A study of the fracture toughness on hybrid syntactic foams

J.A.M. Ferreira[1,a], C. Capela[2,b], J.D. Costa[1,c]

[1]CEMUC, Departement of Mechanical Engineering, University of Coimbra, Rua Luís Reis Santos - Pinhal de Marrocos, 3030-788, Coimbra, Portugal
[2]Polytechnic Institute of Leiria, Mechanical Engineering Department, Morro do Lena - Alto Vieiro, 2400-901 Leiria, Portugal

[a]martins.ferreira@dem.uc.pt, [b]ccapela@estg.ipleiria.pt, [c]jose.domingos@dem.uc.pt

Keywords: fracture, mechanical properties, syntactic foams, hybrid composites.

Abstract. Syntactic foams are attractive materials widely used as the core material in sandwich composites for aerospace and marine applications, but for many other cases is limited due to its brittle behaviour. This paper is concerned to study of the improvement on fracture toughness and flexure properties obtained in foams reinforced by the addition of low volume fractions of short glass fibbers. The foams were manufactured by using epoxy matrix resin filled with hollow-glass micro-spheres with weight content of 2.5% and 15%. Short glass fibber-reinforced were added with weight content up to 3%. The specimens were cut from plates produced by resin transfer moulding. The geometry of the specimens and the tests procedure was done according to ASTM standards. Stiffness modulus exhibits an expected and significant increasing with fibber content, but for the case of the samples with 3% of fibber and 15% of microspheres a decreasing was observed probably caused by the significant presence of microporosities. Contrary to expected only the foams with 2.5% microspheres show an increasing of strength and toughness for reinforcement content up to 1% whiles all other filler and/or fibber content foams exhibits a decreasing of both properties.

Introduction

Low-density sheet moulding compounds based in hollow glass micro-spheres are being increasing used, namely in automotive industry [1], boats and deep-water submarines [2] and core materials, where can present advantages compared with traditional metal, such as: lower weight, less expensive for low volume production in consequence of lower tool costs, no corrosion effects, a more design freedom, etc. Syntactic foams are potential good materials for applications where impact loads occurs in consequence of its ability to reduce impact force [3, 4].

As reported by Kim et al [4] the addition of hollow micro-spheres tends to reduce the Young modulus and ultimate strength. Even the specific values of flexural modulus are only marginally increased for high volume fractions of microspheres. Oldenbo et al [5] studied multi-layer foams and did verify that monotonic flexural stiffness modulus can be increased using materials with different charged formulation layers: low density in the centre and standard sheet moulding compounds in the outer layers. Also the thickness and size of micro-spheres can produce important changes on the mechanical behaviour. Wouterson et al [6] concludes that the effect of the micro-spheres volume fraction on the specific tensile and flexural strength and stiffness depends of the micro-sphere density and thickness to radius ratio.

The authors [7] conclude that fracture toughness K_{IC}, flexural stiffness modulus and ultimate strength decreases significantly with the hollow glass microsphere content increasing. However, the specific flexural stiffness modulus is only marginally affected by microsphere contents and the specific ultimate strength decreases slightly with filler content and the specific K_{IC} is only marginally affected.

Wouterson et al [8] using up 3 wt% short carbon fibres, with length from 3 to 10 mm, to reinforce foams manufactured with 30 vol% phenolic microspheres and epoxy matrix binding, did observe a concomitant strengthening and toughening. The tensile strength, Young's modulus, plane strain fracture toughness increased by 40, 115 and 95%, respectively, for the hybrid reinforced composites with 3 wt% short carbon fibres.

This paper presents the results of a current study of the mechanical characterization of hollow glass micro-spheres filled composites, fabricated with epoxy binder and reinforced with short glass fibber for weight content up to 3 wt%. It was studied the effect of the filler volume fraction and fibber content on the fracture toughness, and flexure stiffness and strength.

