Nigerian Journal of Technology (NIJOTECH)
Vol. 37, No. 1, January 2018, pp. **167 – 172**
Copyright© Faculty of Engineering, University of Nigeria, Nsukka,
Print ISSN: 0331-8443, Electronic ISSN: 2467-8821
www.nijotech.com
http://dx.doi.org/10.4314/njt.v37i1.22

INVESTIGATING WATER ABSORPTION AND THICKNESS SWELLING TENDENCIES OF POLYMERIC COMPOSITE MATERIALS FOR EXTERNAL WALL APPLICATION IN REFRIGERATED VEHICLES

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ABSTRACT

Replacing external metallic wall of refrigerated vehicles has been on the front burner in many published works as weight of the metallic insulated panel continues to pose a challenge on refrigeration unit and environment. As a follow-up to this problem statement, five (5) composite materials were fabricated as replacement options for metallic external sheet for refrigerated vehicles. The key study of this paper is to investigate the moisture absorption and thickness swelling tendencies of these composite specimens as these properties determine the suitability of these materials for refrigerated wall. Part of the methodology adopted in the manufacturing of these composites were based on fibre loading and orientation in the composite panel. Key findings from this experiment shows that the absorption behaviour of composites at 30^o and 60^o was consistent until 60 hours duration of immersion before a significant disparity was observed. In addition, $G_{30}E$ (30% reinforced glass fibre in the epoxy composite) was more resilient to moisture attack as a result of enhanced fiber content. The implication of the study is that $G_{30}E$ reinforced composite material could be adopted as external wall of food transport system because of its lower thickness swelling and water absorption properties.

***Keywords**: Composite materials, refrigerated vehicle, orientation, water absorption, thickness swelling.*

1. INTRODUCTION

Application of polymeric composite materials have gained relevance in engineering application considering its weight reduction advantage over metallic materials. While the impact of lightweight materials appear to be gaining momentum in building and construction, its prospect for reinforcing moisture related structure has not been widely reported in many published works. Another novel application of polymeric composite panels may be found in refrigerated vehicles where lightweight materials are needed to replace the existing metallic sheet of external wall cover. In this paper, attempts were made to adapt the reinforced composite specimen fabricated for external wall of food transport vehicles.

Figure 1 shows the external wall of the refrigerated vehicle reinforced with the metallic sheet and the weight of this body wall is reported by Demharter [2] to constitute extra payload on vehicle system as shown in Table 1.

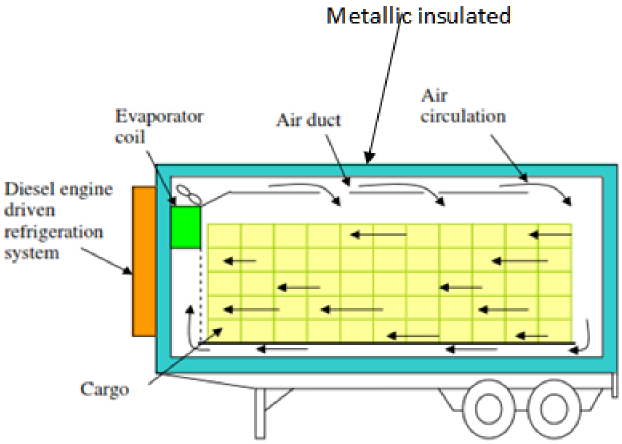

Figure 1: Pictural representation of cooling chamber of a refrigerated vehicle. Adapted from Novaes and Carvalho [1]

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Table 1: Average energy efficiency and energy intensity by vehicle type. Adapted from Tassou, et al. [3]

Vehicle class	Average fuel efficiency (motive only)		Average volume load	Average payload	Average energy intensity by volume	Energy intensity by weight
	Km/l	mpg	Pallet	Ton	Ml/pallet-km	Ml/ton-km
Medium rigid	3.87	10.94	5.78	2.25	33.0	83.8
Large rigid	2.91	8.21	8.69	7.41	31.8	37.1
City articulated	3.14	8.87	11.24	6.57	21.4	36.4
32 ton articulated	3.35	9.48	14.38	10.37	19.1	26.4
38 ton articulated	2.79	7.88	17.11	11.83	18.0	26.0

The implication of this metallic wall is that the entire payload increases from medium rigid to 30ton articulated vehicles which increases the energy demand in these vehicles. The purpose of this work was to develop a polymeric materials that will reduce the entire payload of this insulated panel which will overall reduce the fossil fuel demand in large rigid vehicle type.

