MECHANICAL BEHAVIOUR OF SANDWICH COMPOSITES WITH DIFFERENT CHARGED FOAM LAYERS

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ABSTRACT

Hollow glass microspheres are widely used as core material in sandwich construction, particularly in sea water structures, in consequence of their beneficial properties namely: no corrosion effects, design freedom and low density. Microspheres are commercially provided in many different densities, strength and diameter sizes. In the present study a batch of hollow microspheres Verre ScotchitTM-K20 manufactured by 3M was selected along with epoxy 520 resin and hardener 523 to produce the core foams. Two skins were used: net epoxy resin and carbon laminate composite with 2mm thickness, manufactured using twelve woven, balanced, bi-directional, layers of carbon fibres and epoxy resin matrix. Panels sandwich were manufactured using homogeneous and multilayer core foams with the purpose of improving specific flexural stiffness modulus. It was concluded that the panels with carbon reinforced skins exhibit much higher values of strength and stiffness than non-reinforced; multilayered panels with different loads of microspheres (higher percentage of microsphere in the center and lower in the outer) have also higher resistance and stiffness than the panels with homogeneous microsphere percentage core. A tendency to the increase of both properties was observed when the displacement rate increases from 0.5 mm/min to 10 mm/min for all architectures.

KEYWORDS: Composites, sandwich structures, flexure properties, testing.

1. INTRODUCTION

Low-density sheet moulding compounds based in hollow glass microspheres have good properties, namely no corrosion effects and design freedom. Hollow glass microspheres offer also low density and consequent weight reduction. These materials are particularly able to be used as core material in sandwich structures. For this purpose specific monotonic flexural stiffness can be improved using materials with different charged layers: lower density in the centre and standard sheet moulding compounds in the outer layers, according Oldenbo et al [1].

Sandwich structures are widely used in sea water structures, particularly in naval craft. For these applications, both temperature and sea water reduce foam's moduli. However, sea water effect remains confined to a very thin layer near the exposed boundary of the foam and thereby does not degrade its bulk properties [2,3]. A. Siriruk et al [2] estimated the effect of sea water on foam moduli by means of torsional tests on polymeric foams (PVC H100), obtaining degradation of shear modulus and Young's modulus in the saturated region by more than 70% and 60%, respectively. Recently the same authors [4] studied pre-cracked sandwich composite samples, manufactured by a closed cell polymeric foam core and carbon (or glass) fibre reinforced polymeric composite skins, soaked in sea water for extended periods, concluding that the delamination crack propagates close to the interface in the wet case, while it stays within the foam in the dry samples. Also, significant reduction in fracture toughness due to sea water exposure was observed.

At the interfaces among the face sheets of sandwich structures high shear stress gradients occurs as a consequence of the significant different properties of the materials in contact. These regions are critical for design. To prevent premature failures it is necessary to predict accurately the stress fields. High-order models for the analysis of sandwich composites taking into account the core deformability under compression and shear and the stresses continuity at the interfaces are reported, as for example Frostig [5] and Schwarts-Givli et al. [6]. According Fuchiyama et al [7] stress gradient problem in sandwich composites can be reduced by using for core functionally graded materials, with smooth property variation across the thickness. Recently research in sandwich beams with functionally graded cores has been developed by Sankar [8] and Icardi et al [9].

Panels' behaviour is also influenced by load rate in consequence of microsphere glass foam core compressive properties dependency to strain rate. According P. Li et al [10] both compressive peak and plateau stresses, indicative of fracture resistance and energy dissipation capacity of the foam, respectively, increase almost linearly with the logarithm of strain rate. However, few studies are reported in literature focusing on dynamic properties of glass microspheres syntactic foams, despite their applications at high loading rates. Some examples of these studies are: Woldesenbet et al [11], Capela et al [12] and Song et al [13].

The objective of the present paper is to study the influence of multilayer core foams in the static strength of sandwich panels.

