Development and evaluation of new concepts in the design of honeycombs used in composite panels

|Extended Abstract|

Hugo Alexandre da Costa Araújo

Abstract

Composite sandwich structures are crucial in structural uses for a range of applications in the aerospace and automotive industry that require low weight, high bending strength and high energy absorption. In general, the core of sandwich structures has a two dimensional cellular structure with a regular honeycomb geometry. With standard manufacturing processes, geometric structures are limited, but the emergence of additive manufacturing provides promising alternatives to conventional designs.

The aim of this work is to analyse the effect of the core geometry on the flexural properties of the structure.

For that purpose, three cellular configurations were taken into account, namely regular honeycombs, lotus and hexagonal honeycombs with Plateau borders, as denoted by Ronan et al. [1]. Fused deposition modelling (FDM) was used to obtain samples in PLA (polylactic acid) for those configurations. The flexural properties of cellular structures were evaluated with three point bending tests. A modelling approach of the tests in the three configurations was also performed, by means of finite element simulations.

Results showed that for low relative density, the hexagonal configuration exhibit the best results for absorbed energy and flexural strength when compared to the Lotus and Plateau configurations. However, the Plateau configuration has the highest relative stiffness, while Lotus will be able to withstand higher tensions at intermediate densities.

Innovative configurations for core sandwich composites were designed, simulated numerically and experimentally tested. Two geometries presented an energy absorption capacity which is competitive with the traditional core structures for the same density.

Key-words: Honeycomb; Three-point bending; Aluminium; PLA; FEA

Introduction

A composite material can be defined as a material that results from the combination of two or more materials, where the properties are superiors when compared with the isolated materials used in the composite [2].

There are several advantages in this kind of materials, however the most important are their high strength and stiffness associated with the low density, which allows parts to have the same or better properties to the bulk materials [2]. A case of these materials are the composite panels, also known as sandwich structures, as they are constituted by a nucleus between two or more layers [3], as shown in figure 1.

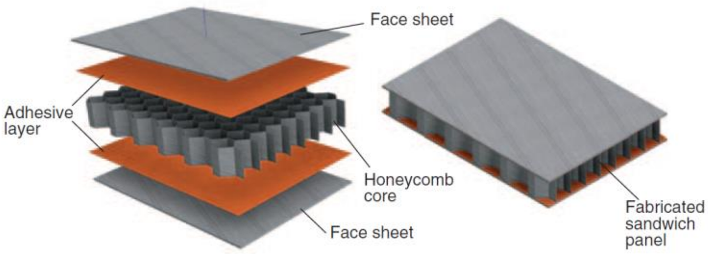

Figure 1 - Composite material with sandwich structure [4]

The principle behind the sandwich structures determines that the face sheets must have high stiffness and must be resistant enough to support the applied load, while the nucleus acts like a placeholder that fixes the face sheets in their position, increasing the stiffness and decreasing the stresses [3].

For the nucleus to be able to fulfill its objective, it has to be stiff enough in the perpendicular direction of the face sheet, in order to ensure that the face sheets maintain the correct distance one from the other and have sufficient stiffness to prevent the sliding of the face sheets when the composite is tested [3, 4].

The application areas of this materials have been increasing due to the advantages referenced, and the principal areas of application are the aerospace, the automotive, the high-speed trains and the ships industries [3, 5]. The materials of the face sheets can be fiber reinforced composites, while the nucleus can be manufacturing with a metal, a polymer or wood [6].

Materials and Methods

To evaluate the designed configuration, shown in Figure 2, it was created 12 samples with SolidWorks (example in Figure 3), 4 of each configuration with different relative density as showed in Table 1. The expressions to calculate the relative density are different and depend of the configuration and for that they are presented below, were the (1) allows to calculate the relative density for the regular hexagonal honeycomb, the (2) allows to calculate for the lotus and the (3) the Plateau [1, 7].