Materials processing and testing

The filler used in present study was the hollow glass microspheres K20 manufactured by 3M™ (St. Paul, Minnesota; USA) nominally with 50% of particles with diameter lesser than 55 μm. The binding resin was the epoxy 520 with hardener 523 supplied by Ashland Chemical Hispania (Benicarlo, Spain). The reinforcement fibre was a chopped strand for general purpose of glass E 3313 supplied by PPG with average length of 6 mm. Resin and hardener were mixed in a mixing pot and afterwards the microspheres (and fibber) were added while stirring. Composite sheets were manufactured by resin transfer moulding in vacuum by using an aluminium mould with a rectangular parallelepiped cavity of 200x200x10 mm. The mould was cleaned using acetone and treated with a release agent fluid green, methylcyclopropene (MCP).

Seven formulations plates were manufacture with different filler and reinforcements contents. The specimens were cut and machined from the moulded plates. The corresponding mixture densities obtained according to Archimedes principle and the contents of the each formulations studied are summarized in Table 1.

Table 1. Materials and composition.

Identification number	Net resin	% weight of glass fibber reinforcement, W_{fr}	% weight of microballons, W_{fm}	Density (g/cm^3)
F1	Epoxy	0	0	1.175
F2	Epoxy	0	2.5	1.075
F3	Epoxy	1	2.5	1.065
F4	Epoxy	3	2.5	1.088
F5	Epoxy	0	15	0.643
F6	Epoxy	1	15	0.655
F7	Epoxy	3	15	0.655

For both flexural and mode I fracture toughness tests the specimens were machined with the dimensions of 65x12x6 mm^3. Mode I fracture tests were performed in three-point bending loading with a span of 48 mm as shows in Figure 1. A pre-crack was produced by tapping and with a razor blade at the crack tip of the mechanical notch on each specimen. The crack length was measured after the test by using a microscopy mounted in an X-Y sliding base. The crack length was measured at least 12 points along the crack front for each specimen. An average standard deviation about 2% of the pre-crack was obtained.

Flexural tests and fracture tests were performed with a Shimadzu AG-10 universal testing machine, using 5kN and 1kN load cells, respectively, equipped with appropriate hardware and software. Flexural and mode I fracture toughness tests procedures were done according to ASTM D790-98 [8] and ASTM D5045-96 [9] standards, respectively. For the flexural properties analysis the load versus displacement curves were obtained directly and the stresses were calculated by using linear elastic bending beam relationships. The bending stiffness modulus was obtained by the linear elastic bending beams theory relationship

$$K_{IC} = \frac{\Delta P L^3}{48 \Delta u I} \tag{1}$$

where: L is the span beam, 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.

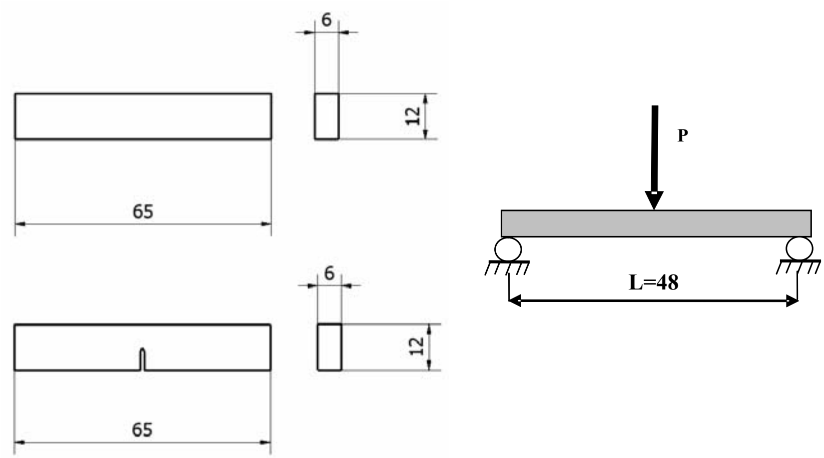


Fig. 1. Schematic view of specimen and loading apparatus for 3PB tests.

For each test condition at least five specimens were tested. Afterwards, the average and standard deviation values of the current mechanical property were calculated for each test condition.