2. MATERIALS PROCESSING AND TESTING

Two types of sandwich panels were manufactured: using homogeneous and multilayer core foams. Hollow glass spheres are commercially provided in many different densities, strength and diameter sizes. The core foams was produced with hollow glass microspheres K20, manufactured by 3M^{TM} (St. Paul, Minnesota; USA), nominally with 50% of particles having diameter lesser than 55 µm. The binding resin was the epoxy 520 and hardener 523 supplied by Ashland Chemical Hispania (Benicarlo, Spain). Two types of face materials were used: epoxy resin and carbon laminate composite with 2mm thickness, the last one manufactured using twelve woven, balanced, bi-directional, layers of carbon fibers, T300 supplied from Toray, and epoxy resin matrix. Core sheets were manufactured by resin transfer molding in vacuum by using an aluminum mould with a rectangular parallelepiped cavity. The mould was cleaned using acetone and treated with a release agent fluid green, methylcyclopropene (MCP). Core sheets with microspheres volume fractions of 19%, 33% and 50% were produced. The panels were manufactured with geometry shown in Fig. 1, using foams sheet layers with 2 mm thickness with different weight fractions adhesively bonded. Skins and core were also bonded. Multilayer core specimens were charged with different formulation layers: lower density in the centre and higher density sheet molding compounds in the outer layers. The specimens were machined from panels with the dimensions of 90x20x12 mm^3 (Fig.1). Five panels' configurations were tested as is summarized in Table 1.

The tests were performed in three-point bending loading with a span of 75 mm, as Figure 2 shows, by using a Shimadzu AG-10 universal testing machine, equipped with a 5kN load cell and TRAPEZIUM software. Fig. 2 shows not only the machine testing and 3PB apparatus and the specimen, but also the ARAMIS technique used to monitor failure evolution. ARAMIS is a non-contact and material independent measuring system providing, for static or dynamically loaded test objects, accurate: 3D surface coordinates, 3D displacements, surface strain values and strain rates.

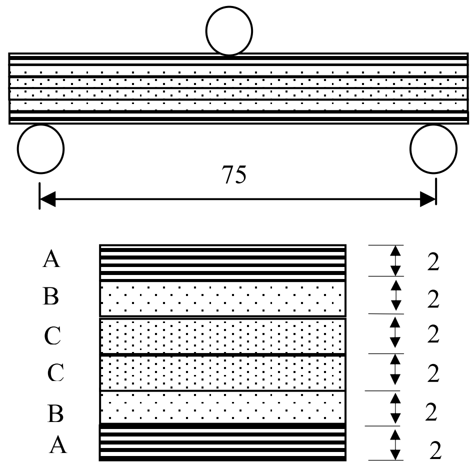

Figure 1. Specimens stacking and dimensions.

Table 1. Summary of the specimen's configuration

Designation	Skin type	Core type	Core Stacking % (in volume)
CHC50	Laminate (C)	Homogeneous (HC)	50/50/50/50
CMC33/50	Laminate (C)	Multilayer (MC)	33/50/50/33
CMC19/50	Laminate (C)	Multilayer (MC)	19/50/50/19
EMC33/50	Epoxy	Multilayer (MC)	33/50/50/33
EMC19/50	Epoxy	Multilayer (MC)	19/50/50/19

The nominal bending stress (σ) was calculated using:

$$\sigma = \frac{3PL}{2bh^2} \tag{1}$$

being P the load, L the span length, b the width and h the thickness of the specimen.

Bending strength was obtained using peak load in equation (1), while the stiffness modulus was calculated by the linear elastic bending beams theory relationship

$$E = \frac{\Delta P \cdot L^3}{48 \Delta u \cdot I} \quad (2)$$

where I is the inertia moment of the transverse section and ΔP and Δu are, respectively, the load range and flexural displacement range at middle span for an interval in the linear region of load versus displacement plot.

