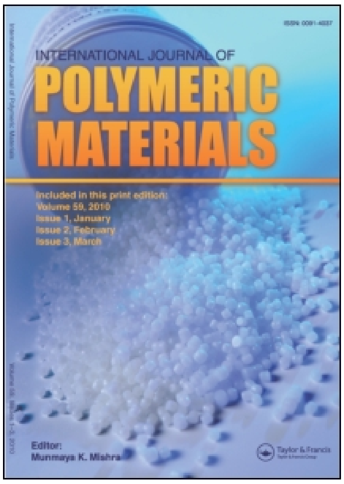

International Journal of Polymeric Materials
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713647664

Effect of Resin:Fiber Ratio on the Properties of Glass Fiber Reinforced Plastic Composites

M. Mariatti[a]; P. K. Chum[a]
[a] School of Materials & Mineral Resources Engineering, Universiti Sains Malaysia Engineering Campus, Penang, Malaysia

To cite this Article Mariatti, M. and Chum, P. K.(2005) 'Effect of Resin:Fiber Ratio on the Properties of Glass Fiber Reinforced Plastic Composites', International Journal of Polymeric Materials, 54: 10, 975 — 984

To link to this Article: DOI: 10.1080/009140390504906

URL: http://dx.doi.org/10.1080/009140390504906

International Journal of Polymeric Materials, 54:975–984, 2005

ISSN: 0091-4037 print/1563-5333 online
DOI: 10.1080/009140390504906

Effect of Resin:Fiber Ratio on the Properties of Glass Fiber Reinforced Plastic Composites

M. Mariatti
P. K. Chum
School of Materials & Mineral Resources Engineering, Universiti Sains Malaysia Engineering Campus, Penang, Malaysia

Studies on the effect of resin:fiber ratios on the properties of GFRPs were carried out. The GFRPS laminated composites were prepared by hand lay-up technique. Five types of resin:fiber ratios were studied such as 4:1, 3:1, 2:1, 1.5:1, and 1:1. The correlation of the resin:fiber ratio with the end physical and flexural properties was analyzed. In the present studies, the effect of water absorption on the flexural properties of GFRPs laminates was examined. As a result, it was found that the properties of GFRPs are governed by the resin:fiber ratio, which further influences the properties of GFRP before and after water absorption test.

Keywords: resin:fiber ratio, fiber content, GFRPs composites

INTRODUCTION

Glass Fiber Reinforced Plastics (GFRPs) are characterized by having a combination of properties such as high specific strength and stiffness, light weight, good processability, and low cost. On many occasions they have replaced such traditional materials as, for example, wood, metal, and ceramics. GFRPs are attractive for aircraft, transportation, construction, and marine applications [1]. Generally, the glass fibers that are used in GFRP laminates can be in two forms that are woven roving and chopped strand mat. For many applications, GFRPs are in laminated structure, therefore they are stacked and impregnated with polymeric resins. Various methods are used in fabrication of GFRPs; they include hand lay-up, spray-up, vacuum bagging, and resin transfer molding technique. Among the mentioned processing

Received 12 June 2004; in final form 21 June 2004.
Address correspondence to M. Mariatti, School of Materials & Mineral Resources Engineering, Universiti Sains Malaysia Engineering Campus, 14300 Nibong Tebal, Penang, Malaysia. E-mail: mariatti@eng.usm.my

techniques, wet hand lay-up is commonly used due to the low cost and ease of processability. Furthermore, the quality of the GFRPs product is governed by many factors such as types of glass fiber used in the composite system, type of resin, fiber content, stacking sequence, void content, and so forth.

In the present study, composite laminated E-glass fiber-polyester plaques were constructed using the hand lay-up method. By holding the amount of fiber content and varying the amount of resin, five types of resin:fiber ratios were obtained such as 4:1, 3:1, 2:1, 1.5:1, and 1:1. Here, the resin:fiber ratios indirectly refer to the variation of glass fiber content. Studies on the effect of fiber content on the mechanical properties of the composites are numerous [2, 3]. However, most of them do not correlate the effect of fiber content with resin:fiber ratio. It is noted that high product performance of composite materials can only be obtained with low resin-fiber ration or high fiber concentration. Here, the optimum ratio of resin and fiber will be determined by using flexural and physical testing.