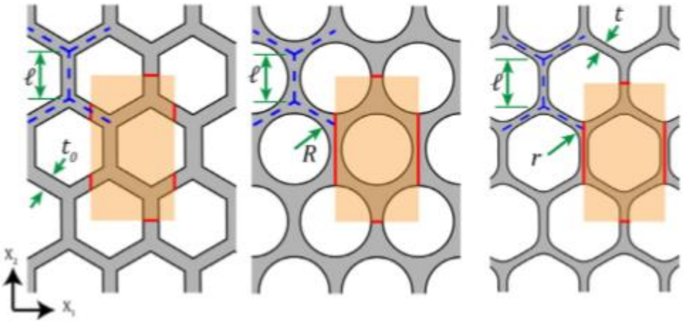

Figure 2 - - Configurations to study: Left) Regular honeycomb; Center) Lotus; Right) Plateau

Table 1 - Samples organization by groups and respective relative density

Groups	*Samples*	*Variables*				*Relative density*
		l	t_0	R	r	
A	1A	10,46	0,8	0	0	0,086
	2A	13,06	0,1	11,26	0	0,101
	3A	10,46	0,8	0	4,184	0,106
B	1B	11,26	2,31	0	0	0,223
	2B	11,26	2,31	8,66	0	0,285
	3B	11,26	2,31	0	4,504	0,243
C	1C	13,18	5,5	0	0	0,424
	2C	10,31	4	6,93	0	0,454
	3C	13,18	5,5	0	5,272	0,444
D	1D	16,08	10,5	0	0	0,612
	2D	9,18	5,5	5,2	0	0,612
	3D	16,08	10,5	0	6,432	0,632

$$\frac{\rho^*}{\rho_s} = \frac{2}{\sqrt{3}}\frac{t}{l}\left(1 - \frac{1}{2\sqrt{3}}\frac{t}{l}\right) \quad (1)$$

$$\frac{\rho^*}{\rho_s} = 1 - \frac{2\pi}{3\sqrt{3}}\left(\frac{R}{l}\right)^2 \quad (2)$$

$$\frac{\rho^*}{\rho_s} = \frac{2}{3}\left[\sqrt{3}\,\frac{t_0}{l} - \frac{1}{2}\left(\frac{t_0}{l}\right)^2 + \left(2 - \frac{\pi}{\sqrt{3}}\right)\left(\frac{r}{l}\right)^2\right] \tag{3}$$

As said before, the samples were evaluated with the method three-point bending by finite elements analysis (FEA) and the materials used were aluminium and PLA (polylactic acid). In order to be able to export the results obtain FEA for the aluminium, a group of study was chosen, group B. In this group a FEA was done with the PLA as material, and the samples were also impressed in PLA through the technic fused deposition modelling (FDM), an additive manufacturing technique.

There are several parameters in this printing technique, however only three were changed according to the material while the others were kept in the default value and the ones that suffer a change were the filling, the layer thickness and the temperature of the bed and the nozzle. The filling of the part was adjusted to 100%, the layer thickness to 0.3mm, the temperature of the bed to 60°C and the temperature of the nozzle to 210°C, as the typical temperature for PLA is between 205 and 215°C.

The impressed samples were tested under the method three-point bending in the laboratory, to validate the results obtain in the FEA, as shown in Figure 4, and the velocity of the test was fixed at 2.5mm/min.

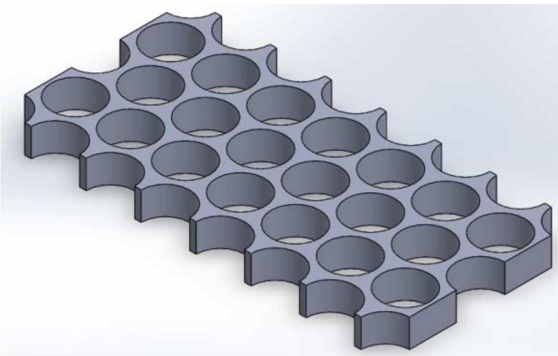

Figure 3 - Sample 2B

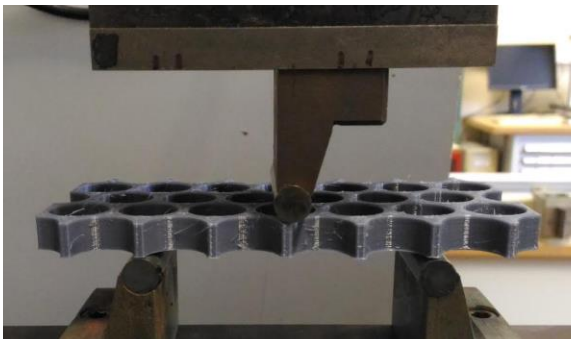

Figure 4 - Test of an impressed sample

Results and Discussion

With the FEA, it was possible to obtain the flexure load-flexure extension plots of every sample, where the results were grouped by their study group, as shown in Figure 5 to Figure 8.

