Mechanical Behavior of Basalt Fiber Reinforced Composites

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Abstract

With the growing adoption of composite materials, new matrix and reinforcement materials have been entering the market at an ever growing rate. These new materials have to be thoroughly tested in order to determine its mechanical properties and possible applications. Basalt fibers offer some advantages versus current materials, it is fireproof, requires no material addition, has better mechanical properties than most types of E-Glass, and it is cheaper than Carbon Fiber. The goal of this thesis is to understand the viability of basalt fibers as part of a composite, by determining its mechanical properties. The composites were tested with a Polyester resin matrix, produced by Resin Transfer Molding. The composites were subjected to tensile, compression, shear and flexural tests. The results were generally good and in line with the mixing rules predicted results, although with a somewhat high coefficient of variance. C-Scan Analysis was performed on the composites, to determine its origin. The analysis showed that the problem was the production method, since the composite layers were not evenly spaced, and possessed different spacing from specimen to specimen

Keywords: Composites, Basalt Fibers, Mechanical properties, C-Scan,

1. Introduction

Composites, with their high specific modulus and strength, are ever increasing in use on in day to day applications, mainly in the aerospace, aeronautic, naval and automotive industries, new materials have been introduced at a fast pace [1]. Basalt fibers (fig. 1), first patented in 1924[2], were the subject of intense development after the 1950's mainly in the Soviet Union. Unfortunately, given its strategic importance, all the research was classified until the 1990.

Figure 1 – Basalt Fibers

With the declassification of the research, Basalt fibers started resurfacing and are again entering the market, as a suitable fiber, with better mechanical properties than Fiber Glass(figure 2) and a much lower price than carbon fibers. With this resurfacing of Basalt fibers, mechanical testing must be performed in order to determine its mechanical properties. This paper is then focused on the results of the mechanical tests performed.

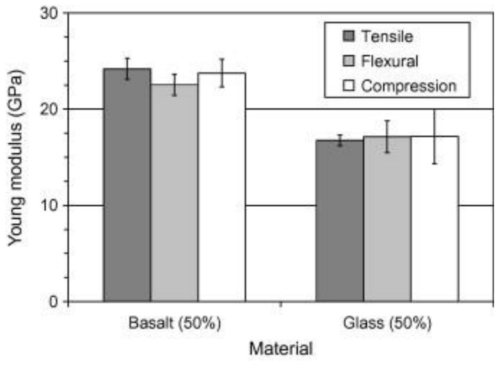

Figure 2- Mechanical properties comparison between Basalt and Glass Fibers

2. Specimens, equipment and test procedure

In order to determine the mechanical properties of Basalt fibers in composites, specimens were produced, with the Basalt Fibers (twill 2/2 weaving with 220 g/m² density) as the Fibers, and Unsaturated Polyester (2.8GPa Modulus of Elasticity, 1200Kg/m³ density) as the matrix. The process used to manufacture the

Composites was Resin Transfer Molding in an ISOJET RTM PISTON 2006 machine. Specimens were tested in tensile, compression, shear and flexural tests. The specimens were subjected to C-SCAN analysis to determine any problems in the composites during production. Finally a Composite paddle was produced by hand lay-up and a model of the same was subjected to finite element analysis to compare the results and validate the tests performed.

The specimen dimensions and test methods are shown in table 1.

Table 1- Specimen dimensions and Test methods

Test Method	Dimensions (mm)
Tensile (ASTM D-3039)	250x25
Compression (ASTM D-3410)	140x25
Bending (ASTM D-790)	140x25
Rail Shear (ASTM D-4255)	150x75

All of the tests were performed in an INSTRON 3369 electromechanical testing machine with a 50kN Loading cell. As shown in figure 3.

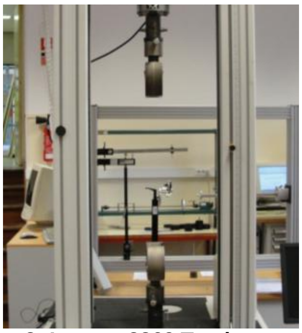

Figure 3- Instron 3369 Testing machine

3. Results and Discussion

3.1 C-Scan

As figure 4 shows, in some areas (blue areas) the ultrasounds produced by the C-SCAN did not fully penetrate the composite, indicating discontinuities.

