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Mechanical behavior of basalt fibers in a basalt-UP composite

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Abstract

With the increasing interest in sustainable solutions in material design in the last decade, research on natural materials (animal, vegetal or mineral) has increased at a rapid pace. Of these materials, Basalt Fibers for composite construction provide an interesting set of mechanical properties, equal or above to those of Glass Fibers, with advantages in terms of cost effectiveness and production to vegetable based Natural Fibers. 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. This paper studies the mechanical properties of a Basalt Fiber composite in an Unsaturated Polyester matrix produced by Resin Transfer Molding (RTM), with the composites subjected to tensile, compression, shear and flexural tests. The results aligned with the predicted values by using the mixing rule, albeit with a high coefficient of variation, which microscopic analysis confirmed to arise from production issues with RTM.

Keywords: Composites, Basalt fibers, Mechanical properties , Unsaturated Polyesther

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1. Introduction

Composites made with fibers such as carbon fibers, glass fibers or aramid fibers and resins such as epoxy have very good properties when designed correctly, although there is one unavoidable problem with such composites

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which is what to do with them at the End Of Life (EOL) stage. While recyclability is a possibility in some composites, most are simply burnt or buried, with the accompanying environmental problems related to those disposal processes Herrmann, Nickel, & Riedel (1998). In order to alleviate these issues, natural fibers and resins have been a very busy realm of study in this last decade, in order to obtain more environmental friendly composites.

As such Natural fibers, fibers of animal, vegetal or mineral basis have surfaced to meet the double requirements of better environmental performance and sustainability.

The most studied "Natural" fibers are vegetable fibers from jute Alves *et al.*, (2010), ramie Gu, Tan, *et al.* (2014), sisal Sangthong, *et al.*(2009), among others. Bio resins study started at the same time as "natural" fibers, generally working together with them to provide true "green" composites Deka, *et al.* (2013), Bakare *et al.*(2014). A good review of the current art in vegetable fibers and Bio resins can be found in La Mantia & Morreale (2011) and Koronis, *et al.* (2013).

There is also another "natural" fiber (although its status as a true natural fiber is debated, given the definition above), which is not plant based, basalt fibers.

Created and developed by the Moscow Research Institute of Glass and Plastic on the former Soviet Republic in the 1950's, Basalt Fibers, produced by the melting and extrusion of Basalt rocks, which themselves are a product of volcanism processes, is a Natural fiber with high mechanical properties and cost-effectiveness Morova (2013). The main production method of basalt fibers is similar to Glass fiber, with the melting of washed and broken Basalt rocks at temperatures around 1500ºC. The material is then pushed through a bushing with hundreds of small holes which is then spun into a yarn, creating basalt fibers.Lopresto, *et al.* (2011).

Initially studied from a civil engineering view, especially the reinforcement and protection of concrete structures, the properties of Basalt fibers soon caught the attention of the engineering community, and extensive studies have been performed on basalt fiber composites, as shown by Fiore, *et al.* (2015), and Dhand *et al.* (2015).

2. Specimens and test methodology

2.1. Specimens

To determine the mechanical properties of the basalt fiber as a part of a composite structure, composite material boards were produced at IST by RTM and prepared in the mechanical laboratories consisting of eight layers of a 2/2 twill bi-axial 0º/90º basalt fiber with Unsaturated Polyester (UP) Resin as matrix with the properties for each material shown in Table 1. Six boards were produced in total with the fiber orientations shown in Table 2. From the total number of fabricated specimens, several were produced to the different test methods used in the study with the dimensions shown in Table 3.

Table 1 – Fiber and resin properties

		Value	**Units**
Unsaturated Polyester	Density	1200	Kg/m³
	Modulus of Elasticity (E)	2.8	GPa
Basalt Fibers	Density	220	g/m²
	Modulus of Elasticity (E)	85	GPa

Table 2 – Composite boards by fiber orientation

Fiber orientation	**Boards**
±45°	1, 2
0/90°	3, 4, 5, 6

2.2. Test Methodology

In order to determine the properties of the composite material produced, 5 test methods were used as to ascertain the behavior of the composite material when subjected to tensile and compressive loads, flexural loads and shear loads. The ASTM test methods used to determine the behavior are shown in Table 3 with the corresponding specimen dimensions. All the tests were performed in a Instron 3369 electromechanical testing machine, running the Instron BlueHill software.

