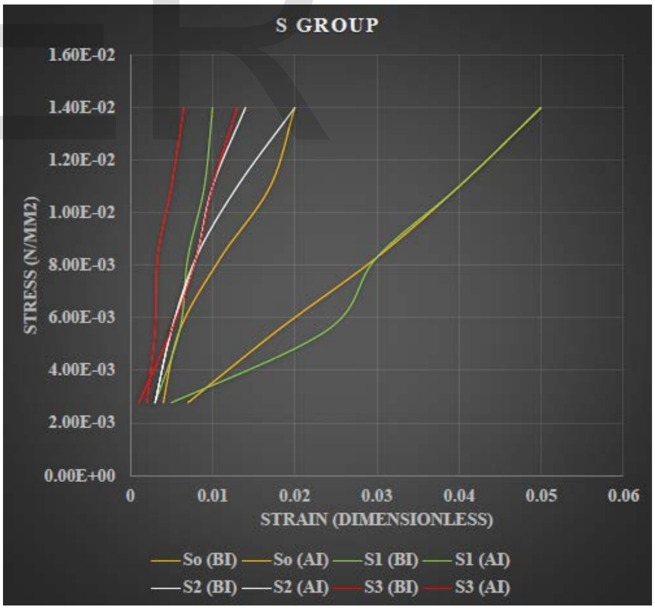

Fig20. Comparison of Stress Strain chara for before impact and after impact Fold Core composites for S0 geometry.

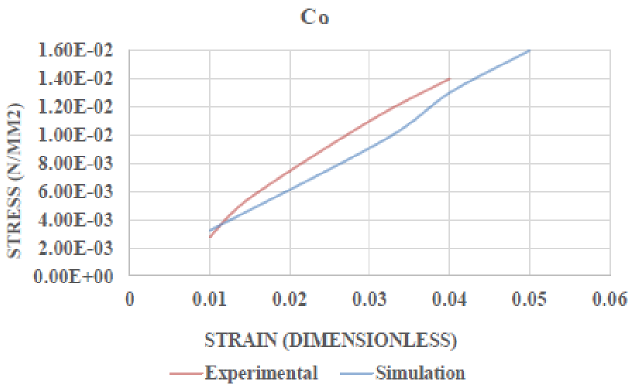

Fig 21.Validation - of experimental and simulational data for C0 geometry

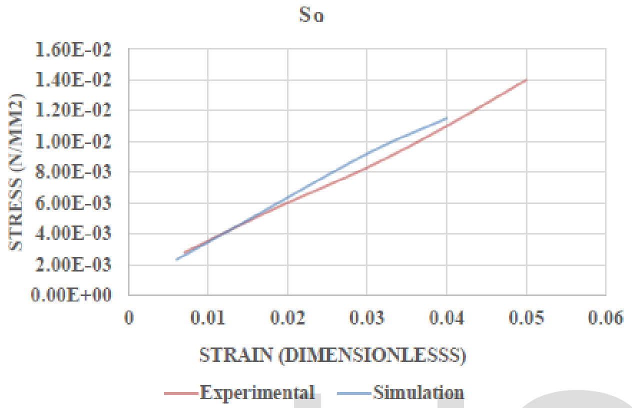

Fig22.Validation - of experimental and simulational data for S0 geometry

The stress strain characteristics for simulation and experimental model are returning a correlation factor of 0.9909 and 0.997 which are close enough for assuming a perfect validation between the experimental and numerical model.

7. CONCLUSION

The fabricated composites were subsequently subjected to controlled transverselow Velocity Impacts. The **Potential Stress Bearing Capacity** of each selected geometric candidate was compared with the **Residual Stress Bearing Capacity** left out in them after the impact. This case wise study, in the form of stress strain characteristics, provides the valuable insights into the impact energy absorptions and residual strength left out in different composites. The study leads to an evident selection of the geometry and layering pattern for enhanced energy absorption in an impact loading and residual strength left out after impact loading.

Further this study can be extended to different refined geometries by altering the core orientations and for those core orientations different layering patterns can be established. The best geometry from these orientations can be obtained by impacting the model structure surface at different greasing angles rather than impacting them at normal. The geometry which can withstand these greasing angles perfectly can be considered best refined geometry.

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