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Performance Probability Prediction of a Sandwich Panel with Honeycomb Core Structure

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Abstract: ***Composite sandwich panels have been increasingly used in aerospace industry for various applications such as floor panels, comportment partitions, bulkheads, and even the skin and wings. It is important to design light weight structure for aircraft operations. The sandwich panel serves this requirement. The sandwich composites are multilayered materials made by bonding stiff, high strength skin facings to low density core material. In this study, composite sandwich panels are created, tested, and assessed under various load conditions employing finite element analysis and experimental equipment. These load situations include edge wise and flat wise loading, where edgewise loads applied in the plane of the sandwich panel and flat wise loads are applied normal to the plane of the sandwich panel. The number of layers in the face sheet and core thickness are optimized without compromising strength.The designed and built sandwich panel with hexacore honeycomb structure has a 53 percent chance of being allowed for usage under severe compressive stress conditions with a 50 percent chance of core height change. With an R-squared value of 0.85, the compressive load has a fairly significant association with the side length of the hexacore. The novel methodology, Monte Carlo Simulation, was used in conjunction with both numerical and experimental methods to compute the required performance parameters, validate them, and estimate the likelihood of those values occurring during the unknown conditions of use in aerospace applications.***

Keywords: Sandwich structures, honeycomb core, composites, design of sandwich, probability prediction

1. Introduction

In the aircraft sector, composite sandwich panels are increasingly being used for floor panels, compartment partitions, bulkheads, and even the skin and wings. For aeroplane operations, it is critical to create light-weight structures. This is where the sandwich panel comes in. Sandwich composites are multilayered materials created by gluing stiff, high-strength skin facings to a low-density core. The high rigidity and low weight ratios are the key advantages of employing the sandwich concept in structural components. These constructions can carry both in-plane and out-of-plane loads and have good compression stability while maintaining outstanding stiffness and strength-to-weight ratios.

To use these materials in various applications, a greater understanding of their static behavior is required, as well as a better understanding of the various failure modes under static loading conditions. Understanding the fundamental behavior of composite structures, as well as a fair introduction to fibre reinforced polymer composites, structural optimization, and sandwich structures, is also required. It is necessary to analyze prior work in this field before constructing composite sandwich panels, as proposed in this study. In the last two decades, there has been a lot of interest in developing a sandwich panel with a honeycomb core.

The lack of a low-cost, high-strength composite sandwich panel for aerospace applications has prompted a thorough investigation. The work done in the early stages of the creation of a composite sandwich with a honeycomb core enlightens current efforts to bring rigor to its rapid development and failure mode analysis. As a result, sandwich panels are popular in high-performance applications where weight is important, such as aeronautical structures, high-speed marine vehicles, and racing cars. Skins made of composite materials are employed in the most weight-critical applications; cheaper options such as aluminum alloy steel or plywood are also widely used. Polymers, aluminum, wood, and composites are among the materials utilized for cores.

These are employed in the form of foam honeycombs or corrugated construction to save weight. Core materials can be chosen for their fire resistance or thermal qualities in addition to mechanical requirements. The most frequent, as well as some unusual, procedures used to make sandwich components for structural purposes, as well as recent innovations and future prospects in terms of both materials and processing pathways, have all been thoroughly discussed previously. Sandwich panels must meet stiffness and strength requirements. The stiffness of honeycomb sandwich panels is easy to forecast, but the strength is more difficult to measure. Face yielding face wrinkling intra-cell dimpling core shear or local indentations are common routes of failure (where the load is applied to the panel). The critical failure mode and corresponding failure load are determined by the properties of the face and core materials, as well as the geometry and loading arrangement of the structure.

A complete understanding of the mechanical behavior of both the skins and the core is required for proper sandwich structure analysis. The skins react in a fairly straightforward manner, and in the case of composite laminates, the aforementioned methods of analysis (i.e. laminated plate theory) make modelling easier. The mechanical modelling of the core material, especially for foams or honeycombs, is more difficult. It is necessary to know how the core reacts to shear loading from the skins or loading normal to the plane of the skins. The behavior is determined by the materials employed in the core as well as the core relative density, which is defined as the ratio of the core density to the density of the solid material that makes up the core. Using material selection charts, Ashby [1] worked on a material selection technique. Based on the preceding methodology, Birmingham et al. [2] have presented an integrated approach to the assessment of different materials and structural forms at the concept stage of structural design. Hull's work [3] contains a comprehensive description of the equations that regulate laminate mechanical behavior. Computer programmes (e.g. Cambridge Composite Designer [4]) based on laminated plate theory are routinely used to do stress analysis for the design of composite laminates (LPT).Miki [5] offered a very useful tool for optimizing laminate design using a graphical technique. The laminate ranking approach was developed by Tsai and Patterson [6] for determining the best ply angles. Quinn [7] has produced a composites design manual that gives engineers with useful knowledge to help them develop GRP CFRP A (aramide) RP composites. Quinn has also developed a useful nomogram [8, 9] that can be used to quickly estimate the prices of the constituent materials (fibre, matrix) in a composite.