Published works from other authors corroborated conclusion drawn from similar studies [4-6] as we can directly see that nearly 40% of the greenhouse gas emissions generated globally are from the diesel engine. Although, fiber-reinforced polymeric composite materials are acknowledged [7, 8] as a potential replacements for metals in situations where excellent strength properties, stiffness/weight ratios are desired, such properties makes this study to beam its searchlight on polymeric composite materials and to determine its suitability as per its water absorption and thickness swelling tendencies.

One of the concerns of polymer composite is its sustainability in moisture related application. Many researchers [9, 10] have raised a lot limitations inherent in polymer composite and it is part of the scope of the study to analyse the water absorption and thickness swelling of these specimen for external refrigerated wall. In many literatures, moisture penetration into reinforced composite materials is mostly transported by three different approaches. The most commonly process involves the diffusion of water molecules inside the micro gaps between polymeric composite chains. Another mechanisms through which moisture penetrates into the composite body materials is the interfacial adjoining gaps between fibers and polymer, where in most cases may be as a result of incomplete wettability and impregnation. Another medium of transportation could be as a result of micro cracks in the composite materials as a result of compounding process of fabrication of the specimens. In most cases, diffusion in glassy polymers is guided by the relative force of the penetrant (moisture) and of polymer segments. In the light of the above, the reinforcing fiber for this composite is fundamentally moisture resistant and as a result could enhance the properties of the matrix.

Etcheverry and Barbosa [11] have carried out an experimental works on the influence of the glass fiber on the adhesion properties of polypropylene and the results showed that the adhesion improvements was significant in the glass fiber reinforced composite than in the neat polypropylene. These results further enhance the mechanical properties of the resulting composite as against unreinforced composite thereby strengthening the moisture resistant property of the emerging composites. In a similar manner, Pérez-Pacheco, et al. [12] investigated the effect of mechanical properties of carbon fiber/epoxy unidirectional laminated composite on exposure to humid environment and the results showed that the mechanical properties of each of the composite differs considerably as humid environment becomes more intense. The impact of fiber surface treatment and coupling agent only enhanced the fiber-matrix adhesion.

2. MATERIALS AND METHODOLOGY.

2.1. Materials

In this present work, Ampreg 21 Epoxy resin and its corresponding hardener were sourced primarily for the manufacture of the composite specimens and glass fibers which serves as the reinforcing fiber, were equally purchased from AMT composites company, Johannesburg, RSA. Besides this, the attractive properties of these materials are presented in Table 2 and 3. These characteristics make these materials suitable for the refrigerated wall application. The selection criteria were only limited to materials of lower thermal conductivity and low density as outlined in the Tables.

Table 2: Physical and thermal properties of epoxy resin materials (Adapted from manufacturer data sheet)

Matrix material	Density^c (g/m^3)	Thermal conductivity^c (W/m°C	Heat capacity^c (J/g°C)	Coefficient of thermal expansion (°C)
Epoxy resins	1.2	0.049	0.640	$11x10^{-5}$

Table 3: Physical and thermal properties of reinforcing fiber (Adapted from manufacturer data sheet)

Fibre material	Density (g/m^3)	Areal density (g/m^3)	Mean fibre diameter (μm)	Thermal conductivity (W/m°C)	Heat capacity (J/g°C)	Coefficient of thermal expansion (°C)
E-glass	2.4	472	15	1.03	0.800	$0.5x10^{-5}$

2.2. Treatment of glass fiber

The glass fiber was preheated and dried in an oven at 200°C for 15 minutes, as specified in the company data sheet, in order to reduce any likely moisture absorption in the reinforcing fiber. Sheets of non-porous Teflon release film were also dried at ambient temperature in order to avoid any moisture interaction.