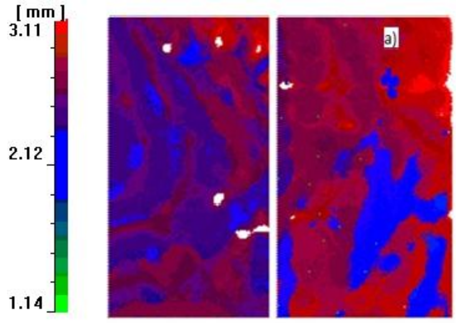

Figure 4 – Sample C-SCAN image showing Time Of Flight

When cutting the composites into the specimens, special attention was given to those areas indicating discontinuities. A microscopical analysis was performed on some of those sections (figure 5 and figure 6), and the cause for the discontinuities was determined.

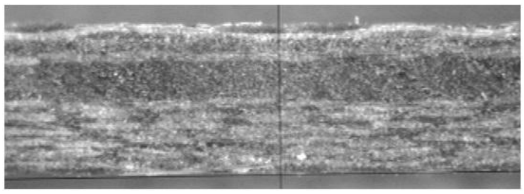

Figure 5 – Sample Specimen taken from the blue area

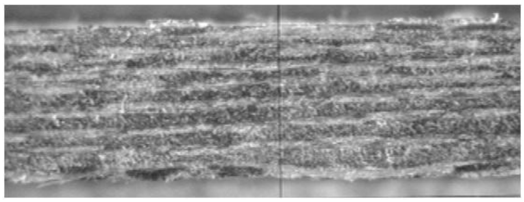

Figure 6 – Sample specimen taken from the Red Area

As the figures show, the discontinuities visible in the C-SCAN analysis are related to the fact that in figure 5, there is a gap between fiber filled with resin, resulting from the RTM process, where the resin used that gap as a preferential channel. In figure 6, representing the red areas, the composite is much more balanced with regular intervals between fibers. This difference in fiber layout will explain some discrepancies in the next tests.

3.2 0/90º Tensile tests

Figure 7 is the plotted results (Tensile stress/Strain) of a sample specimen and Figure 8 is the comparison between specimens from all the boards produced by RTM

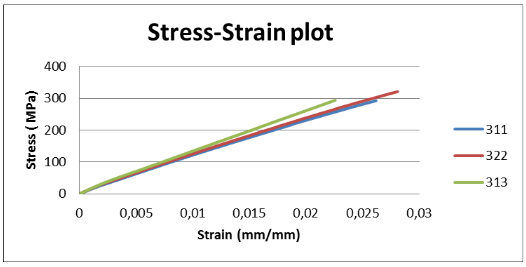

Figure 7 – Stress-Strain plot of a sample board

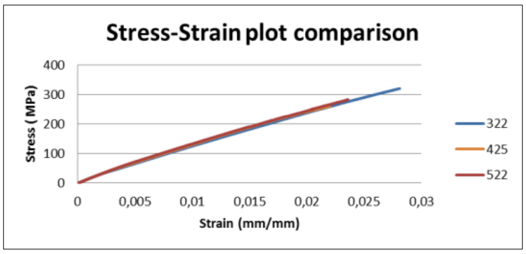

Figure 8- Stress-Strain plot comparison between all boards

Table 2 shows the results for all the specimens tested.

Table 2- Test results Young Modulus and Maximum stress

	Average (MPa)	StDev. (MPa)	Coef. Of variation
Max. Stress	291.1	18.2	6.3%
E	14302	1008	7.1%

As the results show there was no difference between all the specimens tested, which means that in compression the discontinuities found in the C-SCAN analysis had little effect on the specimens. All specimens failed in the same fashion with a first stage of matrix failure on the outside of the composite up to the first fiber layer, parallel to the direction of loading. By the time of maximum load the surface was filled with cracks, but there was no correlation between crack density and final failure of the specimen.

3.3 Compression 0/90°

In the compression tests 12 specimens were tested in compression. Figure 9 is a comparison between all specimens for a given plate.

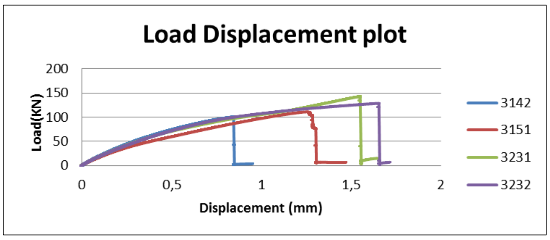

Figure 9 - Load Displacement plot compression

Figure 10 shows the Load Displacement plot of two instrumented specimens to determine the Young's Modulus in compression.