Under shear and out of plane compression, Zhang [10] and Ashby [11] modelled the elastic and collapse behavior of Nomex honeycomb materials. Their models match their findings from trials on a variety of Nomex honeycombs. The in plane biaxial buckling behavior of Nomex honeycombs was also studied by Zhang and Ashby [12, 13]. The transverse shear modulus of a honeycomb core has been modelled by Shi et al. [14] and Grediac [15].The analysis of sandwich beams, panels, and struts has received a lot of attention, and the results have been described in the works of Allen [16] and Plantema [17]. Allen [16] proposed and Gibson and Ashby [10] developed the idea of modelling a sandwich panel as a beam with the simplifying assumptions that the skins are thin relative to the core and that the core material is homogeneous and substantially less stiff than the skin material. Triantafillou and Gibson [18] have devised an optimisation approach for determining the best skin and core thicknesses that satisfy the stiffness requirement while consuming the least amount of energy. Despite the fact that the majority of study in the literature focuses on bending loading of sandwich beams, Kwon et al. [19] and Pearce [20] have looked at the overall buckling and wrinkling of sandwich panels under in-plane compression. Local failures in sandwich structures, according to Meyer-Piening [21], are frequently caused by designers' lack of awareness of important aspects such as displacement distribution through the thickness, axial forces in the face sheets, and the difference between the vertical deflections of the upper and lower face sheets. Design modelling and experimental characterization of a FRP honeycomb panel with sinusoidal core geometry in the panel and extending vertically between face laminates were given by Juli F Davalos and Pizhongqiao [22]. The test sample is subjected to finite element modelling. The result is highly correlated with analytical predictions and experimental values, resulting in excellent results matching.

Reis, Sami, and Engin M. The material characteristics of 3D FRP sandwich panels were presented by H. Rizekalla. [23]. This paper investigated the flexural, shear, tensile, and compressive behavior of sandwich panel face sheets made of FRP and GFRP with foam core and thick fibres connecting the top and bottom face sheets. It summarized an extensive experimental programme that discussed many parameters to evaluate sandwich panel behaviors. Different thermal conductivities in sandwich composites were studied by J. Noack and R. Rolfes [24]. The results of a new layer wise theory for heat conduction in hybrid structures are good matches with test results. A. Petras [25] used the honeycomb mechanism and classical beam theory to analyze failure modes in sandwich beams. The experimental results are consistent with the theoretical predictions. T. Y. Kam and F.M. Lai [26] investigated experimental and theoretical approaches for determining the first ply failure strength of laminated composite plates under a variety of loading circumstances. The first ply failure strength of the plates is predicted using a finite element analysis based on the layer-wise linear displacement theory and the Tsai-Wu failure criterion. When the experimental and theoretical results are compared, there is a lot of agreement. Sun et al. [29] studied the structural parameters of honeycomb-core sandwich panels and Bohara [30] et al. [30] have contributed to the understanding of Performance of an auxetic honeycomb-core sandwich panel.

The work on design and fabrication of composites poses a substantial problem in successfully implementing in aerospace applications in particular, according to a review of the literatures collected and evaluated thus far. There are other areas in this specific field of PMC that need to be investigated in order to develop a better material for UAVs with difficult operating conditions. As a result, our research aims to better understand the material's design and construction before applying it to the production of UAVs.

Numerical Model Set Up and Experimental Validation

One of the research's goals is to create a sandwich panel with a honeycomb core. As a result, the initial step is to design the sandwich panel. The details of a model's design are given here. Finite element analysis is performed using the model.

Design details of the model

According to ASTM, the model's measurements are 150 mm x 26.4 mm x 26.4 mm. Aluminium is used for the core. The core, which is a honeycomb structure, is 26.4 mm thick and has a Young's modulus (E) of 70 GPa and a Poisson's ratio (v) of 0.33. The sandwich panel's face plate is built of EPWM with an E of 49 GPa, a cell thickness of 0.06 mm, a faceplate thickness of 0.55 mm, and a honeycomb side thickness of 3 mm. Its top perspective and internal layout, as well as a transparent view of the sandwich panel with honeycomb core, are illustrated in Figure.1.

