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| Author(s) | Dikshit, Vishwesh; Prasanth, N. A.; Kumar, J. D.; Yap, Yee Ling; Agarwala, Shweta; Yeong, Wai Yee |
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# OUT OF PLANE COMPRESSIVE STRENGTH OF 3D PRINTED VERTICAL PILLARED CORRUGATED CORE STRUCTURE

V. DIKSHIT, N. A. PRASANTH, J. D. KUMAR, YAP Y.L., S. AGARWALA, W. Y. YEONG
*Singapore Centre for 3D Printing, School of Mechanical and Aerospace Engineering, Nanyang Technological University, 50 Nanyang Avenue, Singapore 639798*

**ABSTRACT**: Out of plane compressive strength of the two new type 3D printed sandwich core structure has been investigated. The test specimens were designed in Solidworks and manufactured in Projet 5500X 3D printing machine with the combination of pure ABS and Rubber (Visijet CR-WT & Visijet CF-BK) material to form a different composite series of material named as RWT-FBK 100 plastic were used as material for making the sandwich core panel. Two design samples, each of 5 test specimen were carried out for flatwise compression test in accordance with ASTM standards C365/C365-M. The experimental results would indicate the ultimate flatwise compressive strength $F_Z^{fcu}$ and flatwise compressive modulus $E_Z^{fc}$.

**KEYWORDS:** 3D printing , Flatwise compression test, Lattice, Ttruss, Sandwich

## INTRODUCTION

Sandwich panels were being used for structural and industrial application for many years since 1940. Due to the astonishing properties of sandwich panels, it was being welcomed by many engineering applications like fashion, aerospace, marine and etc (Lee et al., 2016; Yap et al., 2014; Yeong et al., 2005). Till date, there were lots of advancements and researches were going on with sandwich structures to improve the property by reducing its weight and defects (Khoo et al., 2015; Yap et al., 2014, 2015). The traditional sandwich panels were laminated composites and has the separate core and skin, which would be bonded together by the epoxy/resin. The most familiar sandwich panels for aerospace and structural application where a metal matrix composite panel like balsa wood, foam, aluminum honeycomb sandwich, CFRP, GFRP and etc. The new age sandwich structure i.e. 3D printed sandwich panel are now a days getting very familiar in engineering application for recent years (Zhang et al., 2012). Keeping this as an axiom and the scope of sandwich panel, this research has been conducted to revolutionize the additive manufacturing and let to know the importance of it as well as complex things that can be done through the prototyping process(Foo et al., 2007). The main purpose of this study is to find out the ultimate flatwise compressive strength $F_Z^{fcu}$, deflection stress $\sigma_z^{f0.002}$ and flatwise compressive modulus $E_Z^{fc}$ by conducting flatwise compression test on the 3D printed truss like sandwich panel. The result of this test shows the greater load bearing capacity of the panel to withstand heavy load and vibrations. 3D printing finds extensive application in all around and all the areas to capture a permanent place in the industrial market (Dou et al., 2016). 3D printing/Additive manufacturing may have the chance to replace the traditional manufacturing process (Zhang et al., 2013). The property of having high bending stiffness and high compressive strength-to-weight ratios made the researcher for the use of honeycomb topology method to deal with cellular core like structures (Borsellino et al., 2004). Lattice truss structures have been discovered as a substitute for cellular core topology for recent years (Davalos et al., 2001; Dou et al., 2016; Foo et al., 2007; Giglio et al., 2011). The utmost importance in sandwich panel is the design of core–facesheet node interface. Ultimately, this delivers the maximum load that can be shifted from the facesheets to the

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core. Failure at node-bond has been recognized as a failure mode for sandwich structures, particularly for metallic honeycombs (Kujala et al., 2002). These works on the cellular core topology on metals gave us an idea to enter our research into a plastic model of cellular core with truss shaped like structure to withstand the distributed force on the sandwich panel.

Material, shape, structure and its properties decide the strength of the sandwich panel when it particularly comes to plastic composite. An in-depth investigation was done on deciding the composite material series and finally come up with a rigid type of composite material RWT-FBK 100 for both the design samples. The determination of compressive strength and the coparameters were so obtained by conducting the compressive test on INSTRON 5500R ultimate tensile testing machine by following the ASTM C365/ C365-M standard test procedure. This paper will describe about the new age sandwich panel to enhance easy manufacturing and will reduce the complexity of making sandwich structure without compromising the light weight factor and stiffness. A detailed experimental study was conducted to project the complete behavior of the new age sandwich panel and the results were compiled.