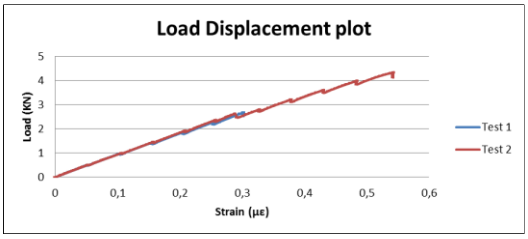

Figure 10 – Load displacement plot

Table 3 shows the results for Maximum Stress in compression for all the specimens

Table 3 – Test Results Max Stress Compression

	Average (MPa)	StDev. (MPa)	Coef. Of variation
Max. Stress	95.2	10.4	10.9%

Table 4 is the Young's Modulus calculated with the instrumented test specimens

Table 4 – Test Results Young's Modulus Compression

	Specimen 1	Specimen 2
Young Modulus (MPa)	18743	18867

As figure 9 shows that the behavior of the test specimens under compressive loads is quite varied with different maximum loads for different specimens, which explains the quite high coefficient of variation. In this test, the discontinuities observed in the C-Scan analysis are in effect, since the least homogenous specimens withstood smaller loads. Of interest if the fact that the Young's Modulus in Compression is somewhat higher than in Tension

3.4 3 point bending tests

Table 5 Shows the results for all the specimens tested in bending.

Table 5- Test results 3 point bending

	Average (MPa)	StDev. (MPa)	Coef. Of variation
Max. Stress	350.9	48.6	13.8%
E	13100	1180	9.4%

As table 5 shows, the Coefficient of variation is very high in the 3 point bending tests. This is due to the fact that discontinuities play a larger role in bending tests since if there is a higher amount of resin on one side of the specimen than on the other, then it produces an imbalance on the specimen due to the Moments produced in the tests, leading to earlier failure in such specimens. The modulus values are again in the same range as the previous tests.

3.5 Rail Shear tests

Figure 11 shows the load displacement curves of the rail-shear tests

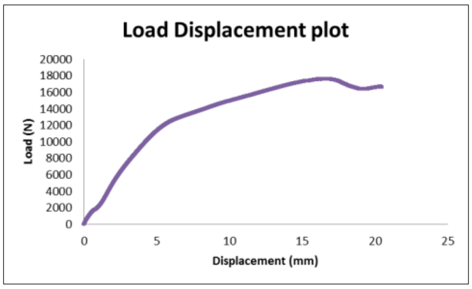

Figure 11- Load displacement plot

Table 6 Shows the results of the tests.

Table 6- Test Results

	61	62	63	64
Maximum Stress (MPa)	41,6	-	48,8	37,2
Average (MPa)		42,5		
St. dev. (MPa)		5,8		
Coefficient of variation		13,7%		

The results show the influence that the discontinuities observed in the C-Scan analysis have on the Rail shear tests cause a high coefficient of variation. Instrumented test specimens where also used to determine pure shear conditions with the results showing very little to no deformation outside the shear plane.

Conclusions

The non-destructive test by ultrasonic scanning enables the detection of areas where there is no uniform distribution of fibers in the composite, caused either by a high concentration of resin between two layers of fibers, or a high concentration of resin in one side of the specimen.

The results of the tensile test are in line with those obtained by use of rule of mixtures, with values of 14.5 GPa and 14.3GPa, respectively thus showing the applicability of the rule of mixtures.

The existence of too many irregularities and variations with respect to the thickness of the blade, as well as the concentration of resin in areas adjacent to the cable, does not allow a realistic analysis of the structure of the blade of the oar the finite element method.

It was possible to control the difficulty of effective manufacturing process for RTM and measure the influence it has on the properties of composite plates. It was possible to verify that the samples from the same plate had values closer to each other, even taking into account that they had all been manufactured following the same procedure and using the same source material.

References

[1] Putting it together - Science and Tecnology of Composite Materials. http://www.science.org.au" (Retrieved October 2012)

[2] Ross A. (2006), Basalt Fibers: Alternative To Glass? , "http://www.compositesworld.com" (Retrieved October 2012)