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Experimental study of the influence of glass microspheres on flexural response of honeycomb structures reinforced with syntactic foams

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ABSTRACT

This paper studies the bending behavior of honeycomb structures by varying their weight through the introduction of glass microspheres. For this purpose, four different types of syntactic foam specimens were manufactured, varying the percentage by volume of glass microspheres between 20%, 30% and 40%. Afterwards, three-point bending tests were performed on each of these groups of specimens based on ASTM D7264/D7264M-15, thus obtaining data that allowed determining mechanical behavior and comparing it with material without glass microspheres. The optimum positive influence of microspheres over specific flexural strength was found at 30% of addition of glass bubbles. Additionally, results of the structures under impact gravity test confirm that 30% is a good proportion for these structures.

1. Introduction

Sandwich honeycombs made of lightweight and cost-effective composite materials with honeycomb cores can form the basis of incredibly strong and resilient structures. Compared to solid and one-piece products, they can save large amounts of material, reducing weight and potentially costs while maintaining specific mechanical properties (Ashby & Gibson, 1997). Nevertheless, the use of honeycomb sandwich design is generally reserved for high-end technical applications, mainly in the aerospace, automotive and marine industries. Due to cellular materials sandwich honeycombs improved their properties due to high specific resistance, high toughness and good energy dissipation (Lu & Yu, 2003). On the other hand, syntactic foams are novel composite materials in which a metal, polymer or ceramic matrix is mixed with microballons in order to create a two-phase (gas and solid) material with a lower density value than the original bulk precursor. Thanks to evolution in production technology and cost reduction, these materials are progressively appearing in application areas such as building, construction, automotive, general transport and more. However, it is necessary to investigate their basic mechanical and strength properties by performing suitable experimental tests before using them in practical and industrial applications. Accordingly, a number of researches have been done to obtain the strength and load bearing capacity of foams (Marsavina et al., 2014; Negru et al., 2018; Sharafi et al., 2018a,b,c; Aliha et al., 2018, 2019; Nemati et al., 2019; Samali et al., 2018). The present study analyses the specific flexural behavior of structures with honeycomb whose cells has been reinforced with a

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syntactic foam filler. Therefore, the material to be studied consists of several phases, making it difficult to predict its mechanical behavior. In an article found in literature, Jhaver and Tippur (2010) study the mechanical properties of structures similar to the ones presented here but subjected to a compression test. Since the sandwich structures are more commonly load in flexion, this paper deals with bending properties. Another difference between Rahul structures and the ones of this document is the material of the honeycomb. While the material of the honeycombs in the former is aluminum, the present study use honeycombs made with nomex. A study more related with this research can be found in (Craven 2011) where researchers propose analytical solutions of this type of material with three different types of cores loaded in flexion. Studies such as that of Lu et al. (2015) carried out for this type of sandwich structures with Nomex core and reinforced with epoxy resin and carbon fiber show how the mechanical properties increase when compared with traditional materials such as aluminum, in addition these materials stand out for their capacity to absorb energy and withstand impacts. The response of sandwich honeycomb structures to dynamic crushing has also been studied in (Ajdari et al. 2011) in which they have shown how the introduction of a density gradient could significantly change the deformation mode. In view of the above, a study predicting the behavior of materials with a reinforced honeycomb structure will provide experimental data that will bring light over the needs of the industrial sector in terms of design and selection of materials.

2. Material and methods

The honeycomb structures reinforced with syntactic foams are formed with honeycomb cores, filled with a mixture of epoxy matrix and glass microspheres. The sheets of the sandwich structures are made with carbon fiber. For construction, the dimensions of the flexural specimens were based on ASTM D7264/D7264M-15 with the dimension length vs thickness ratio of 1:16. Three-point bending tests were performed for the different groups of specimens in a universal testing machine. The following specific resistance results were obtained and are shown in Table 1.

Table 1

Comparison of specific resistance

Sample No.	NOMEX+RESIN		NOMEX+RESIN+MC 20%		NOMEX+RESIN+MC 30%		NOMEX+RESIN+MC 40%	
	Ultimate strength (Mpa)	Deformation at break (%)	Ultimate strength f(% Weight Mpa)	Deformation at break (%)	Ultimate strength f(% Weight Mpa)	Deformation at break (%)	Ultimate strength f(% Weight Mpa)	Deformation at break (%)
MI-FLX-18	55.65	1.77	72.9638133	2.34	63.643323	3.05	59.7075366	2.14
MI-FLX-18	48.69	2.01	63.7804745	2	83.522847	3.56	60.2474691	2.08
MI-FLX-18	53.68	2.26	63.6930141	1.88	58.1409538	3.04	60.8773903	1.86
MI-FLX-18	57.91	1.86	70.3400022	2.57	78.808116	2.76	76.287964	2.2
MI-FLX-18	59.9	2.09	53.6460042	2.05	74.2597872	4.14	67.6940382	2.42
Average	55.1	2	64.8846616	2.17	71.6750053	3.31	64.9628796	2.14