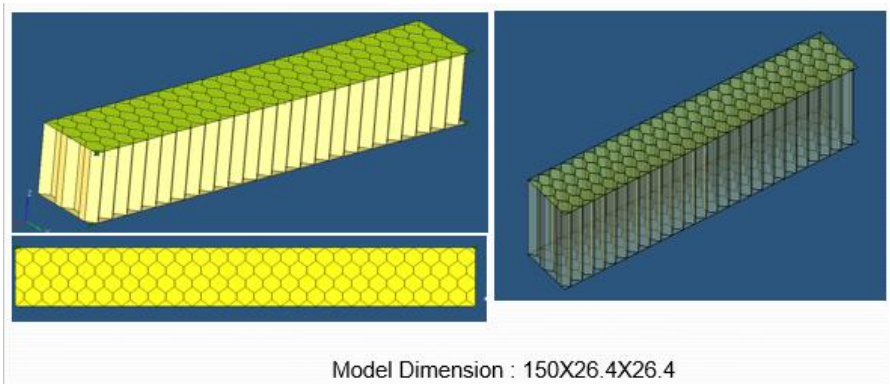

Figure 1: Full scale geometry of sandwich panel model with Aluminum core

The geometry was created with CATIA V5 R17, a CAD programme that allows for more flexibility when creating surfaces with complex geometry. As a result, the model was built utilising the above-mentioned CAD programme and the above-mentioned measurements. Geometry development is one of the most significant aspects of FE analysis, since the quality of the cleaned geometric model has a direct impact on the FE analysis result. So, using CATIA V5, the full model was created according to the dimensions listed above. The interior core layout is seen in Figure.2 along with its dimensions.

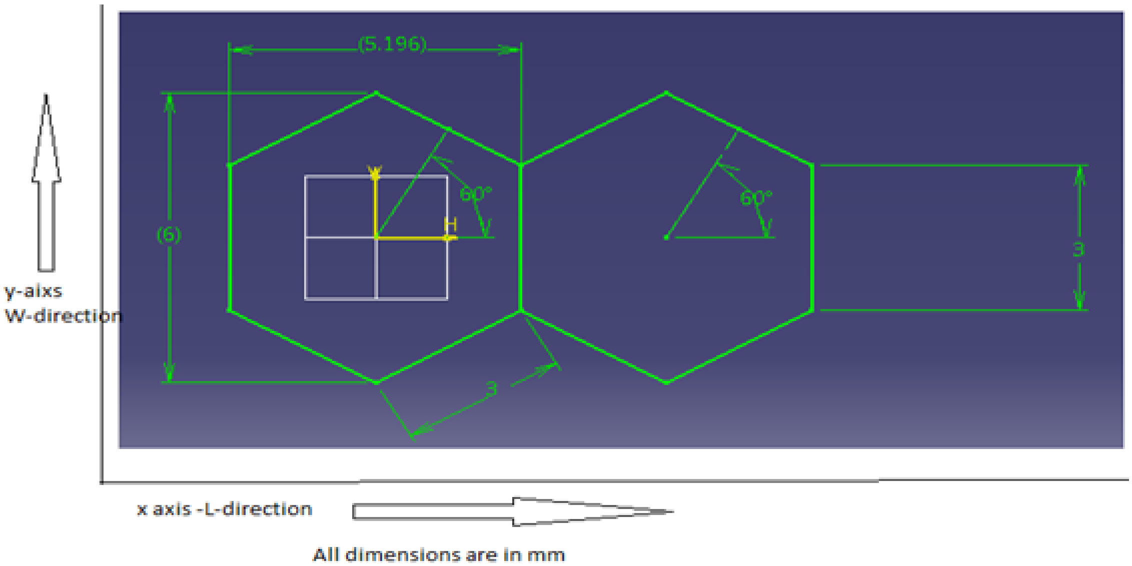

Figure 2: Dimensions of honey comb core in mm in detail

Finite Element (FE) Modeling

The prepared geometry was imported into ANSYS Mechanical APDL during the FE modelling phase, and the preference was set to structural analysis. The geometry was then divided into three parts (IGES format): the top face plate, the bottom face plate, and the core. The material parameters for the study are defined at this step based on the needs of the sandwich honeycomb core composite analysis, which comprises of a face plate epoxy polymer woven mat (EPWM) and an aluminium core. Table 1 lists the materials and their qualities.

