Characterization of novel polymer as a candidate replacement for low-cost GFRP laminates

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Abstract

Companies are always seeking to procure and implement cutting-edge materials that offer performance improvements of past iterations. Material suppliers in BC have been in discussions with some small-to-medium enterprises (SMEs), introducing them to polymer-only materials that can ostensibly replace two-phased composites. This research has focused on comparing the nominal glass-fibre reinforced polymer composite produced by the partnering company, to the proposed replacement material by the vendor. Results obtained indicate that the polymer-only product is not a suitable replacement for the GFRP laminate design used by the company, with the tensile and bending properties (modulus and strength) significantly lower.

Introduction

Composite materials have provided many companies with a competitive edge in various markets, largely due to the high strength-to-weight and stiffness-to-weight ratios for this class of materials [1]. Further, glass-fibre reinforced polymers (GFRP) also offer advantages, in that they are low-cost and the required processing has a low barrier for entry [2]. This has resulted in a wide variety of commodity products produced by GFRP, including pleasure craft, aquatic play structures, sporting equipment and many more.

Despite the plethora of advantages offered, companies are always seeking the next frontier in materials, in order to further optimize their products and processes towards reduced costs. To this end, FormaShape is actively exploring alternative material choices to the E-glass chopped strand mat (CSM) and unsaturated polyester resin (UPE) GFRP. Specifically, the company is in discussion with a vendor recommending the use of a polymer-only formulation that can match the performance specifications of their current composite material. This study is in support of this industrial activity, by providing mechanical test results to directly compare the modulus and failure strength of the materials, in both tensile and bending regimes. This will allow the company to make a more informed decision on material procurement.

Mechanical testing

In order to effectively compare the two materials, samples must be manufactured and tested in the tensile and bending regimes. Namely, tensile testing is performed according to standard ASTM D3039, while 3-point bend testing is conducted according to ASTM D790. These standards specify the required sample dimensions to extract meaningful results from the tests. The samples tested all had nominal dimensions of 120mm (L) x 30mm (W) x 5mm (H). The span/gauge length of the tests were chosen to be closer to 75mm, with the remaining length held in clamps or as overhang for bending samples. To produce the samples, sheets of the material was manufactured in a Light Resin Transfer Moulding (L-RTM) set-up by the company on their worksite. These flat sheets were then cut into the respective samples using an Omega 2652 JetMachining Centre water-jet cutter. All samples were measured using calipers to obtain the true dimensions. Samples were tested in an Instron 5969 50kN load frame. Given the two material types and two mechanical tests, three repeats were performed for each, for a total of 12 tests.

Evaluation of results

Both materials were mechanically tested to obtain the tensile strength, tensile modulus, bending strength and bending modulus. From load vs displacement values, Stress vs Strain curve for all the samples were also plotted using the following formulas:

	Modulus	**Strength**
Bending	$E = FL^3/4wt^3d$	$\sigma = 3FL/2wd^2$
Tension	$E = \Delta\varepsilon/\Delta\sigma$	$\sigma = F/wt$

Table 1. Equations used to calculate the mechanical properties of the materials tested.

Where F is the load in N, L is the span length in metres, w is the width of the sample in metres, t is the thickness of the sample in metres d is the displacement during the test in metres, ε is the instantaneous engineering strain (mm/mm) and σ is the instantaneous engineering stress (N/m^2).

After completing all mechanical tests, the samples were photographed as shown in Figure 1.

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Figure 1. All four classes of samples after mechanical testing was performed.

As can be seen, the GFRP samples' failure modes consistently showed fibre-matrix disbonding and delamination (although the sample remained partially intact by the end), which was also audible throughout the latter stages of the test. Comparatively, the polymer-only samples catastrophically yielded at the point of failure and the break fully detached both halves of the samples. Following the testing, load-displacement data was collected from the load frame and evaluated. The stress-strain curves for both the tensile and bending tests are shown in Figures 2 and 3.

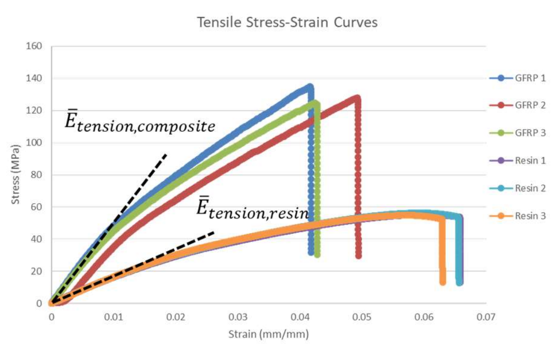

Figure 2. Tensile results for the materials.

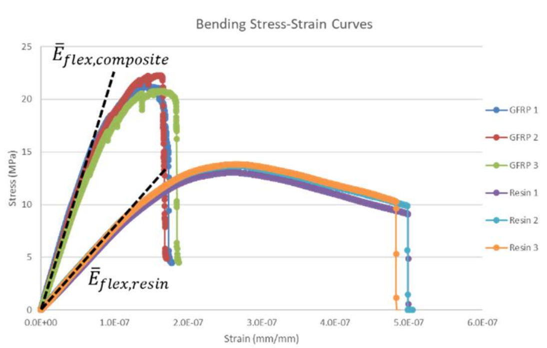

Figure 3. Bending results for the materials.

As can be seen, in both cases, the strength and the modulus of the composite material is significantly higher than that of the pure polymer sample. Namely, the breaking strength of the GFRP material is 230% that of the polymer-only sample. Conversely, the polymer-only material has a higher strain-to-failure (49.7% higher than the GFRP), indicating significant energy absorption. Further, the tensile modulus of the GFRP is 188% greater than the pure-polymer. Similarly, the bending strength of the GFRP was 59% higher and the modulus 182% higher, while the strain-to-failure for the pure-polymer samples were on average 178% higher. While this indicates an interesting trade-off of properties between the two material types, the stiffness- and strength-dominated designs of the company means that the higher strain-to-failure is inconsequential by comparison.

Conclusion

The calculated values of the mechanical properties have been presented in Table 2. The tolerance is indicative of the spread obtained from the three repeats of each test type.

	E-glass/UPE composite		Resin-only sheet	
	Tension	Bending	Tension	Bending
Ultimate tensile strength (MPa)	128 ± 5.46	21.5 ± 0.59	55.4 ± 0.605	13.5 ± 0.33
Failure strain (mm/mm %)	4.47 ± 0.337	1.78e-5 ± 6.62e-7	6.48 ± 0.13	4.98e-5 ± 7.33e-7
Modulus (GPa)	5.12	6.96	1.78	2.47

Table 2. Comparison of the mechanical properties.

Ultimately, the results obtained support the conclusion that the novel polymer-only material proposed by the material vendor is not a suitable replacement for the typical GFRP manufactured by the company.

References

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