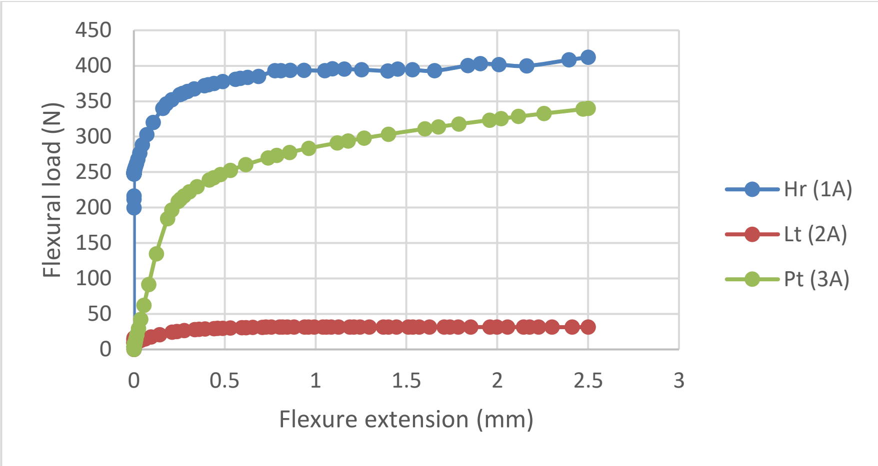

Figure 5 - Flexural load -flexural extension plot of the samples of group A

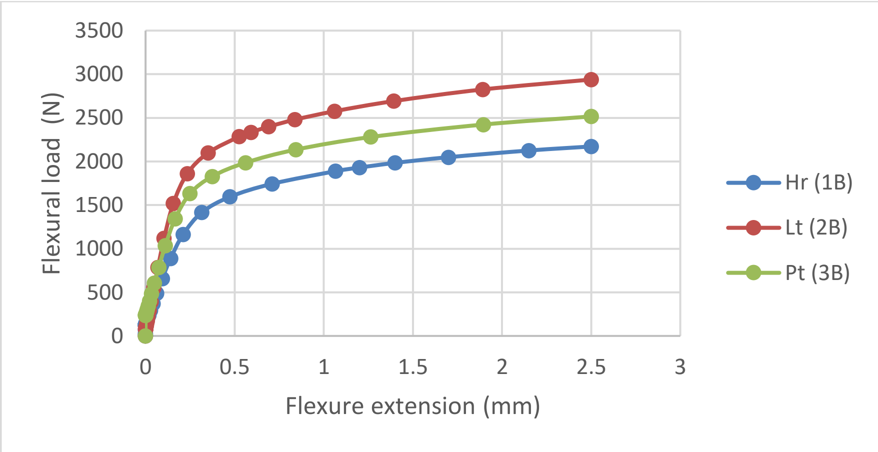

Figure 6 - Flexural load -flexural extension plot of the samples of group B

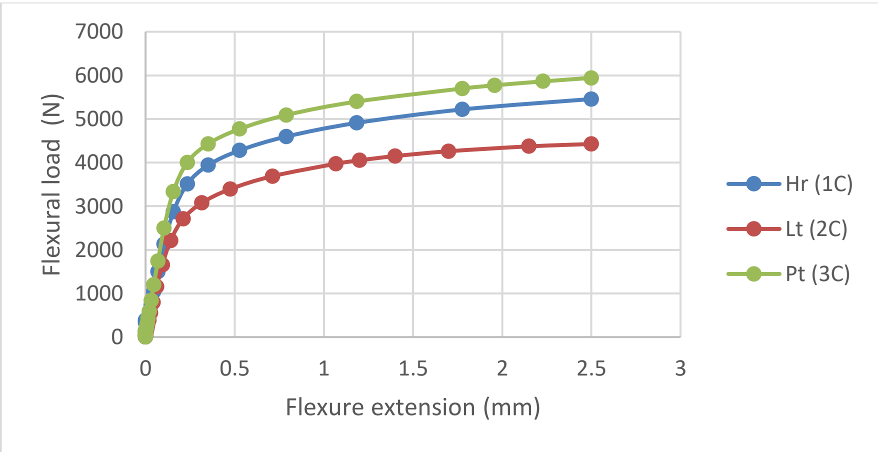

Figure 7 - Flexural load -flexural extension plot of the samples of group C

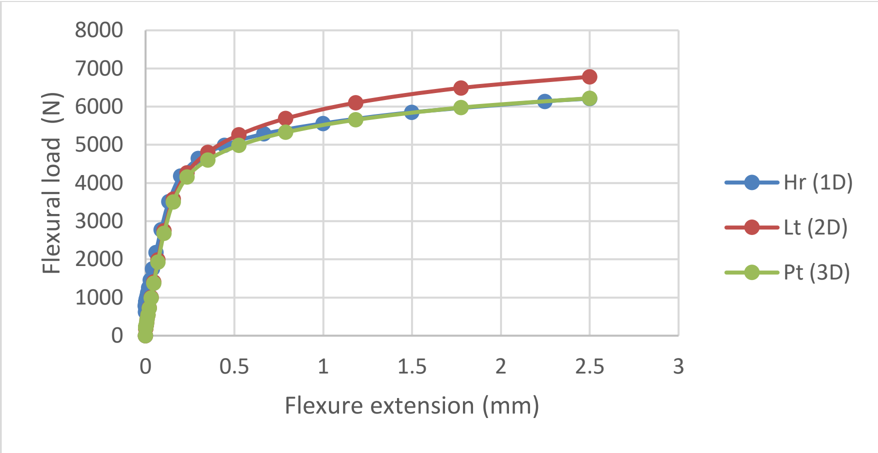

Figure 8 - Flexural load -flexural extension plot of the samples of group D

The results allow us to realize that the relative density is very important in the properties of the part, because the higher the relative density is, the higher the applied force needs to be to cause deformation, that in this case is the deflection of the part.

For the hexagonal and Plateau configurations, the greatest resistance increase of the part is observed when the relative density increases from 0.2 to 0.4, while in the remaining values of relative density there isn't any significant increase. The Lotus configuration exhibits the highest strength increase when the relative density increases from to 0.4 to 0.6.

The Figure 5 to Figure 8 also allow us to comprehend that there isn't a configuration better than the others in all aspects of the study, as each one has its range of relative density, where they present the best results. For instance, the hexagonal configuration, normally used in composite panels, exhibits the best results for low values of relative density, since at all moments of the test it presents higher values of force for the same values of deflection, in comparison with the other configurations, Lotus and Plateau. For the other remaining groups of study, the best configuration status is divided between the Lotus and the Plateau configurations, and for group B it is clear that Lotus is the best configuration, but for group C it is no longer verified, with the Plateau configuration showing the best results.

The results of group D are a little "strange" compared to the others groups, since the Hexagonal and Plateau configurations exhibit very similar results, with only a small difference between them. This difference can be negligible, leading to the conclusion that both have the same behavior.

Comparing the energy absorbed of the configurations studied (Table 2), it is possible to see that at densities of 0.1, 0.2 and 0.4 the configuration that absorbs the highest energy is the hexagonal configuration, while the Lotus configuration exhibits the best results for the density of 0.6.

However, comparing the stiffness values of every sample, the Plateau configuration exhibits the best results for the densities of 0.22 and 0.44, while for the density of 0.6 the configuration with the highest stiffness is the hexagonal one.

The results also show that the hexagonal configuration is the one with the highest values of relative maximum stress for the values of 0.1 and 0.2 of relative density, while for the other values of relative density, the Lotus configuration presents the higher values.