Nowadays, GFRPs are being widely used in wet environment such as water tanks and sewerage tanks because of their excellent water resistance. During long-term use in wet environments, GFRPs often absorb water and the weight of the materials change, and as a result the mechanical properties are reduced. Therefore, the mechanical properties of the GFRPs during long-term use must be estimated exactly in order to design GFRPs structure in a safe manner. The weight change behavior of GFRP in aqueous environment has therefore been widely investigated [4]. To evaluate the actual influence of the weight-change, the flexural testing is performed after the samples reach saturation point, which is 22 days. The flexural strength and modulus before and after water absorption were compared.

EXPERIMENTAL DETAILS

Plaques Fabrication

The 3-ply composite plaques were fabricated using a hand lay-up method. E-glass fiber in the form of chopped strand mats (CSM 450) and woven roving (WR600) were impregnated with unsaturated polyester (Synolac 3310) resin. Methyl Ethyl Ketone Peroxide (MEKP) was used as a catalyst and it was added to the resins or gel coat to initiate the polymerization process. The stacking sequence of the laminate was fixed as chopped strand mat (CSM)-woven roving (WR)-chopped strand mat (CSM). The laminated composites were placed into a 800×340 mm mold followed by curing at room temperature.

Testing and Characterization

The laminate density was determined according to ASTM D 792 by measuring the differences between weight of a specimen in air and water. The fiber volume fraction (V_f) and fiber weight fraction (W_f) were then determined by physical ashing. The apparent void content was then determined according to the ASTM 2734-70.

Samples of 240 mm × 36 mm were cut from the laminates and dried in an oven at 80°C until a constant weight was attained. Each sample was then totally immersed in distilled water at room temperature. The moisture content was monitored, and the measurement continued until all the specimens were saturated. Flexural test was used to measure the properties of the GFRP samples after the exposure. The percentage of weight gain at any time (t), Mt as a result of water absorption, was determined by the following equation,

$$M_t(\%) = (Ww - Wd)/Wd \times 100 \tag{1}$$

where Wd and Ww denote, respectively, weight of dry material (sample weight before immersion) and weight of moist material.

The diffusion coefficient, D can be determined from the following equation,

$$D = \pi[h/4\,Mm]^2[(M2 - M1)/(\sqrt{t1} - \sqrt{t2})]^2 \tag{2}$$

where Mm = maximum moisture content, h = thickness of the samples, t1 and t2 = selected points (time) in the initial linear portion and M2 and M1 = respective moisture content.

The mechanical characterization of the GFRP composites was conducted by flexural test (ASTM D790-98). The size of the flexural specimens was 240 mm × 36 mm, with a span length ratio of 32 and a cross-head speed of Instron 3366 set at 5 mm/min.

RESULTS AND DISCUSSION

Table 1 shows the effect of different resin:fiber ratios on the physical properties of GFRP test specimen. As Table 1 indicates, the fiber weight percents increase as the resin:fiber ratios decrease. That is expected because the amount of resin used during fabrication decreased from the ratio of 4:1 to the ratio of 1:1, so the relative amount of fiber weight increased. The fiber volume fractions do not increase as the fiber weight percent does, because the number of voids increases with the relative fiber content.

It is noted that, in general, the densities of the plaques increase from ratio of 4:1 to 1:1. In this study, the density of glass fiber and

TABLE 1 Physical Properties of Different Resin:Fiber Ratios

Ratio of resin:fiber	Specimen density (g/cm^3)	Fiber weight fraction, W_f (%)	Fiber volume fraction, V_f (%)	Void content, V_v (%)
4:1	1.378 ± 0.004	20.41 ± 0.82	11.07 ± 0.44	4.56
3:1	1.395 ± 0.011	23.98 ± 1.05	13.17 ± 0.58	5.25
2:1	1.449 ± 0.008	33.11 ± 1.43	17.95 ± 0.28	5.66
1.5:1	1.481 ± 0.013	38.41 ± 1.68	22.39 ± 0.98	7.44
1:1	1.525 ± 0.018	48.26 ± 1.65	28.97 ± 0.99	10.33

polyester resin are 2.54 g/cm^3 and 1.3 g/cm^3, respectively, so it is expected that the plaque densities would increase as the fiber weight percent increases. As is known, the differences in physical properties might influence the mechanical properties of the composite materials.