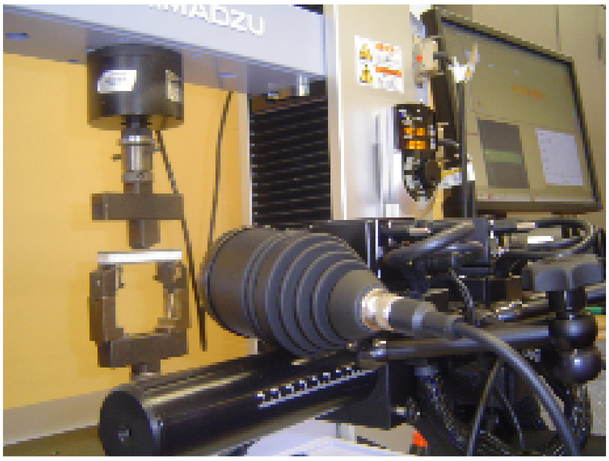

Figure 2. Three-point bending testing apparatus.

3. RESULTS AND DISCUSSION

Fig. 3 a), b) and c) show typical plots of the stress versus bending displacement curves for EMC19/50, CMC19/50 and CHC50 panels, respectively. These curves shows two different aspects which correspond to different failure modes: in epoxy skin panels the failure occurs in the skin and is caused by the bending normal stresses, while in the carbon reinforced panels failure was observed at the foam interlayers as a consequence of shear stress or inside the foam caused by normal stresses. In first case the load increases up to a peak at which occurs an internal break that is followed by a sudden drop of load. The curves for this panel exhibit some nonlinear behavior for high stress level. In the second case the load increase until a peak was obtained corresponding to a core break and a sudden drop of load was observed, but if the displacement continue increasing the load also increase until new core break occurs. Fig. 4a), b) and c) show the aspect and in some cases the evolution of panels failure obtained by ARAMIS technique for EMC19/50, CMC33/50 and CHC50, respectively. These photos confirm the failures modes before indicated.

The displacement rate of the tests influences the values of the stiffness and of the maximum load, but does not influence significantly the aspect of the stress versus displacement curves.