*Table 2 - Initial stiffness, absorbed energy, relative maximum stress, relative initial stiffness and relative absorbed energy values of Al samples. * - The value presented is very high due to numerical problems, since the flexural load-flexural extension does not present a slope zone.*

Sample	Relative density $\left(\frac{\rho^*}{\rho_s}\right)$	Initial stiffness (N/mm)	Absorbed energy (J)	$\sigma_{max} \Big/ \frac{\rho^*}{\rho_s}$	$Initial\ stiffness \Big/ \frac{\rho^*}{\rho_s}$	$Absorbed\ energy \Big/ \frac{\rho^*}{\rho_s}$
1A	0,09	27 734,76*	$7{,}46 \times 10^{-2}$	1 677,78	308 164,00*	0,83
2A	0,10	1 667,70	$1{,}32 \times 10^{-2}$	1 720,00	16 677,00	131,66
3A	0,11	1 092,69	$7{,}83 \times 10^{-2}$	1 272,73	9 933,55	711,93
1B	0,22	7 843,89	$5{,}44 \times 10^{-1}$	759.09	35 654,05	2 471,14
2B	0,28	10 754,71	$6{,}19 \times 10^{-1}$	528,57	38 409,68	2 210,64
3B	0,24	9 341,35	$5{,}58 \times 10^{-1}$	700,00	38 922,29	2 323,58
1C	0,42	20 519,24	1,20	342,86	48 855,33	2 850,93
2C	0,45	17 622,50	$9{,}80 \times 10^{-1}$	348,89	39 161,11	2 178,85
3C	0,44	24 057,35	1,23	334,09	54 675,80	2 791,43
1D	0,61	31 590,64	1,19	249,18	51 787,93	1 957,24
2D	0,61	26 408,87	1,36	260,66	43 293,23	2 234,49
3D	0,63	25 814,08	1,22	236,51	40 974,73	1 931,26

The results of PLA samples is presented in the Table 3 and in Figure 9 and Figure 10.

Table 3 - Initial stiffness, absorbed energy, relative maximum stress, relative initial stiffness and relative absorbed energy values of PLA samples

Sample	Relative density $\left(\frac{\rho^*}{\rho_s}\right)$	Initial stiffness (N/mm)	Absorbed energy (J)	$\sigma_{max} \Big/ \frac{\rho^*}{\rho_s}$	$Initial\ stiffness \Big/ \frac{\rho^*}{\rho_s}$	$Absorbed\ energy \Big/ \frac{\rho^*}{\rho_s}$
1B	0,22	305,42	$8{,}57 \times 10^{-1}$	294,27	1 388,27	3,90
2B	0,28	492,43	1,26	226,50	1 758,68	4,50
3B	0,24	383,10	1,027	268,67	1 596,25	4,28

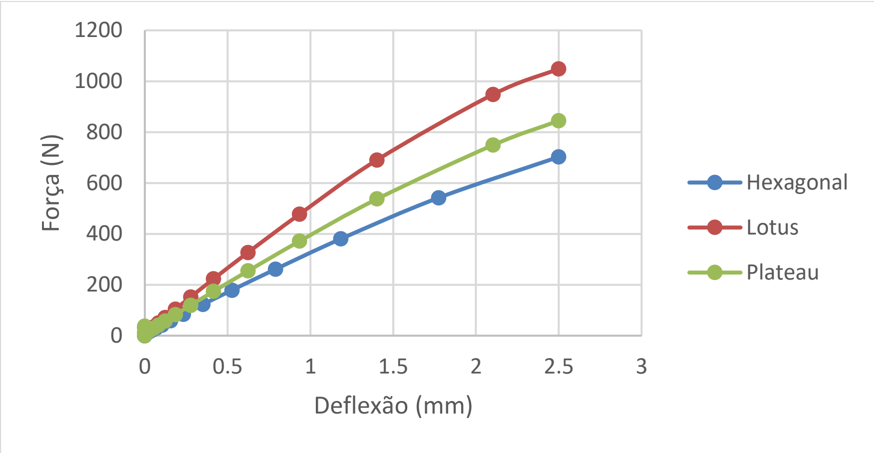

Figure 9 - Flexural load -flexural extension plot of the samples of group B testes by FEA