According to the ASTM D5045-96 standard [9] the stress intensity factor for mode I fracture toughness in three-point bending loading is calculated by the equation (2)

$$K_{IC} = \frac{P_Q}{B\sqrt{W}} \left\{ \frac{6\sqrt{c}\left[1.99 - c(1-c)(2.15 - 3.93c + 2.7c^2)\right]}{(1+2c)(1-c)^{3/2}} \right\} \tag{2}$$

where: P_Q is the maximum force in this case where a brittle behaviour of the materials was observed, c=a/W, a is the crack length, B is the specimen thickness and W the specimen width.

Results and discussion

Figure 2 shows typical load- bending displacement curves for foams with 15% wt of microspheres and different values of reinforcement fibre content and also for net resin. It was observed a slight increase of stiffness when fibber content increases up 1%, but contrary to expected it decays for 3% wt of fibber reinforcement. The flexure strength appears small variation with the increasing of reinforcement content. In all cases both stiffness and flexure strength are much lower than the same properties of the net resin.

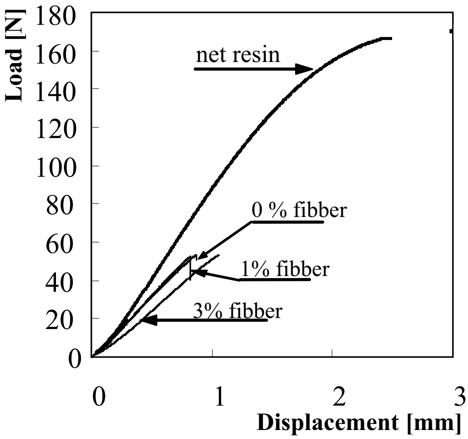


Fig. 2. Load – displacement curves for different values of reinforcement fibre content.

Figure 3 shows the average values and the standard deviation of the stiffness modulus, obtained by equation 1 for a composite formulation, against the weight fibber content. Figure 4 shows the average values and the standard deviation of the ultimate strength, in terms of the absolute values, against the weight fibber content. The ultimate strength was defined as the maximum bending stress obtained at middle span. Figure 5 shows the average values and the standard deviation of the fracture toughness, K_{IC}, obtained by equation 2, against the weight fibber content. Table 2 summarizes the absolute average values of the mechanical properties plotted in Figures 3-5. All three properties show significant lower values for foams with 15% wt than for foams with 2.5% wt of microspheres according with other studies [4,5]. Contrary, to the significant mechanical properties benefits observed by Wouterson et al [8] for carbon fibbers reinforced hybrid foams, the addition of low content glass fibber reinforcement did not increases significantly the values of the three properties and in some cases decays were observed. Stiffness modulus exhibits an expected and significant increasing with fibber content, but for the case of the samples with 3% of fibber and 15% of microspheres an important decreasing was observed probably caused by the significant presence of microporosities as shows Fig. 6c). Flexure strength and toughness exhibits a high sensitivity to the composite architecture, particularly, the fibber orientation and homogeneous distribution and microposities. In fact only the foams with 2.5% microspheres show the expected increasing of strength and toughness for reinforcement content up to 1% whiles all other filler and/or fibber content foams exhibits a decreasing of both properties. These properties decreasing were caused by the tendency to some fibber agglomeration and preferential orientation (Fig. 6b) and high porosity (Fig. 6c) growing with fibber and/or filler content.

Fracture surfaces were exanimate in scanning electronic microscopy (SEM) showing Figure 6 some pictures of these observations. Figure 6a) shows the fracture surface of a 2.5% wt microsphere and 1% wt fibber sample where it can be observed predominantly the separation between the microspheres (and the fibber) and the net resin. It is also observed a significant level of microporosities and plastic deformation bands in net resin. . Figure 6b) shows the SEM observation of a 15% wt microsphere and 1% wt fibber sample, showing a significant change of failure mechanisms in relation to previous picture. In this case a significant broken of fibbers and microspheres was observed. The plastic deformed of net resin was not observed. This picture reveals also a tendency to some fibber agglomeration and preferential orientation.