2.3. Mould Preparation

The square plate mould with dimensions: 480 × 480 x 3 mm was specifically fabricated for the development of the specimen test in line with other published works [13, 14] assembled with base and top plates, for the easy removal of the specimen, without sticking. The mould cavity was thoroughly cleaned in order to avoid particles interaction with the epoxy resin and were coated the inner layers of the mould with polyvinyl alcohol (PVA), for easy removal of the composite specimens.

2.4. Preparation of the Composite Test Specimens

Glass-fiber-reinforced epoxy resin were fabricated using hand-lay-up technique and the concept of fiber orientation was specifically considered in this work in other to ascertain the water absorption and thickness swelling tendencies of the composites when compared with unoriented composites as reported elsewhere [12, 15]. Newly manufactured ampreg-21 epoxy resin, which belongs to the larger family of epoxides was used as the matrix material and woven E glass fiber was used as a reinforcing fiber. The ampreg 21 epoxy resin and the corresponding Ampreg 21 hardener were mixed in a ratio of 100:33 by weight as prescribed in the manufacturer data sheet and all the composites were fabricated at room temperature. This experimental work fabricated five (5) composite sheets at different degrees of orientations and fiber loading. $G_{10}E$, $G_{20}E$ and $G_{30}E$ denote 10%, 20% and 30% weight of glass fiber respectively. $G_{10}E_{30}$ represents 10% weight of glass fiber at 30° orientation while $G_{20}E_{60}$ represents 20% weight of glass fiber at 60° orientation.

2.5. Water Absorption and Thickness Swelling Test.

Rectangular composite panel specimens of dimension 22.4mm x 66.2mm were used for water absorption and thickness swelling tests as per ASTM D-570-98. Fifteen samples were dried with three representing each composite sheet. All the samples were heated in an oven at 160°C for about 30mins in order to freeze any initial moisture that may be present in the samples and later cooled at room temperature condition for 4hrs. The initial weights and corresponding thicknesses of these samples were measured thereafter, to the nearest 10^{-3}g and 10^{-3}mm, respectively. All the specimen were later immersed in distilled water and studied on hourly basis for 7 days at room temperature (22±3°C). All the samples were measured with the digital balance and vernier caliper and the results were analysed. The moisture absorption and the thickness swelling were then estimated using the relations.

$$m(\%) = \frac{m_f - m_i}{m_i} \times 100 \tag{1}$$

$$TS(\%) = \frac{h_f - h_i}{h_i} \times 100 \tag{2}$$

where m_i is the oven-dried mass of the specimen before it was immersed in distilled water, while m_f is the final mass of the specimen after its immersion in water. Three samples were analysed for each panel and were reported. where h_i is the initial thickness (mm) of the composite specimen after it was oven-dried and h_f is the final thickness of the specimen after it was immersed in distilled water.

2.6 Flexural Test.

The flexural tests of the composite panels were conducted according to ASTM D790 using an INSTRON mechanical testing machine, model 4303 with a 10 KN load.

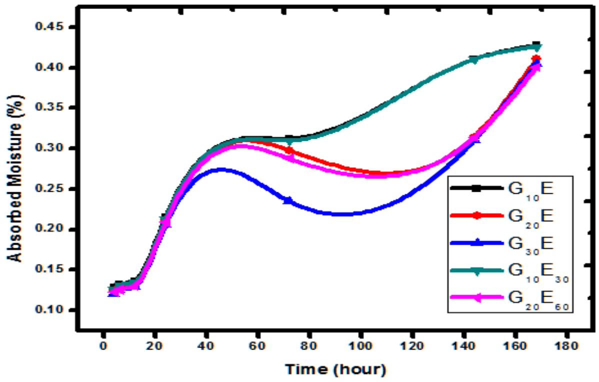

Figure 2: Plot of % moisture absorption for all the composite panels against immersion time.