Materials and their properties

Table 1: Material properties used in sandwich panel's FE analysis

Serial No.	Material	F_{tu}, MPa	F_{ty}, Mpa	F_{cy}, Mpa	F_{su}, Mpa	E, Gpa	G, GPa	Density, Kg/m^3	Poisson's ratio (v)
1	Aluminum core	427	275	275	255	72	27	2795	0.33
2	EPWM	--	--	--	--	47	13	1883	0.35

The core is made of aluminium generated as an isotropic material, while the second material model for EPWM was created with the linear orthotropic and all the material constants were allocated according to the above-described table.

The experimental setup and the honeycomb-structured 3D printed sandwich panel

For varied loading circumstances of the sandwich panel, the experimental setup-beam test set up, shown in Figure.3 (a), was adopted. A honeycomb-structured 3D printed sandwich wing panel with a hexagonal honeycomb structure sandwiched between top and bottom panels was used for the experiment, as illustrated in Figure 3 (a). The specimen, shown in Figure.3 (b) is made to scale with the FE model.

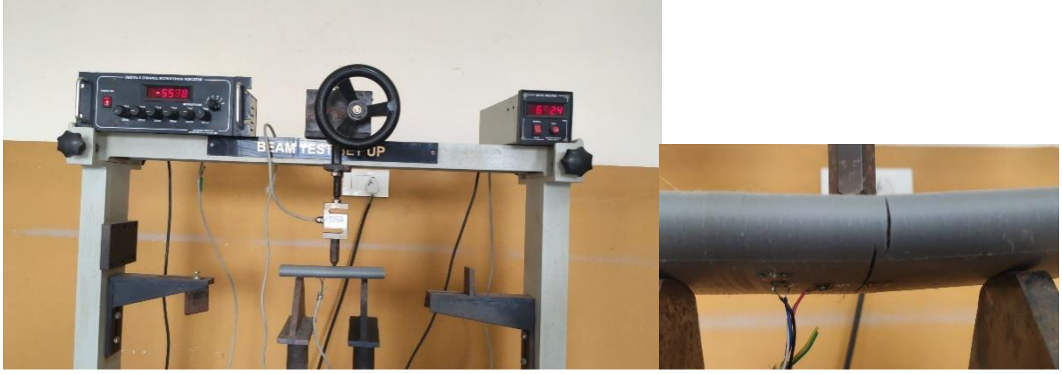

Figure 3 (a): The experimental set-up used for the testing of honeycomb-structured 3D printed sandwich panel