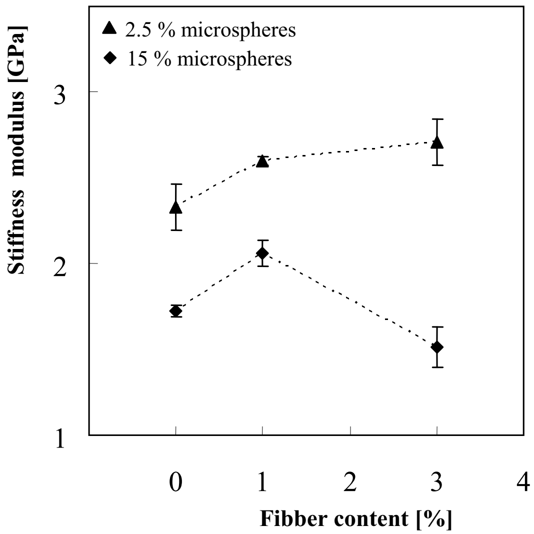


Fig. 3. Stiffness modulus against fiber weight fraction.

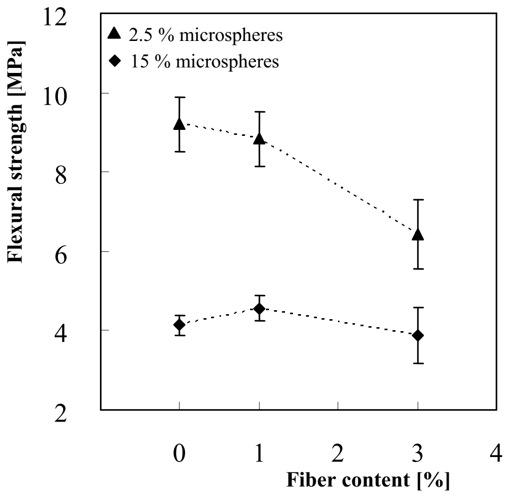


Fig. 4. Ultimate flexure strength against fibber weight fraction.

The fracture of one sample with 15% wt microsphere and 3% wt fibber is shown in Fig. 6c) where is not evident significant change of failure mechanisms in relation to previous picture. Only a significant increasing of microporosities was observed.

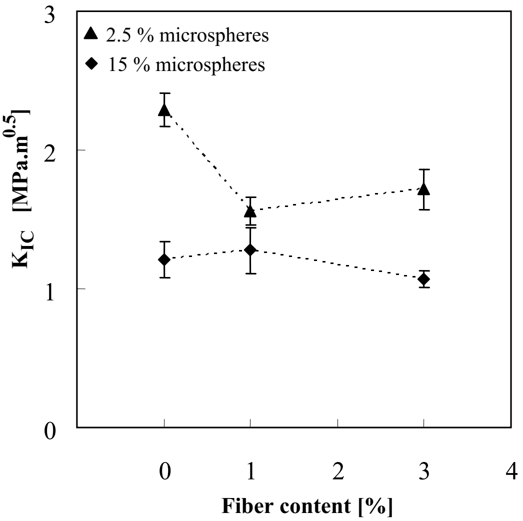


Fig. 5. Fracture toughness versus fibber weight fraction.

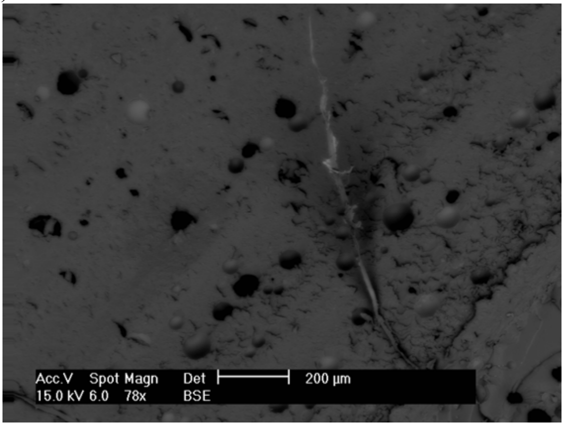
Table 2. Average values of flexural properties and fracture toughness.