Figure 1 represents the flexural strength and void content of glass fiber reinforced polyester laminate as a function of the resin:fiber ratio. In addition, the flexural strength of the glass fiber reinforced polyester laminate increases with the decrease of resin:fiber ratio. The flexural strength seems to obey the rule of mixture. From the graph, it was observed that composite laminate with higher glass fiber content has higher void content. It was reported in a previous work [3] that the reinforcing efficiency of the fibers began to fall when the fiber concentration exceeded 20 vol%. This is because of the poor wetting

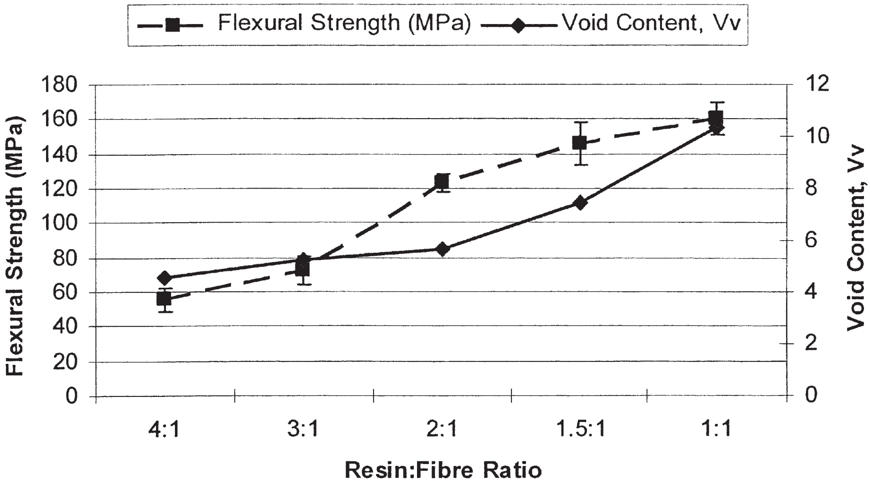

FIGURE 1 Flexural strength and void content vs. resin:fiber ratio.

obtained at high fiber content. Consequently, as the fiber content of the composite increases, the void content increases. Previous studies [2, 5] observed that the flexural strength reduces at high fiber content due to high void content. However, the trend shown here does not follow the trend observed in the previous work; it can be seen that the flexural strength increased with increasing fiber content and void content. This indicates that factors other than void content also play an important role in determining the flexural strength of this material. As known, apart from void content there are many other factors that influence the strength of composite system such as interphase properties, fiber orientation, fiber aspect ratio, and so on.

Figure 2 correlates the effect of resin:fiber ratios with strain at peak and matrix volume fraction (V_m). Examining the data as a function of resin:fiber content, it is clear that decreasing the ratio of resin:fiber or lowering the resin content results in a higher strain at maximum load. Previous work [6] on flexural properties of Acrylonitrile Butadiene Styrene (ABS)–glass fiber composites reported that the deflection or strain at peak represents the flexibility of the composite system. In their study, the flexibility is observed to correlate with amount of matrix content. Consequently, higher amount of resin content results in higher flexibility or deflection at peak. On the contrary, here it can be seen that the strain at peak decreases with the amount of matrix

