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Investigation on Compression Behavior of 3D Printed Core Material Used for Aerospace Applications

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***Abstract*:**

Employing continuous carbon fiber 3D printing for sandwich structure fabrication presents an innovative solution to streamline production and enhance design flexibility in aircraft component manufacturing. By integrating the core structure directly into the printing process, the need for intricate bonding procedures is circumvented, potentially reducing both costs and production time. The study's findings underscore the pivotal role of core shape in determining the mechanical properties of the sandwich structures. Overall, leveraging continuous carbon fiber 3D printing holds promise for optimizing structural performance in aerospace components. This approach enables the flexible design of core shapes and the seamless integration of high-performance materials, contributing to the development of lighter, stronger, and more cost-effective aerospace structures in the future.

The compression studies were carried out with and without fillet and its role was investigated. The combined effective mean compression strength was found and the results were compared with the literature. The tests were conducted as per ASTM standards and the results were averaged. The specimen size was fixed at 60x60 mm^2 with varying height of 15, 20 and 25mm to review the effect of thickness on the compressive strength of 3D printed core material. The specific energy absorption SEA was computed and compared for the specimen of square and cylindrical type. The influence of nozzle diameter, thickness, core pattern are compared and its effects are studied in detail. It was found that core with fillets provided better compressive strength as compared to those without fillets. Further, the thickness played a significant role in compressive strength.

Keywords: Compression strength, 3-D printing, Creep, sandwich, Core material, PLA

1. Introduction:

In structural engineering, sandwich composite materials are widely used in weight-critical applications in motorsports and aerospace industries where foam has been an ideal feature for forming sandwich cores. These materials, however, show a significant deformation under bending and can be limited when scaled. As a result, researchers developed alternative materials with better mechanical properties including 3D Printed Core Materials. Several studies, both experimental and numerical, highlighted the superiority of those structures over conventional foam sandwiches in terms of their bending, buckling and impact resistance. Using 3D printing, the compressive resistance of a square and cylindrical core material which was printed was investigated.

This paper shows the significance and advantages of utilizing a 3-D printing assembling process over customary assembling procedure preparation about its present and potential applications. 3-D printing technology utilizes the procedure of added substance assembling process where items are fabricated layer-by-layer approach, over the cross-area of arrangement of layers. This layer assembling is frequently identifying with Rapid Prototyping technology that is utilized to make parts for long-term consistency. While the working of 3D printers is similar to laser or inkjet printers and makes use of feed material in the form of powder or granules building an image or a structure on layer-by-layer basis. The aim of the study is to develop a framework for infill patterns and study relevant background to support the material for fabrication with consistency without compromising on the dimensional accuracy of the model. Infill is an integral part of the object occupied between the shells or walls and usually measured in terms of infill percentage. There are several infill shapes available and among all triangular and honeycomb infill are popular. The infill percentage varies from zero to 100% and 20% be usually the standard density for any prototype to applicable to its engineering usage. Less is the infill percentage, less capacity to withstand stress and results in failure. However, infill has too many extrusion issues and does not bind with outer walls effectively resulting in failure. The functional properties of the sandwich structures were quantified by shape evaluations and three-point bending tests. Three-point bending tests showed maximum load and flexural modulus increased as effective density increased for all core shapes. Because the mechanical properties depended on the core shape, continuous carbon fiber 3D printers can be used to flexibly design core shapes that satisfy the desired strength and stiffness