2.1. Epoxy resin properties

Table 2

Properties of epoxy resin

Density (20°C)	1.1	g/cm³
Modulus of elasticity	3100	N/mm²
Resistance to compression	101	N/mm²
Impact resistance	21	KJ/m²
Temperature without deformation	50	°C

(Source: (Pf-Group, 2018))

2.2. Glass microspheres K1 $3M^{TM}$ *properties*

Table 3

Glass microspheres

Density	0.125	g/cm³
Compressive strength	1.7	MPa
Crush resistance	250	PSI
Particle size	65	D50 micrometers
Brand		3M

(Source: (3M, 2018))

2.3. Nomex Honeycomb properties

Table 4
Nomex Properties

Face-to-face cell size	3.175	mm
Density	0.048	g/cm³
Thickness	6.35	mm
Cell size face	3.175	mm
Cell expansion	10	%

(Source: (Corporativo, 2018))

2.4. Carbon Fiber 3K

Type 3K carbon fiber must be cure between 132°C and 154°C, has a Young modulus of 7600 MPa and Poisson's ratio of 0.39. (Motoring, 2018)

2.5. Preparation of honeycomb specimens reinforced with syntactic foams and carbon fiber for bending test

First, the quantities of epoxy resin, hardener and volume fraction (20%, 30% and 40%) of glass microspheres respectively were calculated. Then the resin and hardener were mixed in a ratio of 10:7, in a precipitation vessel, this ratio is very important and should be as accurate as possible. Once the mixture was visibly homogeneous, the glass microspheres were placed, and continued stirring until a homogeneous mixture of the syntactic foam was obtained.

Then the syntactic foam mixture was placed in a vacuum chamber where a vacuum pressure of approximately 70 kPa was reached. This pressure was maintained for 5 minutes, then the flow valve was closed and the vacuum pump was turned off maintaining the pressure for 4 more minutes. Next, the precipitation vessel with the syntactic foam mixture was removed from the vacuum chamber, returning the mixture to atmospheric pressure. The surface slang of the mixture was eliminated. This process was carried out 3 times in order to achieve the maximum extraction of the air inclusions in the syntactic foam mixture.

To create the test specimens, first clean the mold observing that it has no inclusion of any kind. Next, the carbon fiber was placed in the cavities of the mold and the mixture of syntactic foam is poured into the cavities of the mold. Once the foam is placed, samples were kept for 4-5 minutes to allow air bubbles to come out. The nomex material is placed by means of an immersion process. Next, place the carbon fiber on the upper surface. In the curing step, specimens were introduced into the oven at a temperature of 154 º C for one hour, with heating regime of 2.5 [ºC/min]. After that, the oven is turned off and it is expected to cool gradually so that there is no buckling of the material. Once completely cooled, the specimen is removed from the mold and our final specimen is obtained and ready to be tested.

For the group of specimens for the impact test, the same procedure as mentioned above was performed. The only difference is the size specimens. For impact test, specimens of 50*50 (mm) and a thickness of 6.85 [mm], referring to standard ASTM-D3763-18, which were tested by a gravity impact equipment.

3. Results and discussion

As mentioned above, the method detailed in ASTM D7264/D7264M-15 was used.

Procedure A: Three-point bending

- Thickness-span ratio: 1:16
- Test speed: 1mm/minute
- Number of specimens for each group to be tested: 5

Fig. 1 shows the specific strength as a function of deformation for the three groups of specimens. The 30% concentration group of glass microspheres would be the one with the most notable improvement, with a 9.86% reduction in weight with respect to pure material, it has a greater specific resistance to bending. The 40% concentration group of glass microspheres presented improvements in their properties reducing their weight with respect to pure material by 9.86%. The 20% concentration group of glass microspheres reduced their weight by 8.57% but in the same way improving their properties with respect to pure material.