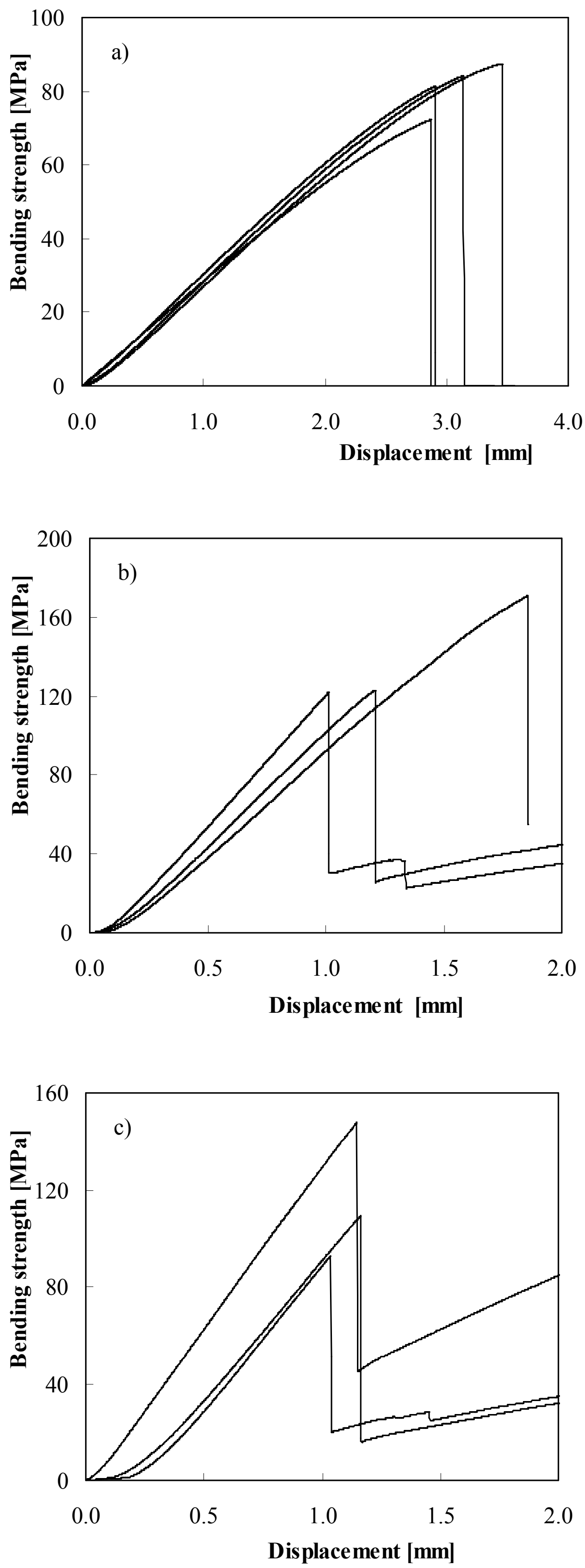

Figure 3. Stress versus displacement curves: a) EMC19/50 b) CMC19/50 c) CHC50 panels.

For each test the stiffness modulus was obtained by linear regression of the load versus displacement curves considering a loading segment ranging from load zero and the maximum displacement value corresponding to a correlation factor at least 99%. Stiffness was calculated using equation (2). The bending strength was calculated for each test using equation (1) for the load corresponding to the first peak of load versus displacement curves.

The average values of the stiffness and bending strength obtained for each test condition are shown in Table 2 and plotted against the displacement rate in Figures 5 and 6, respectively.

In spite the high dispersion obtained for these tests, particularly for those carried out in outer carbon reinforced skins, it can be unequivocally concluded that: the panels with carbon reinforced skins show values of strength and stiffness much higher than non-reinforced ones and the multilayered panels with different microspheres fractions have higher resistance and stiffness than the panels with single foam core. Both properties tend to increase when the displacement rate increases from 0.5 to 10 mm/min.

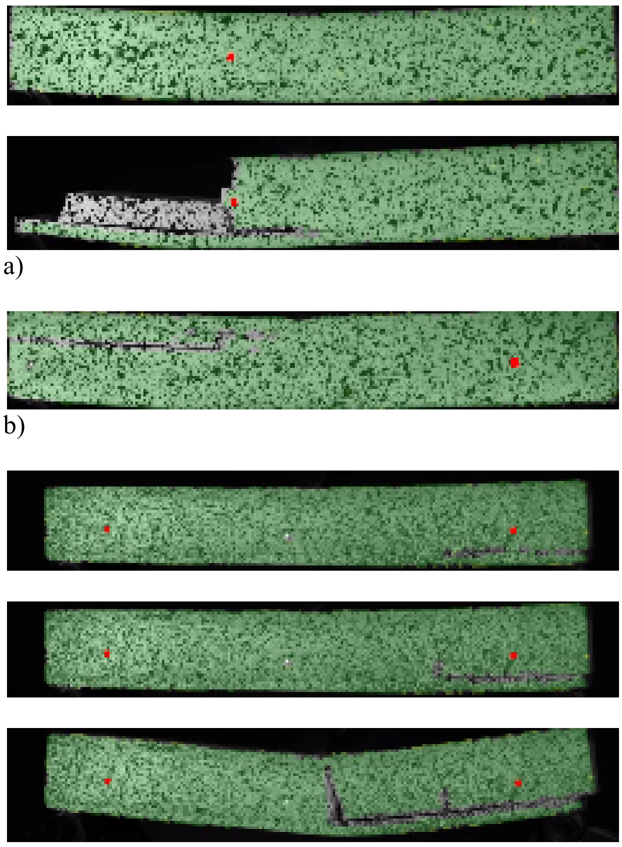

Figure 4. Failure evolution: a) EMC19/50 b) CMC33/50 c) CHC50 panels.

Table 2. Summary of test conditions and average values of the stiffness and strength

Designation	Load Rate (mm/min)	Stiffness (GPa)	Flexural Strength (MPa)
CHC50	10	9305.5	104.1
	0.5	8349.5	85.6
CMC33/50	10	9888.1	113.5
	0.5	8603.5	95.6
CMC19/50	10	10369.8	120.0
	0.5	9135.4	114.3
EMC33/50	10	2472.0	60.0
	0.5	2375.4	52.9
EMC19/50	10	2492.6	88.5
	0.5	2278.0	81.3

