Experimental Study of a Honeycomb Structured 3D Printed Sandwich Panel

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***Abstract*—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 glueing stiff, high-strength skin facings to a low-density core. Using finite element analysis and experimental equipment, composite sandwich panels are constructed, tested, and evaluated under various load circumstances. Edge wise and flat wise loading, where edgewise loads are applied in the plane of the sandwich panel and flat wise loads are applied normal to the plane of the sandwich panel, are examples of these load conditions.**

Without sacrificing strength, the number of layers in the face sheet and core thickness are optimised. The fluctuation of stresses with respect to loads put on a 3D printed sandwich panel with a hexagonal core was investigated in an experimental investigation. For a loading range of 1 - 60 kg, strains in both the x- and y-directions of the panel show a mean difference of 0.28. The standardised values of the strains were used to compare them using Bayesian Estimation, which outperforms the t Test.

***Index Terms*—Sandwich structures, honeycomb core, composites, design of sandwich, experiment.**

I. INTRODUCTION

Composite sandwich panels are increasingly being employed in the aircraft industry for floor panels, compartment dividers, bulkheads, and even the skin and wings. The creation of light-weight structures is crucial for aeroplane operations. The sandwich panel is used in this situation. Sandwich composites are made by attaching stiff, high-strength skin facings to a low-density core. The sandwich concept's main advantages in structural components are its high stiffness and low weight ratios. These structures can support both in-plane and out-of-plane loads, and they have excellent compression stability while maintaining high stiffness and strength-to-weight ratios. To use these materials in a variety of applications, a deeper understanding of their static behaviour, as well as the numerous failure modes under static stress circumstances, is essential. It's also necessary to have a basic understanding of composite structure behaviour, as well as a basic understanding of fibre reinforced polymer composites, structural optimization, and sandwich structures. Before manufacturing composite sandwich panels, as proposed in this paper, it is required to review previous work in this subject. There has been a lot of interest in building a sandwich panel with a honeycomb core over the last two decades.

A detailed analysis was sparked by the lack of a low-cost, high-strength composite sandwich panel for aerospace applications. The work done in the early stages of developing a honeycomb core composite sandwich illuminates ongoing efforts to bring discipline to its rapid development and failure mode analysis. As a result, sandwich panels are widely used in high-performance applications requiring low weight, such as aeronautical constructions, high-speed marine vehicles, and racing cars. In the most weight-critical applications, composite skins are used; however, less expensive choices such as aluminium alloy steel or plywood are also extensively used. The materials used for cores include polymers, aluminium, wood, and composites. The materials used in the core, as well as the core relative density, which is defined as the ratio of core density to the density of the solid material that makes up the core, determine the behaviour. Ashby [1] developed a material selection technique using material selection charts. Birmingham et al. [2] have proposed an integrated approach to the assessment of different materials and structural forms at the concept stage of structural design based on the prior methodology. Hull's work [3] provides a thorough explanation of the equations that govern laminate mechanical behaviour. Stress analysis for the design of composite laminates is frequently performed using computer programmes based on laminated plate theory (e.g. Cambridge Composite Designer [4]) (LPT). Miki [5] provided a very effective graphical technique for optimizing laminate design. Tsai and Patterson [6] established the laminate ranking method for selecting the optimal ply angles. Quinn [7] has created a composites design manual that provides engineers with valuable information for developing GRP CFRP A(aramide)RP composites. Quinn has also devised a useful nomogram[8,9] for estimating the pricing of the constituent materials (fibre, matrix) in a composite fast.

Zhang[10] and Ashby[11] modelled the elastic and collapse behaviour of Nomex honeycomb materials under shear and out of plane compression. Their models correspond to the results of tests on a variety of Nomex honeycombs. Zhang and Ashby[12,13] investigated the in plane biaxial buckling behaviour of Nomex honeycombs. Shi et al.[14] and Grediac[15] modelled the transverse shear modulus of a honeycomb core. The analysis of sandwich beams, panels, and struts has gotten a lot of attention, and the results have been published by Allen[16] and Plantema[17].Triantafillou and Gibson[18] developed a method for identifying the optimal skin and core thicknesses that meet the stiffness criteria while using the least amount of energy. Despite the fact that most research in the literature focuses on bending loads of sandwich beams, Kwon et al.[19] and Pearce[20] investigated overall buckling and wrinkling of sandwich panels under in-plane compression. According to Meyer-Piening [21], 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 frequently causes local failures in sandwich structures. Juli F Davalos and Pizhongqiao [22] presented design modelling and experimental characterization of a FRP honeycomb panel with sinusoidal core geometry in the panel and extending vertically between face laminates. Finite element modelling is applied to the test sample. The outcome is closely correlated with analytical predictions and experimental values, resulting in excellent match results. Some of the interesting contributions pertinent to the present research are published in Refs.[23-25].