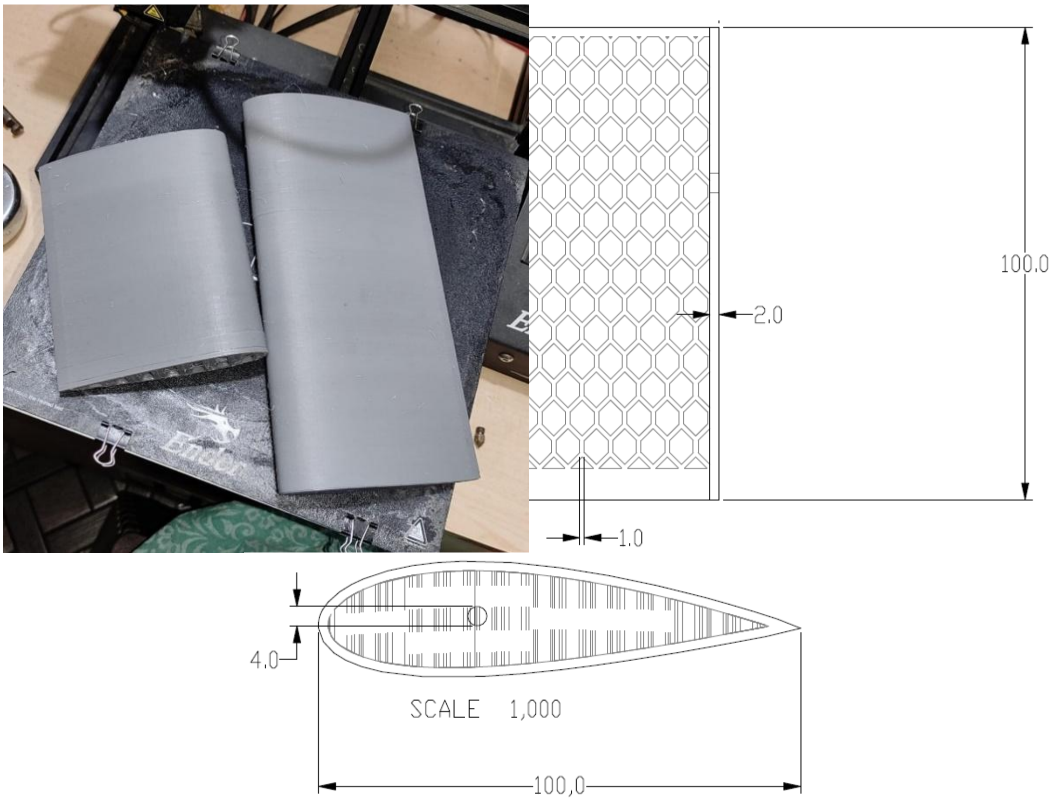

Figure 3 (b): Honeycomb-structured 3D printed sandwich panels used in the above experimental setup

Figure.4shows the plots for comparison of load versus stress distribution, Figure.4depicts plots for comparison of load versus % strain variation, Figure.5shows plots for comparison of load versus displacement and % strain variation. These comparisons are made between the results obtained from FE analysis and the results published in the literature, Ref [27]. In the reference, the results were noted from the tensile test done on the same specimen as per ASTM standard. The trend of the plot shows that there is fairly good matching between the FE prediction and experiment. The matching is fairly well.

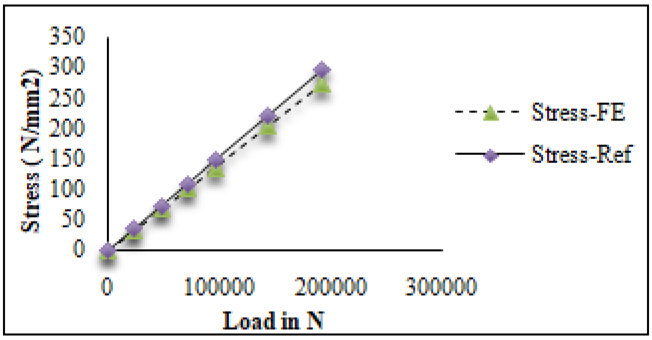

Figure 4: Plots for comparison of load vs stress variation between FEA predicted values and that of the Ref [27]

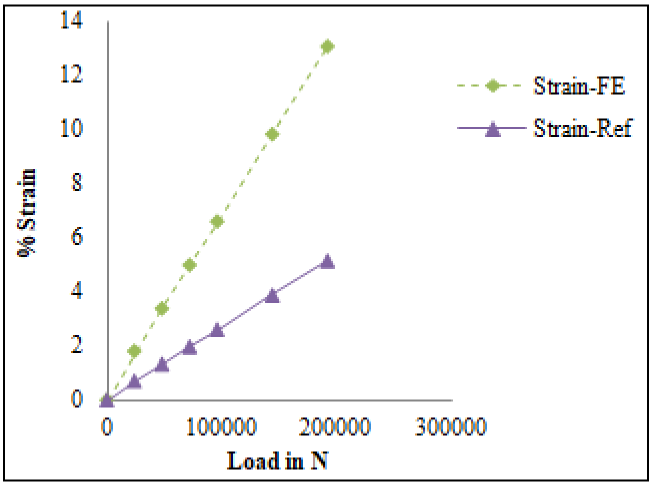

Figure 5: Plots for comparison of load vs % strain variation between FEA predicted values and that of the Ref [27]

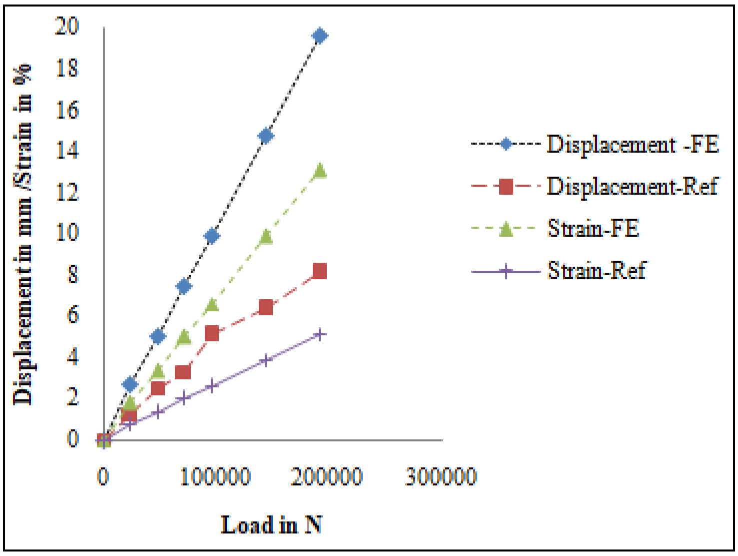

Figure 6: Plots for comparison of load vs. displacement & % strain variation between FEA predicted values and that of the Ref [27]

Flat wise compression strength (σ) and Elastic Modulus (E_c) of honeycomb structure

In the Figure. 7 is shown the description of a unit cell of hexagonal honeycomb structure.