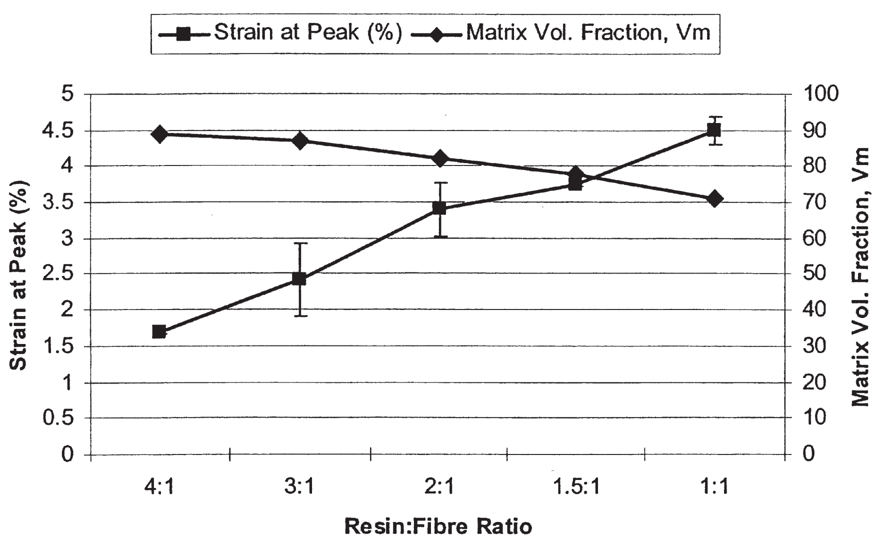

FIGURE 2 Strain at peak and matrix volume fraction, V_m vs. resin:fiber ratio.

content. This is because the matrix used in the present study was polyester, and as a thermoset resin, the crosslinked structure restricts the movement of polymer chains. Thus, higher amount of polyester resin content does not have any significant influence in increasing the strain at peak of the GFRP composites. On the contrary, higher matrix content shows lower strain at peak.

Figure 3 shows the flexural modulus and fiber volume fraction (V_f) as a function of the resin:fiber ratio. It was thus realized that the trend of the flexural modulus is consistent with that of V_f. For example, the lower resin:fiber ratios with the highest fiber content (V_f) result in higher value of flexural modulus. The same observation was also reported by many researchers [2, 5], where it was stated that the flexural modulus of a composite is strongly dominated by the V_f.

Composite applications frequently entail contacts with liquids or vapor, either aqueous or organic, affecting the immediate and the long-term performance of the materials. Polyester-glass fiber laminated composites are widely used in the construction industry as water tanks and sewerage tanks. Thus, problems pertinent to the role of permeability of composite materials must be of prime consideration as limiting factors. This applies in particular to the most

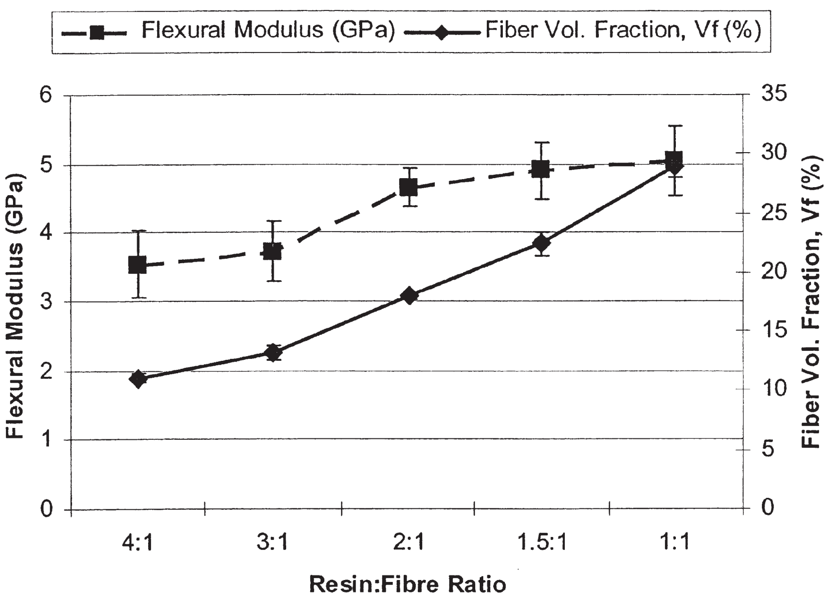

FIGURE 3 Flexural modulus and fiber volume fraction, V_f vs. resin:fiber ratio.

common phenomenon of moisture penetration in composities, which has become a principal limitation for industrial usage of such products. Water usually penetrates from the outer surface of the composite inward through continuous interfacial paths, and attacks the resin. Thus, it was felt pertinent to study the water absorption characteristics of different resin:fiber ratios.