According to a survey of the literatures collected and appraised thus far, work on composite design and manufacturing offers a significant difficulty in successfully implementing in aeronautical applications in particular. Other aspects in this topic of PMC need to be explored in order to build a better material for UAVs operating in harsh environments. As a result, our research intends to gain a deeper understanding of the material's design and construction before using it to make UAVs. The purpose of this research is to use experimental methods to investigate panel behaviour and material properties, as well as to evaluate the quality of a honeycomb structure sandwich panel for UAV applications.

II. EXPERIMENTAL SET UP

The experimental setup - beam test set up, depicted in Figure., was used to test the sandwich panel under various loading conditions. The experiment used a honeycomb-structured 3D printed sandwich wing panel with a hexagonal honeycomb structure sandwiched between top and bottom panels, as shown in Figure.1(a). The model's dimensions are 150 mm x 26.4 mm x 26.4 mm, according to ASTM. The core is made of aluminium. The honeycomb structure's core is 26.4 mm thick, with a Young's modulus(E) of 70 GPa and a Poisson's ratio(μ) of 0.33. EPWM (Epoxy Polymer Woven Mat) is used to make the sandwich panel's face plate, which has 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. The specimen in Figure.1(b) is made to scale with the original FE model, which is described in detail above.).

Figure. 1(a) The experimental set-up used for the testing of honeycomb-structured 3D printed sandwich panel

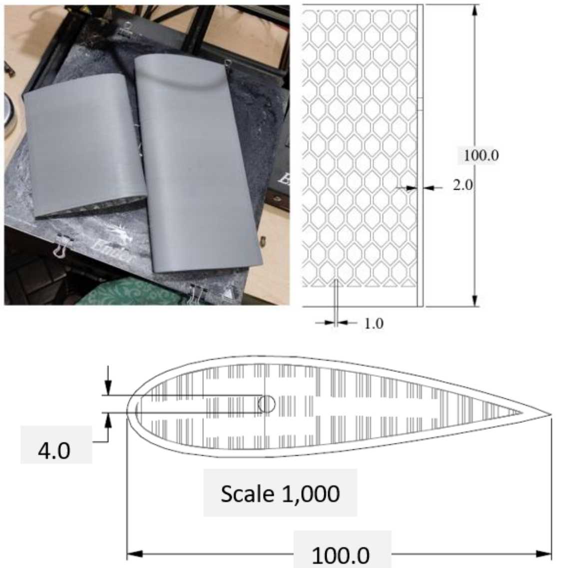

Figure. 1(b) Honeycomb-structured 3D printed sandwich panels used in the above experimental setup

In the Figure. 2 is shown the description of a unit cell of hexagonal honeycomb structure. This gives the foundational understanding of the core used in the specimen. The specimen is 3D printed and used in the experiment.

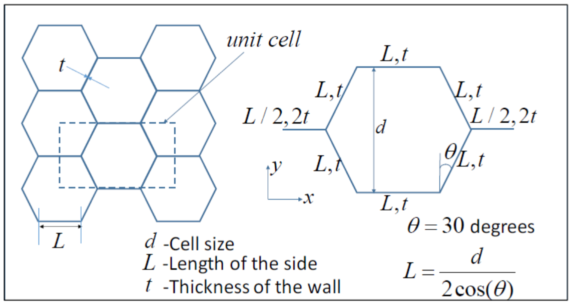

Figure.2 Description of a unit cell, Ref[23]

Figure. 3 shows the plots for comparison of load versus stress distribution, Figure.3 depicts plots for comparison of load versus % strain variation, Figure.4 shows 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 [24]. 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.