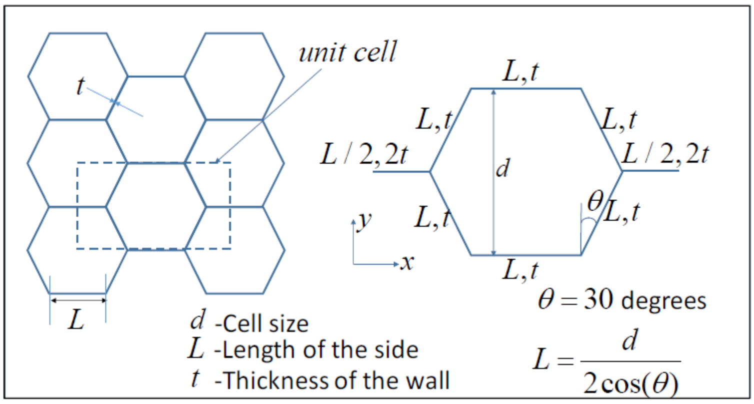

Figure 7: Description of a unit cell, Ref [28]

The flat wise compression strength, $\sigma = \frac{P}{L^2}$, where P is maximum failure load the structure can bear under the unit area and $E_c = \frac{(P_{60\%}-P_{30\%}).h}{\nabla h_c L^2}$ is the flat wise compression modulus of elasticity of sandwich structure. In the equation mentioned above, $P_{60\%}$ and $P_{30\%}$ are 60% and 30% failure loads, L is the side length of test piece and ∇h_c is the displacement increment. Figure.8 shows the variation of compression load with the side length of the test piece (L). The strong correlation (R-squared =0.84) between maximum failure load and side length is observed in the plot. That means the regression model fits well into the data of P and L

. So, the design of sandwich panel will have P and L as important variables. For different P values (expressed in %), the compressive strength, σ, has been plotted against the side length of core, L in the Figure.9.The compressive strength is the higher (by 3 times) than that at the lowest side length.

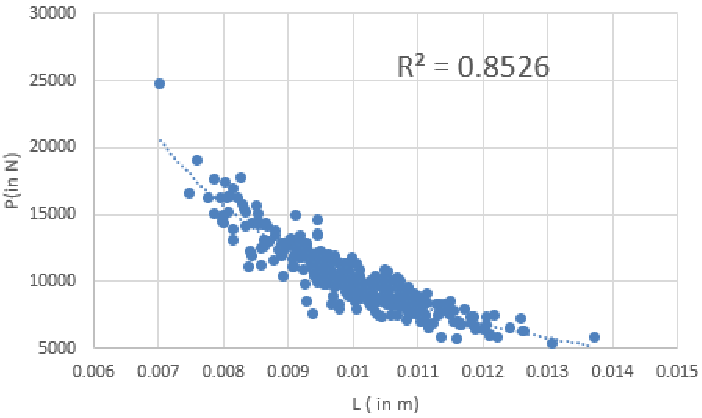

Figure 8: Variation of compression load with the side length of the test piece (L)