Data of % of apparent weight gain or water uptake versus time are presented in Figure 4. In all cases, it is apparent that the absorption process is sharp at the beginning and leveled off for some length of time where it approaches equilibrium. It is considered that the change of weight gain (Mt) for all samples is a typical Fickian diffusion behavior. Apparently, lower resin:fiber ratio or higher fiber content was found to have a higher absorption rate when compared to the other resin:fiber ratios. As observed, higher fiber content in low resin:fiber ratio results in higher amount of void content. Void content in the materials is known to be a major factor driving water diffusion. Other factors that might contribute to a higher absorption rate are the fiber-matrix interphase, degree of fiber wet-out, and so on.

It is of interest to determine whether or not changes in flexural strength and modulus occurred after water absorption. To answer the question, the flexural properties were measured of specimens that were immersed for 22 days. Figure 5 shows the effect of water absorption on flexural strength and modulus. As expected, the flexural strength and modulus decreased with moisture absorption. It should be noted that severe debonding may occur at the fiber-interface and, as a result, the flexural strength and modulus of the composite reduced. The flexural modulus of all samples decreases by about

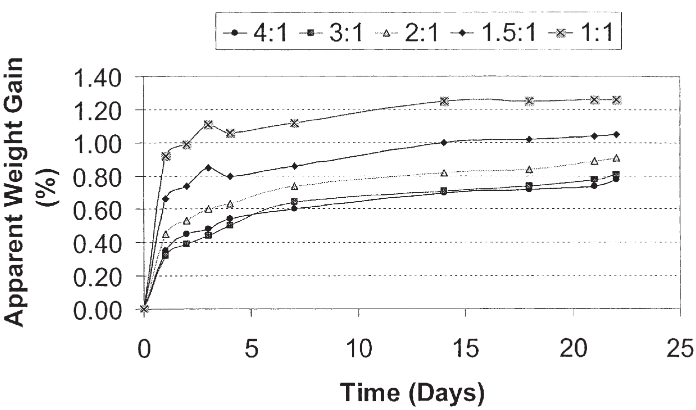

FIGURE 4 Water absorption behavior of different resin:fiber ratios.