Identification number	Flexural elastic modulus (GPa)	Flexural strength (MPa)	K_{IC} ($MPa.m^{0.5}$)
F1	2.6	141.6	3.15
F2	2.3	92.1	2.29
F3	2.6	88.3	1.56
F4	2.7	64.2	1.72
F5	1.7	41.3	1.21
F6	2.1	45.6	1.28
F7	1.5	38.7	1.07

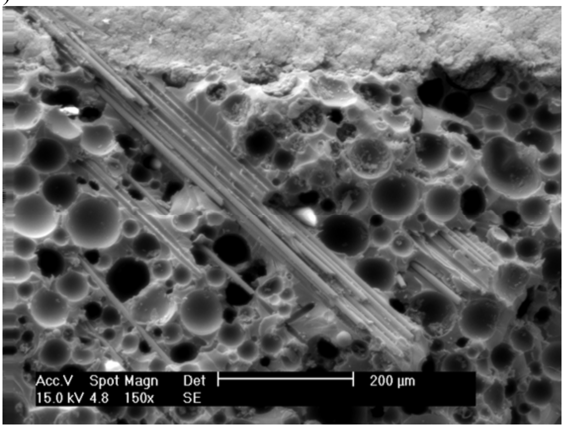
Conclusions

Flexural stiffness and strength and fracture toughness of hollow glass microsphere /glass fibre reinforced hybrid composites have been evaluated. All three properties show significant lower values for foams with 15% wt than for foams with 2.5% wt of microspheres. Stiffness modulus exhibits an expected and significant increasing with fibber content, but for the case of the samples with 3% of fibber and 15% of microspheres a significant decrease was observed probably caused by the significant presence of microporosities. Contrary to expected only the foams with 2.5% microspheres shows an increasing of strength and toughness for reinforcement content up to 1% whiles all other filler and/or fibber content foams exhibits a decreasing of both properties caused by the tendency to some fibber agglomeration and preferential orientation and high porosity growing with fibber and/or filler content.

a)



b)



c)

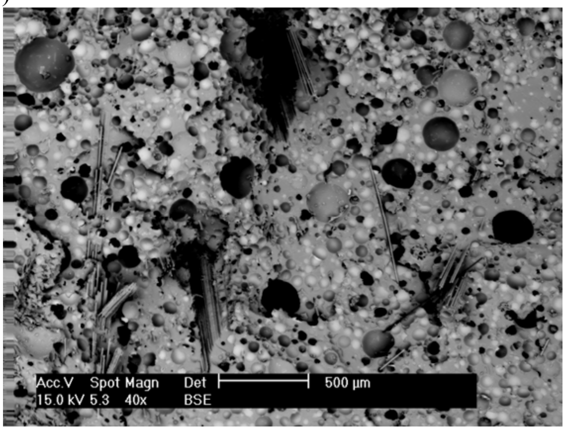


Fig. 6. SEM observations: a) 2.5% wt microsphere and 1% wt fiber; b) 15% wt microsphere and 1% wt fibber; c) 15% wt microsphere and 3% wt fibber.

Acknowledgments

The authors would like to acknowledge Project nº PTDC/EME-PME/66549/2006, promoted by Portuguese Foundation to science and Technology, for funding the work reported.

References

[1] - B.V. Gregl, M.A. Khamis: Reinforced Plastics (Oct. 1997), 34- 37.
[2] - R.A. Malloy, J.A. Hdson, International encyclopaedia of composites, edited by S. M. Lee, (VCH), (1990), p. 355.
[3] - H.S. Kim, H.H. Oh: J. Appl. Polym. Sci. Vol. 76 (2000), 1324-1328.
[4] - H.S. Kim, M.A. Khamis: Composites Part A: Appl. Sci.and Manuf. Vol. 32 (2001), 1311-1317.
[5] - M. Oldenbo, S.P. Fernberg, L.A. Berglund: Composites Part A: Appl. Sci.and Manuf. Vol. 34 (2003), 875-885.
[6] - E.M. Wouterson, F.Y.C. Boey, X. Hu, S.C. Wong: Compos. Sci. Technol. Vol. 65 (2005), 1840-1850.
[7] - J.A.M. Ferreira, C. Capela, J.D. Costa: submitted to Journal of Polymer Composites (2008).
[8] - E.M. Wouterson, F.Y.C. Boey, X. Hu, S.C. Wong: Polymer Vol. 48 (2007), 3183-3191.