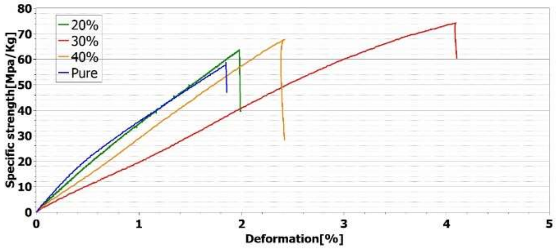

Fig. 1. Comparison between specific strength and deformation

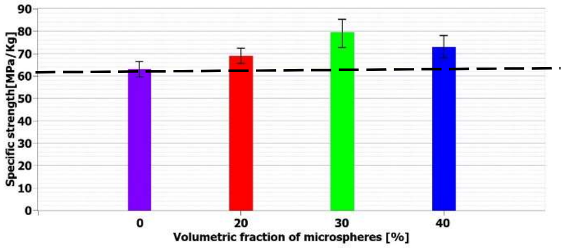

Fig. 2. Specific resistance vs. volumetric fraction of microspheres

The proportion of glass bubbles has a direct influence on the specific resistance and stiffness obtained for the different types of specimens. It is clear from the graph that changes in specific stiffness and resistance is not significant for the 20% group while an optimum concentration has been reached at 30% later it will be shown that the failure for this case begin in the nomex but not in the mixture of resin and glass bubbles. In the case of the 40% group, the concentration of microspheres was excessive, so that the resin could not cover all the spaces, leaving voids in which the microspheres collide and facilitate the propagation of breakage in the specimens. As can be seen in Fig. 2, the specific resistance vs. volumetric fraction of glass microspheres exceed the properties of the pure material for all the test tube groups (20%, 30%, 40%); Standing out the concentration group of 30% glass microspheres among the three groups, but also presenting a greater deformation. All the specimens showed a plastic behavior increasing their deformation and resistance to flexion up to the point where they fail.

As far as specific rigidity is concerned, the best results were produced with a percentage of microspheres of 40%, however the three groups of test tubes decreased their specific rigidity with respect to the pure material, as can be seen in Fig. 3. Additionally, the impact test carried out helps to analyze how the impact of the striker affects the surface of the material at different heights and concentration of glass bubbles. In this study, the same bubble glass fraction were used (20%, 30%, 40%) and specimens were subjected to impacts of 50 and 115 cm of height.

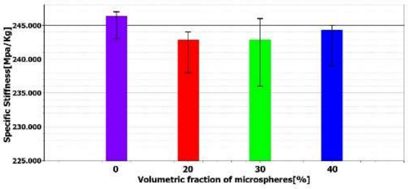

Fig. 3. Specific stiffness vs. volumetric fraction of microspheres

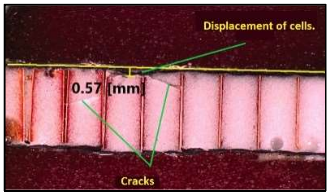

Fig. 4. Failure resulted from an specimen of 40% concentration glass microspheres, height of impact h=50 cm

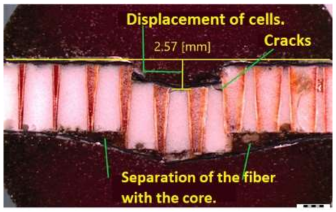

Fig. 5. Failure resulted from an specimen of 40% concentration glass microspheres, height of impact h=115 cm

Fig. 4 shows how the fracture propagates near the tip of the striker, the fracture configuration is similar for the 20% and 30% specimens. Fig. 5 shows the failure resulted from specimen of 40% concentration glass microspheres and height of impact h=115 cm. For this specimen a relatively high displacement of 2.57 (mm) was observed. For 20% and 30% a displacement of 1.43 (mm) and 1.14 (mm) were seen, respectively. The figures suggest that the material during the impact test is not able to behave as a single material and separates into their components. Fiber sheets separate from core and failure is also observed through the nomex material. For a concentration of 20% of glass bubbles, the specimens do not have good impact resistance, because the glass bubbles are not evenly distributed throughout the reinforcement and by the presence of air inclusions in the resin. For this reason, stress is not evenly distributed and spaces exist in the resin where there is greater concentration of glass bubbles causing failures in this zones. In the case of the 40% group of glass microspheres, due to the greater concentration of microspheres in the resin phase, the supported efforts were greater, directing them towards the nomex phase and causing the failures to occur there, displacing them downwards and causing the separation of the carbon fiber when detached. The best results were obtained in the group of 30% concentration of glass bubbles, achieving that the efforts do not accumulate in a single phase, the glass bubbles by distributing uniformly throughout the resin help not to produce fault concentrators in any of the phases, achieving that the efforts are also distributed uniformly.

4. Conclusions

- Glass microspheres positively influence honeycomb structures by decreasing their weight and increasing their specific flexural strength making this material more suitable for some applications.
- The best response to flexural stresses could be obtained by mixing a percentage of 30% by volume of glass bubbles despite of not being the group with the lowest weight, it supported an ultimate flexural specific strength of 71.67MPa/kg which is roughly 30% higher than the one of pure material. For this specimen, the reduction of weight was 9.86%
- The response of the specimens for bending test were more promising than the impact ones. In the impact tests, the nomex phase failed early, moving downwards without allowing the force to be distributed over the other phases.
- For the impact test the concentration of 30% of glass bubbles was the best, behaving as a single body and the displacement of the cells was lower than the rest of concentrations of glass bubbles.
- The 30% by volume group of glass bubbles presented a better distribution of bubbles in the resin, so the material was not brittle to have an agglomeration of bubbles as was evident in the 40% group.

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