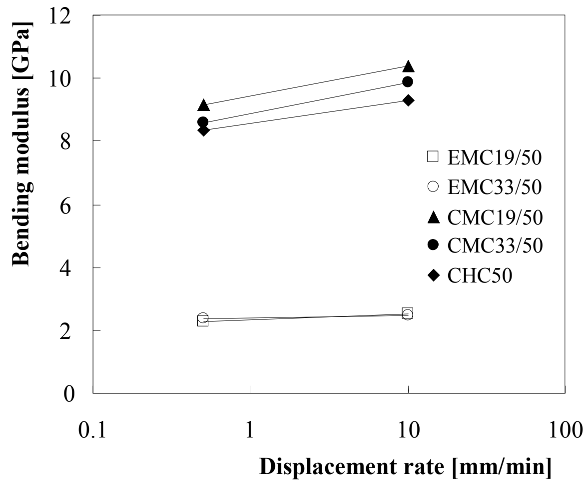

Figure 5. Average stiffness versus displacement rate.

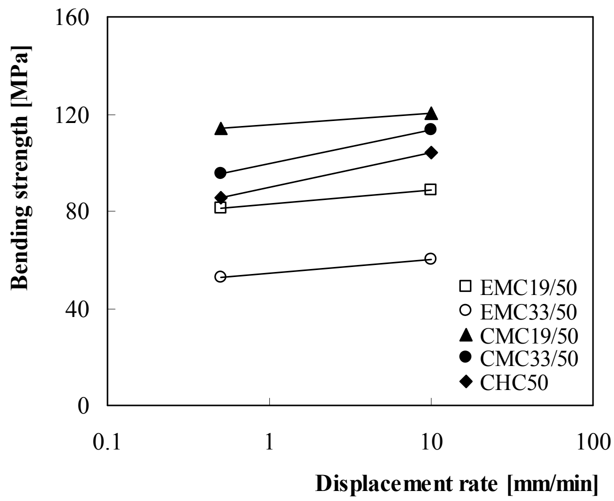

Figure 6. Average strength versus displacement rate.

A 2D numerical model was developed in order to understand the experimental results obtained for the sandwich composites. Only half-specimen was studied with adequate boundary conditions. Figure 7 illustrates the finite element mesh, composed of 21895 linear isoparametric elements and 22312 nodes, the deformed shape and the boundary conditions.

Six layers with distinct material properties were considered. Both the core and the skin of the sandwich composite were assumed to be homogeneous and isotropic with the Young's modulus indicated in table 2. The compressive properties of syntactic foam are slightly different from tension properties, therefore different properties were considered above and below half height of the specimen.

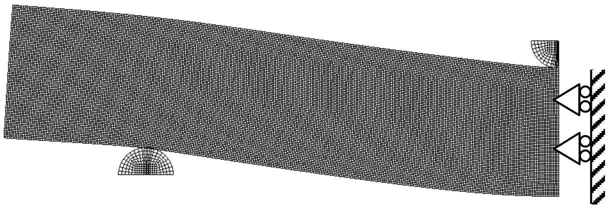

Figure 7. Finite element mesh and deformed shape (x5) (plane strain, F=2000N)

Table 2. Material properties in the numerical model.

Layer	CMC 19/50	E (GPa)	CHC 50	E (GPa)
6	Laminate	58	Laminate	58
5	Foam (19%)	1.24	Foam (50%)	1.12
4	Foam (50%)	1.12	Foam (50%)	1.12
3	Foam (50%)	1.79	Foam (50%)	1.79
2	Foam (19%)	2	Foam (50%)	1.79
1	Laminate	58	Laminate	58

Figure 8 shows the load versus displacement curves for the CMC 19/50 and CHC 50 composites. The stiffness showed variations of 3.1 %, when the volumetric fraction of particles was increased from 19 to 50% in two of the syntactic foam layers. Notice that the global stiffness is mainly controlled by the skin in these composites. The sudden drops of figure are not observed because this preliminary numerical model does not predict failure.