## MODELING, MATERIAL AND MANUFACTURING

### *Geometric modeling of core*

The geometry of the sandwich panel has been designed in such a way that should withstand greater load bearing capacity. Two different types of samples were designed by two ideas, the former is the vertical pillar corrugated sine wave cellular truss core and later is the vertical pillar corrugated trapezoidal cellular truss core. Various designs were considered in the selection process and out of 15 designs, these two designs had been selected for specific reasons and the mathematical calculations behind it. Figure 1and 2 shows the single segment of the designs which were further developed to form a fully developed sandwich structure.

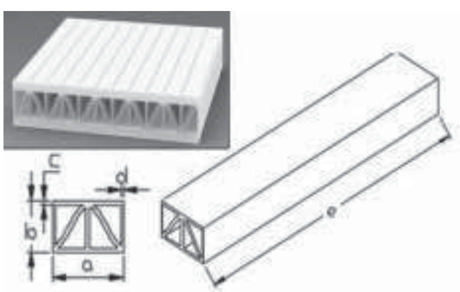


Figure 1 Vertical pillar corrugated sine wave structure

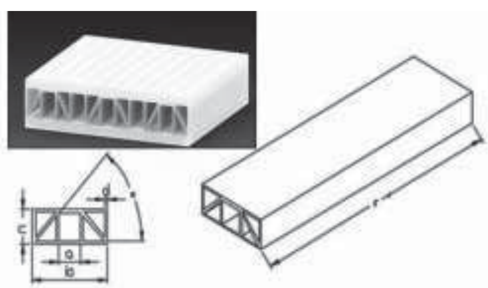

Figure 2 vertical pillar corrugated trapezoidal

Table 1 shows the dimensions of cellular core segments. The traditional sandwich panels were made by manufacturing the core and skin separately and they both were joined with the help of epoxy/resin, but in the new age sandwich structures, both the face sheet and core were manufactured together in a single machine by the variety of resins. The surface finish was found good and realistic which can be used directly for some specific applications after printing, post processing and cleaning. This process of making the sandwich panel ensures that it is cheap, economical and worthwhile for particular applications in complex core manufacturing. The cost of using the epoxy/resin will considerably get reduced and the curing process time of sandwich panel will also be neglected.

Table 1 Shows the dimensions of cellular core segments

| Designs | Dimensions (in mm) | | | | | |
|---|---|---|---|---|---|---|
| | a | b | c | d | e | f |
| Vertical pillar corrugated sine wave structure | 18 | 12 | 1 | 0.5 | 100 | - |
| Vertical pillar corrugated trapezoidal structure | 8 | 28 | 12 | 1 | 45˚ | 100 |

***Manufacturing of sandwich panel***

The sandwich panels were manufactured by using the high performance 3D printing machine Projet 5500X. 3D Systems' ProJet® 5500X brings the premier quality, most accurate and toughest multi-material composites based on 3D Systems' latest MultiJet Printing (MJP) technology. The ProJet 5500X prints and fuses together flexible (Black rubber) and rigid material (ABS) composites layer by layer at the pixel level. After the design were done in Solidworks, it has been converted to .STL file and imported in Geomagic 3D systems' software for selecting the composite materials, preview and alignment. There is a wide range of composites that the machine could print but as a matter of fact only one variance composite were used for this analysis. Both designs, around ten specimens were printed using RWT-FBK 100 material (Table 2) which was the combination of pure ABS-Black Rubber (Visijet CR-WT & Visijet CF-BK). At last post processing were done to remove the support material (wax).

Table 2 Shows the properties of the composite material RWT – FBK 100

| Material | Appearance | Density @80˚C (Liquid), $g/cm^3$ | Tensile Strength, MPA | Tensile Modulus, Mpa | Elongation at break, % |
|---|---|---|---|---|---|
| ASTM | - | D - 4164 | D - 638 | D - 638 | D - 638 |
| Visijet RWT-FBK100 | Very Light Grey | 1.04 | 36 | 1650 | 10 |

**EXPERIMENTATION**

***Setup and observation of specimen behavior during testing***

The round base loading platen for compression test were attached to the INSTRON 5500R universal testing machine and the machine were calibrated with reference to ASTM standards. All the specimens were checked for its dimensions and maintained the sizes up to the accuracy as per ASTM standards as length and width were maintained within 250 microns variations say 100.021 mm and the thickness were maintained within 13 microns say 16.043 mm. As the color of the base plates and the test specimen were looks similar the thickness side surface were painted with green and blue color to get a clear picture of crushing of the sandwich panel. The test was carried out at the speed of 0.5 mm/min. During the test, a slight deformation of the test specimen was noted and further in time of the failure of test specimen, the crushing sound was clearly noted. The expected parameters like compressive load and displacement were recorded by the machine. The predictable experimental graphs were obtained through the test.