Table 3 – Test Method specimen dimensions

Test Method	**Specimen Dimensions (mm)**
ASTM D 3039 Tensile properties	250x25
ASTM D 3410 Compression	140x25
ASTM D790 3 point bending	140x25
ASTM D 3518 In Plane shear	250x25
ASTM D 4255 Rail shear	150x75

Fig. 1 – Instron 3369 testing machine

3. Results and discussion

3.1. Tensile Tests (ASTM D3039)

Table 4 shows the average, standard deviation and coefficient of variation of the maximum stress and modulus of elasticity of the ASTM D3039 tensile tests.

Table 4 – Average maximum stress and modulus of elasticity tensile tests

	Max Stress (MPa)	E (Mpa)
Average	291.4	14302
Stdev	18.2	1008
CV	6.3%	7.1%

As table 4 shows the value of the Modulus of elasticity is between the values of the fiber and the resin as expected. In order to determine the tests it was decided to compare the experimental value with analytical values obtained by the composites mixing rules. A specimen with no visible production defects and cut to tight dimensional specifications was used in order to calculate volume and weight:

$$Volume = \ 0.0000328\, m^3 \tag{1}$$

$$Area = 0.01368\, m^2 \tag{2}$$

$$M_{specimen} = 0.05182\, Kg \tag{3}$$

With the number of layers and area density of the fibers the mass of the fibers was calculated:

$$M_{fibers} = 0.024\, Kg \tag{4}$$

and from there the matrix volume was obtained:

$$M_{specimen} = M_{fibers} + \rho_{matrix} V_{matrix} \rightarrow \ V_{matrix} = 2.311 \times 10^{-5}\, m^3 \tag{5}$$

With these values the specific density of both fiber and resin was calculated.

$$\vartheta_{matrix} = \frac{V_{matrix}}{V_{specimen}} = 0.704 \tag{6}$$

$$\vartheta_{fibers} = 1 - \vartheta_{matrix} = 0.296 \tag{7}$$

Using a Krenchel factor of $\eta = 0.5$, for biaxial fibers aligned with the main directions and the Modulus of Elasticity for both resin $E_m = 2.8GPa$, and fibers $E_f = 85GPa$,the composite modulus of elasticity is:

$$E_c = \ \eta E_f \vartheta_f + E_m \vartheta_m = 14.5\ GPa \tag{8}$$

Which is for all intents and purposes the value obtained experimentally.

3.2. Compression Tests (ASTM D 3410)

Table 5 shows the average, standard deviation and coefficient of variation of the maximum stress and modulus of elasticity of the ASTM D3410 compressive tests. As table 5 shows the max stress is lower for the ±45º composite material due to the scissoring effect suffered by the fibers when in compression in this orientation.

The modulus of elasticity in compression is about 24% higher than in tension, which is either a characteristic of the material, which should be further studied or there was a problem in how the modulus was calculated. The variability quite high, a factor that will repeat in subsequent tests which will be discussed in section 3.5.

Table 5 - Average maximum stress and modulus of elasticity compression tests

	Max Stress (±45°) (Mpa)	**Max Stress (0°/90°) (Mpa)**	**E (Mpa)**
Average	77.5	95.9	18805
Stdev	10.1	10.4	876.8
CV	13.04%	10.90%	14.60%

3.3. Three point bending (ASTM D790)

Table 6 shows the average, standard deviation and coefficient of variation of the maximum stress and flexural modulus of elasticity of the ASTM D790 flexural tests. As in the compression tests the maximum values of stress and modulus of elasticity is again lower in the ±45° composite material due to the fact that a composite with a 0°/90° orientation is more suitable to compressive and tensile solicitations (since the fibers are normal to the loading plane).

Table 6 - Average maximum stress and flexural modulus of elasticity 3PB tests

	Max Stress (±45°) (Mpa)	**E (±45°) (Mpa)**	**Max Stress (0°/90°) (Mpa)**	**E (0°/90°) (Mpa)**
Average	181.2	7011	350.9	13191
Stdev	25.3	824.7	48.6	1250
CV	14%	11.76%	13.80%	9.40%

3.4. In Plane shear (ASTM D 3518) and Rail shear (ASTM D 4255)

Table 7 shows the average, standard deviation and coefficient of variation of the maximum stress and shear modulus of the ASTM D3518 in plane shear tests and ASTM D4255.