Conventionally manufactured polymeric materials (e.g. injection molding) have superior fatigue performance than FDM printed materials. Unlike conventionally manufactured polymers, FDM-made polymers have layer by layer adhesion and the influence of printing parameters make fatigue analysis complex and critical. Researchers were also studied and valuated the compression behavior of the selected honeycomb lattice pattern by doing a comparative simulation analysis using SOLID WORKS for a basic solid and the infill pattern. The reason for selecting a honeycomb infill pattern was for its greater compression and shear resistance, compact size and isotopic geometry compared to other infill shapes. In this work, the control of print variables, such as infill density, material, layer thickness and print orientation has been evaluated. A series of compressive test specimens with different print characteristics specified in ASTM D695 standards for compression testing of polymer materials were produced using Fortus 400 3D printer. Sandwich composite structures used in the present study are widely used in aerospace, naval, sporting and automotive applications due to their high stiffness/weight ratio, high strength/weight ratio, and energy absorption capacity. This work also shows the importance of design features i.e., the effect of fillets on the compressive strength of the model. This work also allows to choose material and height for application where for less weight component high compression strength is needed.

2. Modeling and experimental methods

The model was designed and extruded such that it facilitated square and cylinder infill between the two faces of the model. The bottom face of the model was taken as selected as a reference edge and grounded and the load was applied downwards i.e. into the model to perform compression perpendicularly to the model at different loading conditions. The density of PLA was recorded around 0.022 g/mm^3 based on the data obtained from modelling software and the mass is 7.43 grams. The young's modulus for PLA 3.1 GPa with poisons ratio around 0.3 for the materials. After all the relevant data input, the model was progressed for static simulation. Study and analyze the compression behavior of the model. The fig. shows the 3D model of core material.

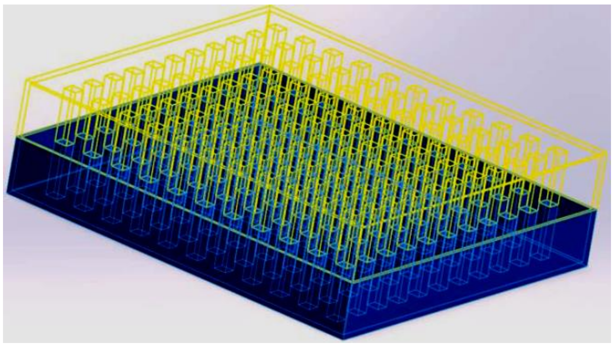

Fig. 1: 3D model of core material

3. Results and discussion

3.1 Finite Element Analysis

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Finite element analysis was carried out for the 3D model of core material. The analysis results obtained are discussed in the following section. Total deformation is the continuum mechanics transformation of a body from a reference configuration to a current configuration. . In a continuous body, a deformation field results from a stress field induced by applied forces or is due to changes in the temperature field inside the body. Max strain energy: - Strain energy is defined as the energy stored in a body due to deformation. The strain energy per unit volume is known as strain energy density and the area under the stress-strain curve towards the point of deformation. When the applied force is released, the whole system returns to its original shape. Max equivalent stress: - Equivalent stress is theoretical average stress in interested section of component whereas Max principal stress is actual highest stress in the fibers of component that are at orientation to loading plane. In this context, the interface properties play a relevant role because relaxation is due to the breaking of bonds and their propagation. In terms of creep behaviour, the fibre–matrix interface is also very important because the bonds' breakage and their propagation control the creep displacement. Therefore, the creep process is delayed because both elastic deformation and viscous flow are retarded by the presence of fibres. Nevertheless, reducing the size of the reinforcements and an increase in their weight content promotes aggregation and the consequent loss of mechanical properties. The Fig.2 depicts the strain energy absorption by the 3D printed model. The study indicates that the increase in compressive displacement suggests that the modified dimensions of composites exhibited greater resistance to compression over time compared to other two cases. This could be attributed to the reinforcing effects of the added fibers, which enhance the mechanical properties of the composite material. Furthermore, the discussion touches on the mechanisms behind stress relaxation and creep behavior in polymers. Stress relaxation refers to the decrease in stress over time under a constant strain, which can occur due to physical and/or chemical phenomena. On the other hand, creep behavior involves the gradual deformation of a material under a constant load over time, and it is often attributed to molecular motion in the polymer structure.