***Measurement of mechanical response***

The expected result like compressive strength and compressive modulus were noted and investigated in this paper. The maximum compressive load was noted as 39.364 kN and the maximum compressive extension at failure were noted as 1.05834 mm for the vertical pillar corrugated sine wave core sandwich panel and 34.492 kN were noted as the compressive load and 0.658 mm as a compressive extension failure after deducting the initial displacement, then from the experiment the graph were plotted for detailed investigation.

## RESULTS AND DISCUSSION

In the first design, all the test samples were tested by following the normal axial compression test procedure as per ASTM 365/365M so in the load Vs displacement graph, the initial region called toe compensation were given to the model to get the chord slope. Later, the shifting of the graph from the original co-ordinates to the left side which were done meeting at a point of zero at the displacement to get a clear picture of chord slope (Figure 4). In the second design samples, the initial displacement was compensated in the machine itself and so the resulted graph was starting from the zero at the displacement with an initial force was noted (Figure 5). Variation of compressive modulus and compressive strength are shown in Figure 6 and 7.


Figure 4 Load Vs Displacement of the vertical pillar corrugated sine wave samples

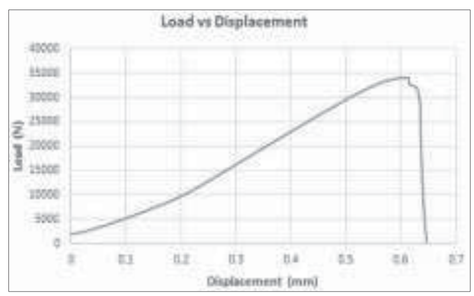


Figure 5 Load Vs Displacement of the vertical pillar corrugated trapezoidal samples

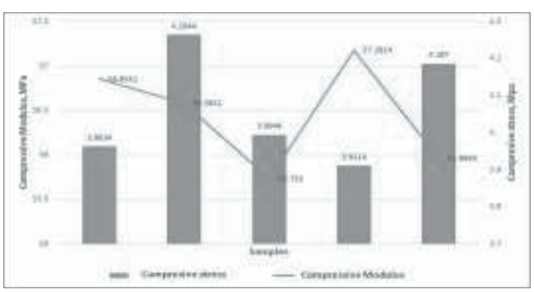

Figure 6 Variation of compressive modulus and compressive strength in vertical pillar corrugated sine wave samples

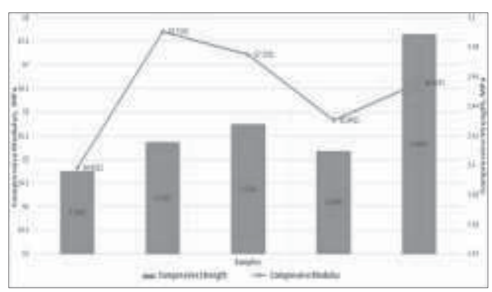

Figure 7 Variation of compressive modulus and compressive strength in the vertical pillar corrugated trapezoidal samples

The Table 3 shows the calculated values of avg. compressive strength, avg. compressive modulus and deflection stress for both the design samples which were calculated from the statistics method as mentioned in the ASTM standard. It has been noted that the Avg. comp. strength for sine wave core structure is higher than the trapezoidal core structure and detailed discussion was undergone about the outcome of the upcoming section.

Table 3 Avg. Values of compressive strength, compressive modulus & deflection stress

| **Samples** | **Avg. Compressive Strength $F_Z^{fcu}$ (MPa)** | **Avg. Compressive Modulus $E_Z^{fc}$ (Mpa)** | **Deflection Stress $\sigma_z^{f0.002}$ (MPa)** |
|---|---|---|---|
| Vertical pillar corrugated sine wave core | 4.06416 | 56.4634 | 0.1897 |
| Vertical pillar corrugated Trapezoidal core | 3.42802 | 66.44904 | 0.1675 |

## CONCLUSION

The compressive strength, compressive modulus and the deflection-stress were determined by conducting compression test on new age sandwich panels for two type of truss like structure designs. Decent results were obtained from the experiment for both samples which shows that the compressive strength and deflection-stress of the corrugated sine wave structure were moderately higher than the vertical pillar trapezoidal wave structure, whereas the compressive modulus for trapezoidal structure were higher of about 12.12% than the sine wave structure. The overall picture shows that the vertical pillar corrugated sine wave core was played a moderately higher performance than vertical pillar corrugated trapezoidal core.

## ACKNOWLEDGMENTS

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