Table 7 - Average maximum stress and shear modulus in plane shear tests

	In Plane Shear		**Rail Shear**	
	Max Stress (Mpa)	G (Mpa)	Max Stress (Mpa)	G (Mpa)
Average	42	2715.3	42.5	2279.9
Stdev (MPa)	5.3	263.1	5.8	
CV	12.61%	9.70%	13.70%	

Although the maximum shear stress is similar in both shear tests, the shear modulus is lower in the rail shear test than in the in-plane shear tests. One possible reason for this difference is due to the complex stress state and the highly non uniform stress distribution in the test area, coupled with a non-pure shear stress state, in both test methods. With all of the value taken into account the whole picture of the mechanical properties of the Basalt-UP Composite material is shown on Table 8.

Table 8 – Mechanical properties of the Basalt-UP Composite material

	Thickness (m)	**E11 (Pa)**	**E22 (Pa)**	**E33 (Pa)**	**G12 (Pa)**	**G13 (Pa)**	**G23 (Pa)**
Basalt	3.13E-04	1.4E+10	1.40E+10	1.40E+10	2.70E+09	2.70E+09	2.70E+09

	+S1 (Pa)	**+S2 (Pa)**	**-S1 (Pa)**	**-S2 (Pa)**	**S12 (Pa)**
Basalt	4.60E+08	4.60E+08	-4.00E+08	-4.00E+08	4.20E+07

3.5. A note about variability

In the obtained results the coefficient of variation was high hoovering between 10% and 14%. In order to understand this high value of variability a microscopic analysis of the specimens was performed in order to determine whether the distribution of the fibers in the composite was even. The images obtained are shown in Fig. 2 with the lighter areas corresponding to the basalt fibers and the darker areas to the UP resin.

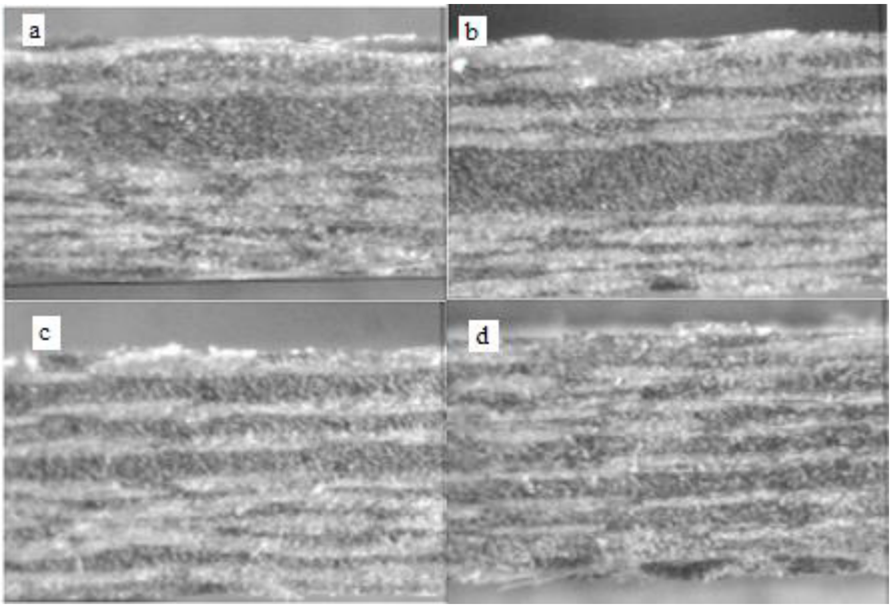

Fig. 2 – Microscopic inspection of test specimens a) thick resin layer between ply 3 and 4 b) thick resin layer in the middle of the composite c) layer thickness differences due to a higher volume of resin in plies 1 2 and 3 d) constant thickness layers

All the specimens studied are represented in these four images. In all of them, the fiber/resin distribution near the injection port flows in between two random layers, for at least 1/5th of the board length as seen in Fig.2a) and b). In some specimens the distribution remains the same from entry port to exhaust port but in most of them, as the resin flows through the board it begins to penetrate more and more layers (Fig. 2c)) until that, in some of the specimens the fiber/resin distribution is almost homogenous from layer to layer (Fig. 2d)).

This distribution also accounts for the fact that the standard deviation is smaller in the tensile tests, since even with the distribution of resin seen on fig. 2a), the impact of such a distribution is less impactful than:

- Instability it may have caused in the compression tests, leading to premature failure;

- differences in distribution of fiber/resin causes problems in the bending tests since there could be different fiber volumes being tested in the compression side of the beam and on the tensile side of the beam, which coupled with the differences in compressive and tensile moduli increase the variability;
- Shear behavior is also affected by the differences in resin distribution, although it is harder to quantify.