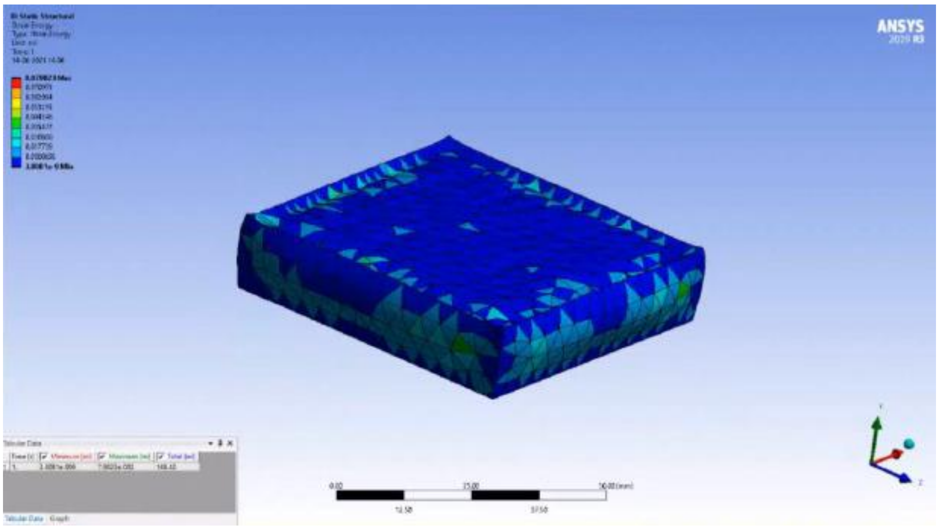
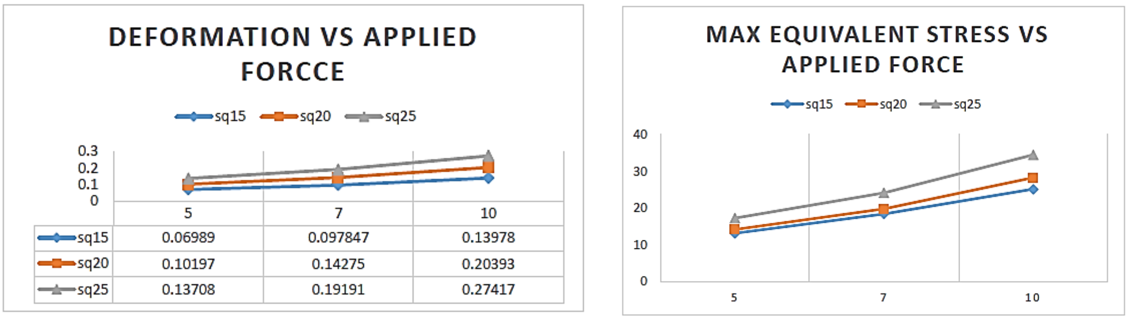


Fig 2: Strain energy distribution in the printed model



	5	7	10
sq15	0.06989	0.097847	0.13978
sq20	0.10197	0.14275	0.20393
sq25	0.13708	0.19191	0.27417

Fig 3: Analysis results

Conclusions

The present work shows the significance of utilizing a 3-D printing assembling process over customary assembling procedure preparation about its present and potential applications. The combined effective mean compression strength was found and the results were compared with the literature. The tests were conducted as per ASTM standards and the results were averaged.

The specimen size was fixed at 60x60 mm^2 with varying height of 15, 20 and 25mm to review the effect of thickness on the compressive strength of 3D printed core material. The specific energy absorption SEA was computed and compared for the specimen of square and cylindrical type. Models having fillets showed less total deformation, max equivalent strain energy and max stress in the model. Hence models with fillets more efficient in the aerospace industries. As the cross section area of square as the sandwich material is more it showed less total deformation, max equivalent strain energy and max stress in the model compared to model having cylindrical structure. Hence models with more cross section area can be chosen for higher strength of the models. Plastic materials can be in certain applications as they also provide high compressive strength with light weight of the material.

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