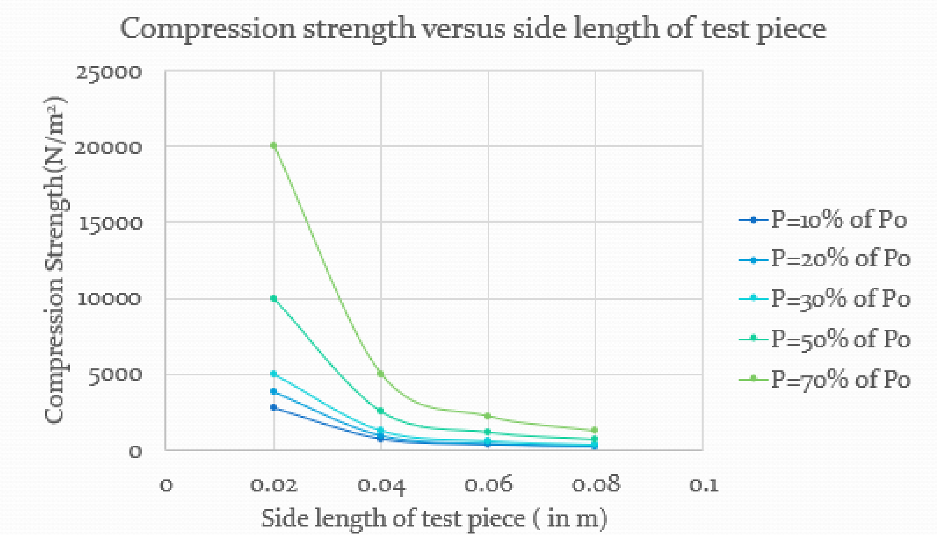

Figure 9: Variation of compression strength with the side length of the test piece (L) for different P

Figure.10 shows the variation of compressive modulus of elasticity, E_c with respect to the height of honeycomb structure, h. It is noted from the plot that E_c is almost 5 times higher at $P_{10\%}$ than that at $P_{50\%}$.

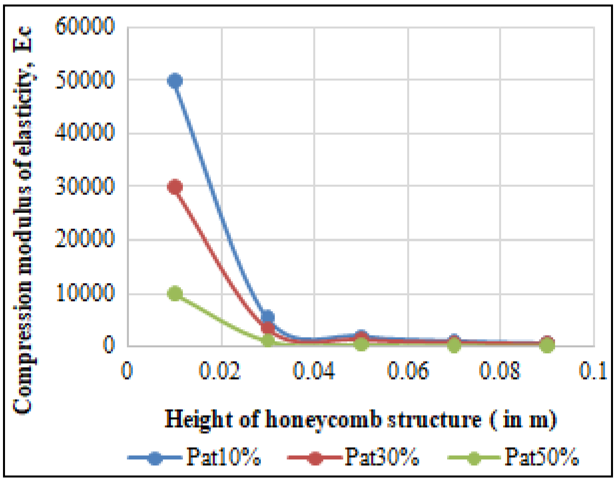

Figure 10: Variation of compression modulus of elasticity with height of the honeycomb structure

Figure.11 shows the variation of compressive modulus of elasticity, E_c with respect to the rise in honeycomb core height, Δh for different increments of L (measured in %). For the side length increase by 10% , E_c shoots up by almost 20 times of its value noted when the side length increase by 50%.

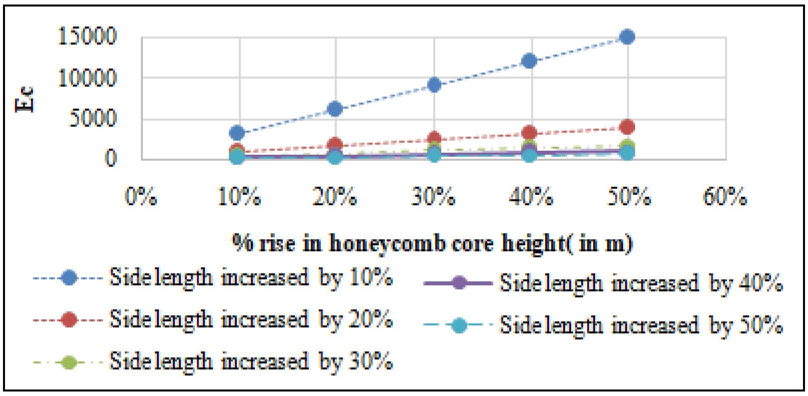

Figure 11: Variation of E_c with % rise in honeycomb core height

Figure.12 shows the likelihood of acceptance of performance parameters of honeycomb-structured laminate for different uncertain conditions under which it will operate. The probability of acceptance of σ beyond 10 KPa is almost 53%. In the same way, the probability of acceptance of other parameters such as E_c (being negative) , P (greater than 1 N) and Δh (longer than 0.001 m) are 16%, 49% and 50% respectively.