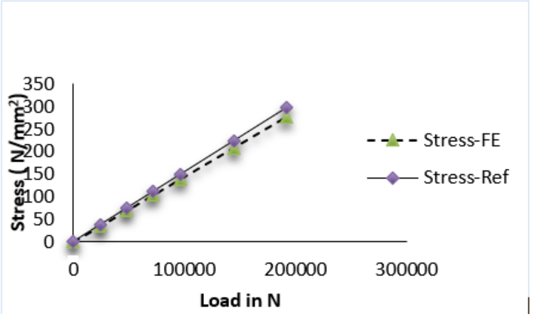

Figure.3 Plots for comparison of load vs stress variation between FEA predicted values and that of the Ref [24]

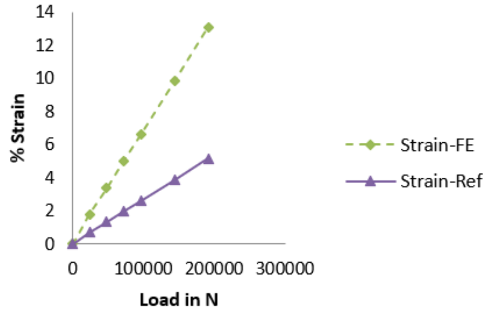

Figure.4: Plots for comparison of load vs % strain variation between FEA predicted values and that of the Ref [24]

In the Figure.5 is shown the comparison of three different stresses such as average stress, true stress and stress obtained from the experiment at a specific strain rate for the hexagonal composite core. Though the difference exists among them the linearity of strain and strain relation is observed in all the cases.

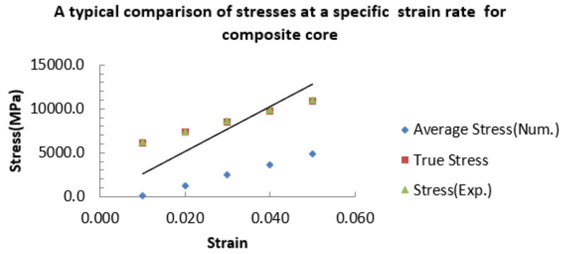

Figure.5 Comparison of three different stresses with respect to stain for the same specimen

The Figure. 6 depicts the comparison of the displacement and strain computed from numerical simulation with the displacement and strain calculated from experiment. Differences do exist between the displacements and between the strains, however, the trend is quite satisfying. Due to the experimental challenges the exact numerical conditions were not created but the loading and displacements were equivalent. The reference value published in the literatures and the values computed during the present study have difference.

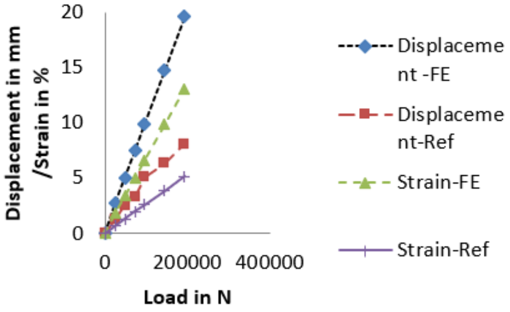

Figure. 6 Plots for comparison of load vs displacement & % strain variation between FEA predicted values and that of the Ref [24]

The Figure. 7 shows the variation of strains in both x- and y-directions during the gradual loadings of the specimen. It is noted that there is difference between the two types of strains observed both at lower and higher values of loads but the trend of their variations was quite interesting. The proof of the difference between the means (0.28) of the strains were depicted in the Figure.8. It means that for the same loading the strain in x is more than that in the y-direction of the specimen.