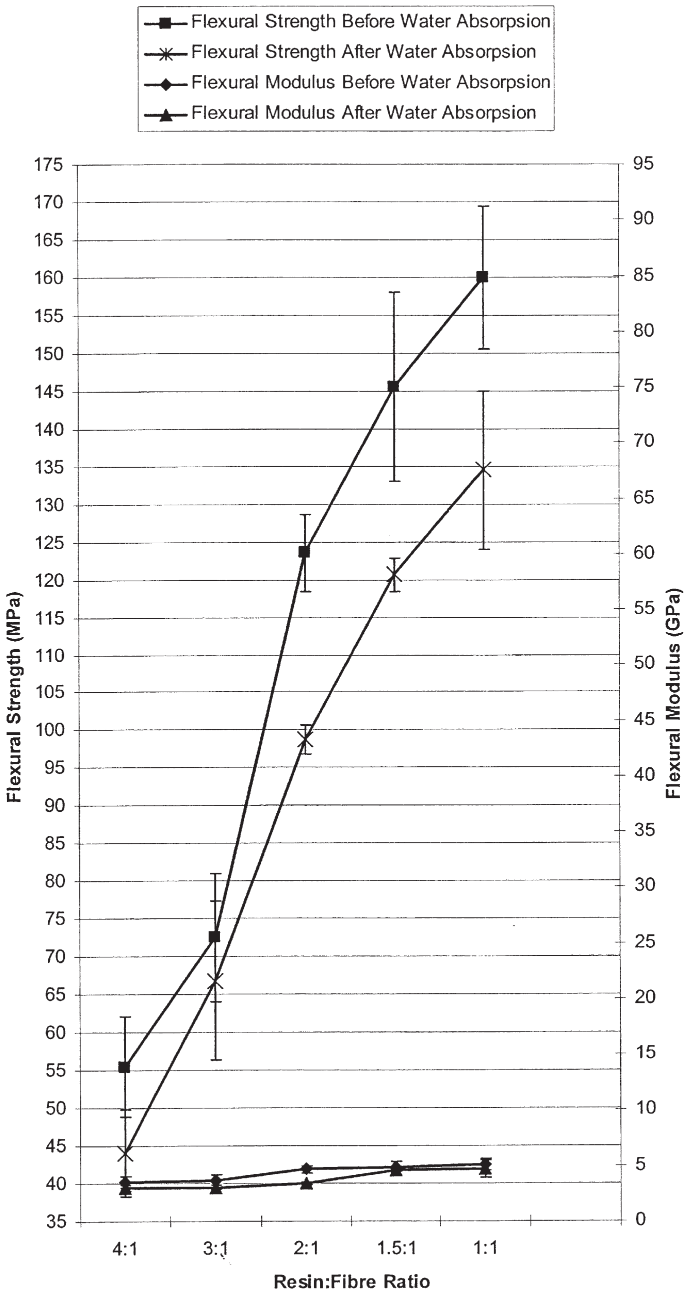

FIGURE 5 Flexural strength and modulus of different resin:fiber ratios, before and after water absorption test.

TABLE 2 Correlation between Resin:Fiber Ratio and the Thickness, Diffusion Coefficient (D) and Maximum Moisture Content (Mm) of GFRP Samples

Ratio of resin:fiber	Thickness, mm	D ($\times 10^{-12}$) $m^2\ s^{-1}$	Mm (%)
1:1	2.06	5.34	1.25
1.5:1	2.53	6.34	1.03
2:1	3.54	8.10	0.9
3:1	5.70	14.12	0.8
4:1	5.33	11.55	0.78

6–27% after the exposure. Although flexural modulus is a fiber-dominated property, preivous work [7] has showed that moisture exposure can induce a change in failure mode from fiber dominated to matrix dominated. Flexural strength was strongly affected by water absorption with a strength loss of 9 to 21%. This large decrease was possibly due to poor interfacial adhesion and change in failure mode, which has been shown by many researchers [7, 8]. Other reasons, such as matrix swelling and softening, may also contribute to the strength reduction.

Table 2 summarizes the thickness, diffusion coefficient (D), and moisture content at saturation level (Mm) of the spegmen. It was found that from the values of D, laminates with low resin:fiber ratios exhibits better resistance toward water absorption. From Eq. 2, it is noted that D value is proportional to the thickness and D is the reciprocal value of the Mm.

In short, from the experiments carried out on different resin:fiber ratio, it is apparent that decreases in resin:fiber ratio result in increased flexural strength and modulus, however, with higher void content and higher water absorption rate.

CONCLUSIONS

The effect of resin:fiber ratios on physical and flexural properties (before and after water absorption) were investigated. On the basis of the experimental results and discussion of this study, the following conclusions were obtained:

1. Lower resin:fiber ratio produces GFRP plaques with higher fiber volume fraction (V_f), fiber weight fraction (W_f), and void content.
2. Lower resin:fiber ratio or higher fiber volume content (V_f) results in higher flexural strength and modulus of GFRP composite.

3. Higher void content resulted in higher weight gain and higher water saturated level. Water absorption decreased the flexural strength and modulus of GFRP composite laminates.

REFERENCES

[1] Smith, W. F. (1990) *Principles of Materials Science & Engineering*, (MacGraw-Hill, New York).
[2] Lee, N. J. and Jang, J. *Composites Part A: Applied Science & Manufacturing*, **30**, 815 (1999).
[3] Thomsan, J. L., Vlug, M. A., Schipper, G., and Krikor, H. G. L., *Composites Part A: Applied Science & Manufacturing*, **27**, 1075 (1996).
[4] Akay, M., *Polymers & Polymer Composites*, **2** (6), 349 (1994).
[5] Jang, J. and Han, S., *Composites Part A: Applied Science & Manufacturing*, **30**, 1045 (1999).
[6] Mariatti, M., Nasir, M., Ismail, H. *Journal of Reinforced Plastics & Composites*, **21**, 711 (2002).
[7] Whithey, J. M. and Husnab, G. E. *Experimental Mechanica* **18** (5), 185 (1978).
[8] Drzal, L. T. and Madhukar, M. *Journal of Materials Science*, **28** (3), 569 (1993).