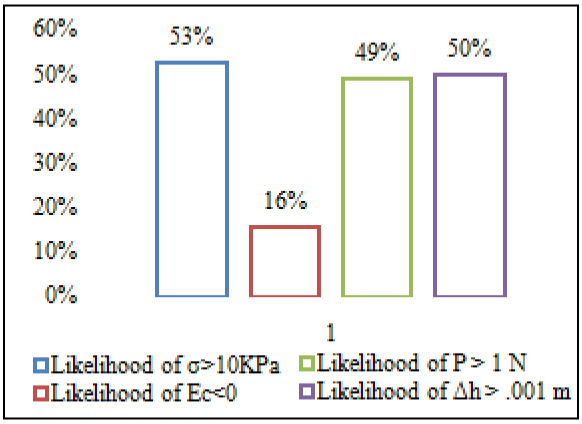

Figure 12: Likelihood of σ, E_c, P and Δh being accepted for use

Flexural Stiffness (D)

The flexural stiffness, $D = \frac{l^2 a.\Delta P}{16.f_1}$, where l is the span length, a is the overhanging length of specimen, ΔP is the load increment value of the initial section of the curve, f_1 is the deflection increment value of overhanging point (the average of left and right points) has been computed for the same specimen and matched with the experimental values of the piece. From the plot shown in the Figure.13, it is noted that the flexural stiffness at f1=0.002 is almost 2 times higher than that at f1=0.006 for a specific span length and when a is fixed.

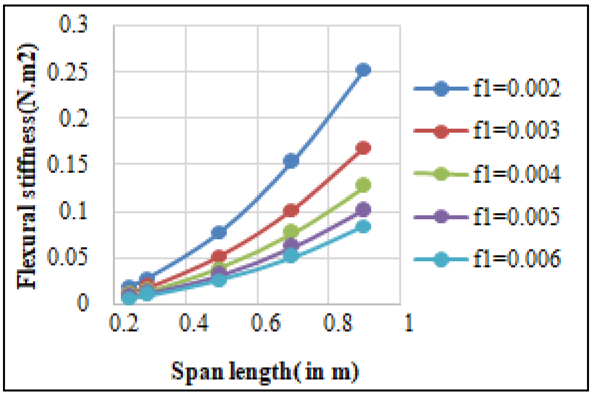

Figure 13: Variation of flexural stiffness with respect to span length

From the plot shown in the Figure.14, it is noted that the flexural stiffness for ΔP=5.0 is almost 4 times higher than that at ΔP =1.0 for a specific deflection increment.

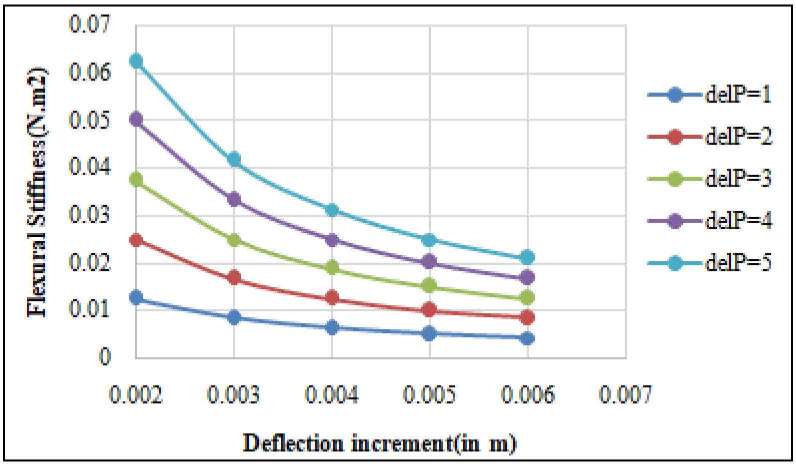

Figure 14: Variation of flexural stiffness with respect to deflection increment

2. Conclusions

In this study, the performance probability parameters of a sandwich panel with honeycomb core structure were calculated. To compute the parameters, FEA (Finite Element Analysis) was used, followed by a validation of the essential parameters using previously published data. Experiments were carried out on a honeycomb-structured panel that was 3D printed. The anticipated compressive strength and flexural stiffness values for various operating circumstances of the panel were then computed. Under extreme compressive stress conditions, the planned and produced sandwich panel with hexacore honeycomb structure has a 53 percent chance of being approved for use, with a 50 percent possibility of core height change. To compute the required performance parameters, validate them, and predict the likelihood of those values occurring during the unknown situations, Monte Carlo Simulation was used in conjunction with both numerical and experimental methods. At P10 percent, the E_c is over 5 times more than that at P50 percent. E_c increases by nearly 20 times when the side length is increased by 10% compared to when the side length is increased by 50%. For a given deflection increment, the flexural stiffness of P=5.0 is nearly 4 times higher than that of P =1.0. It has been stated that an unmanned aerial vehicle (UAV) wing is suitable for use.

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