4. Conclusions

The experimental results of the tensile tests agree with analytical calculations via the composite mixing rules with a relative error of 1.32%. The modulus of elasticity in compression is about 24% higher than the modulus of elasticity in bending. In the tensile, compression, and flexural tests the failure occurs suddenly due to first ply failure of the outmost layer.

The shear tests show a difference in the shear modulus values between the rail shear and the ±45º tensile test although given that the specimens in each test came from different boards, it is difficult to evaluate which value is closer to the actual value which suggests further tests should be performed.

Given the variability of the results and the resin distribution on the specimens produced by RTM further study must be performed on the manufacturing methods used in IST in order to produce better specimens.

Finally the results of the Young's modulus place the basalt fibers in between E-Glass fiber composites and Carbon fiber composites.

References

Alves, C., Ferrão, P. M. C., Silva, A. J., Reis, L. G., Freitas, M., Rodrigues, L. B., & Alves, D. E. (2010). Ecodesign of automotive components making use of natural jute fiber composites. *Journal of Cleaner Production, 18*(4), 313-327. doi: http://dx.doi.org/10.1016/j.jclepro.2009.10.022

Bakare, F. O., Åkesson, D., Skrifvars, M., Bashir, T., Ingman, P., & Srivastava, R. Synthesis and characterization of unsaturated lactic acid based thermoset bio-resins. *European Polymer Journal*(0). doi: http://dx.doi.org/10.1016/j.eurpolymj.2014.11.045

Deka, H., Misra, M., & Mohanty, A. (2013). Renewable resource based "all green composites" from kenaf biofiber and poly(furfuryl alcohol) bioresin. *Industrial Crops and Products, 41*(0), 94-101. doi: http://dx.doi.org/10.1016/j.indcrop.2012.03.037

Dhand, V., Mittal, G., Rhee, K. Y., Park, S.-J., & Hui, D. (2015). A short review on basalt fiber reinforced polymer composites. *Composites Part B: Engineering, 73*, 166-180. doi: http://dx.doi.org/10.1016/j.compositesb.2014.12.011

Fiore, V., Scalici, T., Di Bella, G., & Valenza, A. (2015). A review on basalt fibre and its composites. *Composites Part B: Engineering, 74*(0), 74-94. doi: http://dx.doi.org/10.1016/j.compositesb.2014.12.034

Gu, Y., Tan, X., Yang, Z., li, M., & Zhang, Z. (2014). Hot compaction and mechanical properties of ramie fabric/epoxy composite fabricated using vacuum assisted resin infusion molding. *Materials & Design, 56*(0), 852-861. doi: http://dx.doi.org/10.1016/j.matdes.2013.11.077

Herrmann, A. S., Nickel, J., & Riedel, U. (1998). Construction materials based upon biologically renewable resources—from components to finished parts. *Polymer Degradation and Stability, 59*(1–3), 251-261. doi: http://dx.doi.org/10.1016/S0141-3910(97)00169-9

Koronis, G., Silva, A., & Fontul, M. (2013). Green composites: A review of adequate materials for automotive applications. *Composites Part B: Engineering, 44*(1), 120-127. doi: http://dx.doi.org/10.1016/j.compositesb.2012.07.004

La Mantia, F. P., & Morreale, M. (2011). Green composites: A brief review. *Composites Part A: Applied Science and Manufacturing, 42*(6), 579-588. doi: http://dx.doi.org/10.1016/j.compositesa.2011.01.017

Lopresto, V., Leone, C., & De Iorio, I. (2011). Mechanical characterisation of basalt fibre reinforced plastic. *Composites Part B: Engineering, 42*(4), 717-723. doi: 10.1016/j.compositesb.2011.01.030

Morova, N. (2013). Investigation of usability of basalt fibers in hot mix asphalt concrete. *Construction and Building Materials, 47*(0), 175-180. doi: http://dx.doi.org/10.1016/j.conbuildmat.2013.04.048

Sangthong, S., Pongprayoon, T., & Yanumet, N. (2009). Mechanical property improvement of unsaturated polyester composite reinforced with admicellar-treated sisal fibers. *Composites Part A: Applied Science and Manufacturing, 40*(6–7), 687-694. doi: http://dx.doi.org/10.1016/j.compositesa.2008.12.004