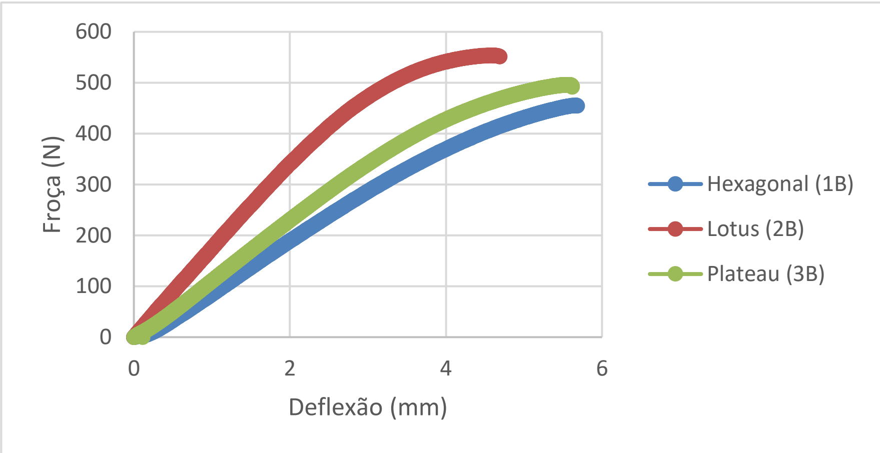

Figure 10 - Flexural load -flexural extension plot of the samples tested in the laboratory

To understand if the results obtained for the aluminium simulations can be extrapolated to reality, the PLA tests were carried out. By comparing the plots in Figure 9 and Figure 10, it is possible to notice that in both situations the configuration that exhibits the greatest resistance to deformation is the Lotus configuration.

Comparing the relative maximum stress values of each configuration, it is possible to understand that the hexagonal configuration presents the maximum values, while for the values of relative stiffness and absorbed energy, the best results were recorded in the Lotus configuration.

The Figure 11 illustrates a sample after the three point bending test and by comparing it with the Figure 11 after the numerical simulation, it is possible to see that the areas identified in red, that represent the location of high stresses, are the areas where the fracture of the PLA samples occurred.

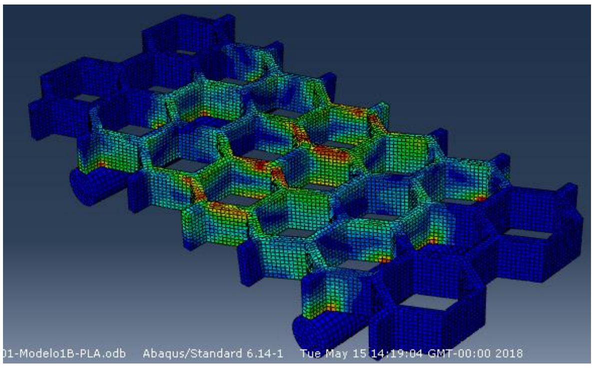

Figure 11 - Sample 1B after the simulation (t=120)

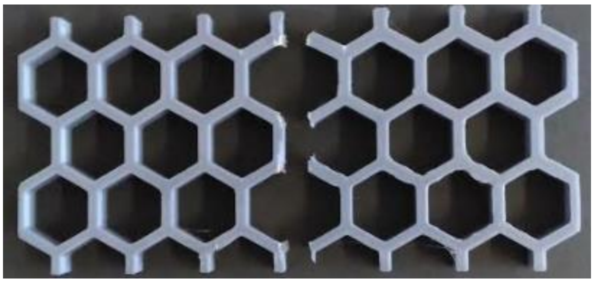

Figure 12 - Sample 1B after the three point bending test

Conclusion

The evaluation of the three concepts studied allowed to understand which configurations absorb higher energy, have higher stiffness and support higher stress in comparison with the results obtained with the configuration normally used, the hexagonal configuration.

There is no single configuration that exhibits the highest values of the previous parameters. For instance, for densities of 0.2 and 0.4 the configuration Plateau presents the higher relative stiffness values, but for the relative density of 0.6, the geometry that presents higher stiffness is the hexagonal.

The Lotus configuration also exhibits better results than the hexagonal configuration, but its performance depends on the value of the relative density, since this configuration presents the worst recorded results in groups A and C.

Comparing the results obtained with the PLA samples tested in the laboratory with the results obtained from the numerical simulation, it is possible to notice that in both situation the Lotus configuration presents the best results, followed by the Plateau configurations and after the hexagonal configuration. Through this analysis, we can validate the results obtained in the numerical simulation of the aluminium samples and extrapolate them.

Considering the situations described above, it was concluded that the best option depends on the relative density, which may be the hexagonal in terms of energy absorbed at lower densities, or the Plateau configuration which has greater stiffness. The Lotus configuration will be predominant at the maximum stress level at low densities.

References

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