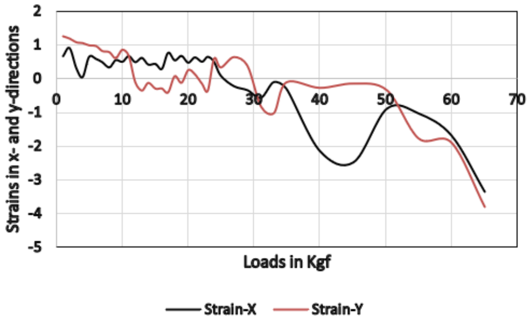

Figure.7 shows the variation of strains in both x- and y-directions

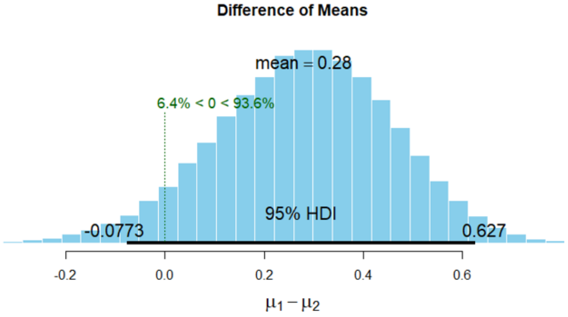

Figure. 8 Difference of means between the strains in x- and y-directions of the same specimen

After the experiment, it was deemed to visualise the distribution of strains in x- and y-direction. Before the experiment it was thought that the distribution of the strains under the loading would be linear in nature. However, the post experiment data distribution of both the strains in the x- and y-directions was flound to be normal . The blue lines are data and the red lines are the posterior distribution of the same data. Group 1 and Group 2 indicate the data of strains in x and y directions, respectively. The mean strains are concentrated around -1 and 1. The y-axis is the density of the posterior distribution. In the Figure.9 is shown the posterior distribution of strains calculated from the experiment.

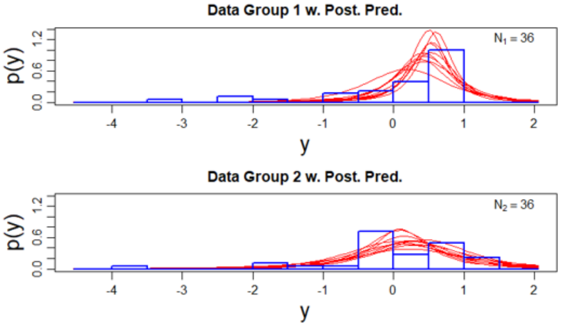

Figure.9 The posterior distribution of data of strains in x- and y-directions

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

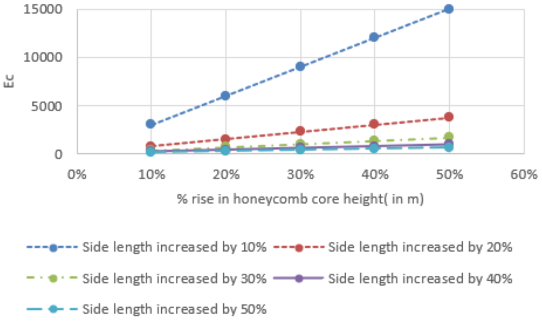

Figure.10 Variation of Ec with % rise in honeycomb core height

The flexural stiffness, D=(l^2 a.ΔP)/(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.11, 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.

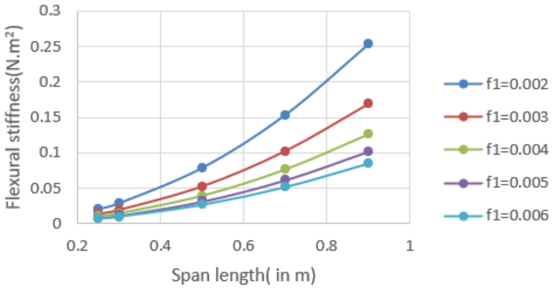

Figure.11 Variation of flexural stiffness with respect to span length

III. CONCLUSIONS

Experiments were conducted out on a 3D-printed honeycomb-structured panel. The panel's expected compressive strength and flexural stiffness values were then calculated for various operating conditions. Edge wise and flat wise loading, where edgewise loads were applied in the plane of the sandwich panel and flat wise loads were applied normal to the plane of the sandwich panel, are examples of these load conditions. For a loading range of 1 - 60 kg, the stresses in both the x- and y-directions of the panel indicate a mean difference of 0.28. The standardised values of the strains were used to compare them using Bayesian Estimation, which outperforms the t Test.

Ec 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 span length and when an is fixed, the flexural stiffness at f1=0.002 is nearly 2 times higher than that at f1=0.006. Although there are differences in the displacements and strains, the overall trend is fairly pleasing. The exact numerical conditions were not produced due to the experimental challenges, but the loading and displacements were equal.

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