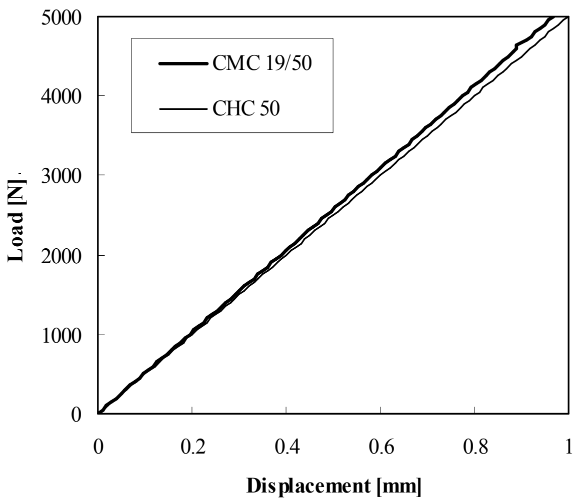

Figure 8. Force versus displacement curves.

Figure 9 shows stresses measured along the thickness of specimen. τ_{xy} was measured at the symmetry line of the specimen, while σ_{yy} was obtained at a distance of 10 mm from central line. The vertical stresses are compressive, as could be expected, and have the highest value near the central pin where the bending stresses had to the contact stresses. The shear stress no longer shows the influence of central pin having maximum values of 5.4 MPa in the section studied. Figure 10 shows the stresses measured along a longitudinal line of the specimen. The line considered is at y=9mm, therefore is the central line of the foam layer immediately below the upper skin. The stresses show a wavy behaviour., where the influence of the central pin is evident for the highest values of d.

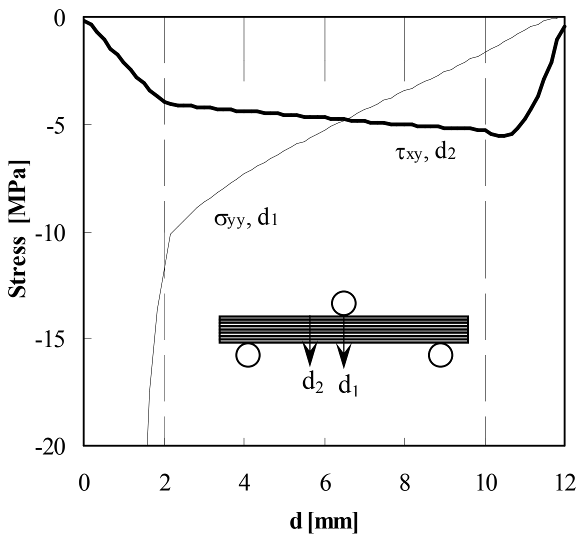

Figure 9. Stress field along thickness.

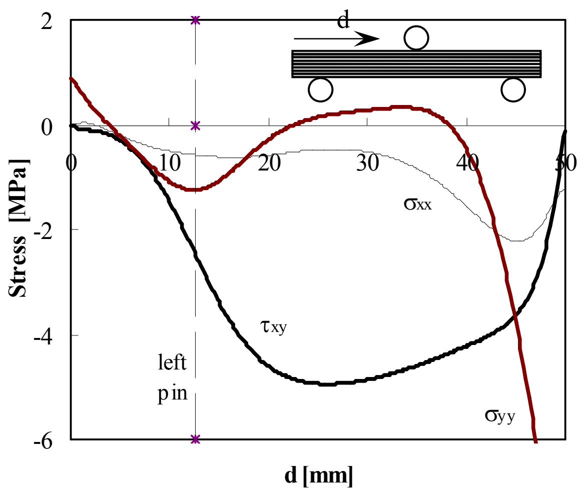

Figure 10. Stress field along longitudinal line.

4. CONCLUSIONS

The bending stiffness and strength of sandwich panels manufactured using homogeneous core and multilayer core foams were obtained. The main conclusions are that: the panels with the skins reinforced with carbon exhibits much higher values of strength and stiffness than non-reinforced; multilayered panels with different loads of microspheres (higher percentage of microsphere in the center and lower in the outer) have also higher resistance and stiffness than the panels with homogeneous microsphere percentage core. A tendency to increasing on both properties was observed when displacement rate increases from 0.5 mm/min to 10 mm/min for the architectures of the panels.

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