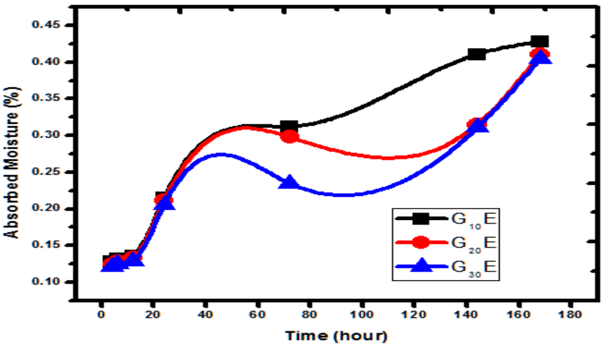

Figure 3: Plot of % moisture absorption for all composite materials at 0° fiber loading against immersion time

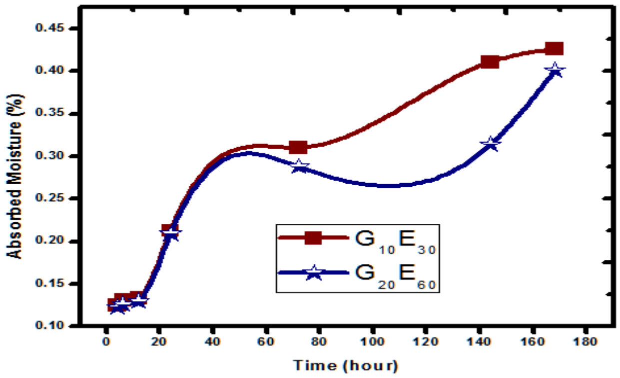

Figure 4: Plot of % moisture absorption for all oriented reinforced composite against immersion time

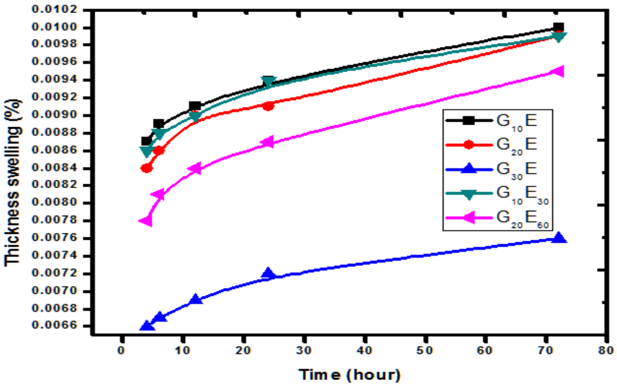

Figure 5: Plot of % thickness swelling against immersion time for all composite panels

The dimensions of the sample specimen were: 12.5mm in length, 6mm in width and 2mm thickness [16] and all the specimens were subjected to a 3-point bending until failure and fracture occurred in the specimens. A cross-head speed of 2 mm/min was adopted for this test, as specified in many past works. The span to thickness ratio adopted, was 15:1 as reported by Satish, *et al.* [17]. Three sample specimens were run for each composite panel and the average standard deviation were reported.

3. RESULT AND DISCUSSION

The absorption behaviours of all the composite specimens, measured at room temperature for a maximum period of seven days are shown in Figures 2-4 using the Equation (1) and (2).

It can be seen in Figure 2 that the percentage moisture absorption of all the specimens showed considerable rise as the exposure time increases, but there are significant reduction in the percentage water absorption as the fiber content increases. All the plots are parabolic in nature and these plots tend towards a convergence at a pseudo-equilibrium state (or a steady state situation), where no further water absorption increment was noticed.

The behaviour of the composite panels at 0° fiber orientation is shown in Figure 3. As observed from the plot, the moisture absorption of $G_{30}E$ appeared to be on the declining side when compared with the $G_{20}E$ and $G_{10}E$ composites. This behaviour reinforces the water resistance property of glass fiber reinforced composite as against natural fiber reinforced composite [18, 19].

Figure 4 shows the absorption behaviour of composites at 30° and 60° was consistent until 60 hours duration of immersion before a significant disparity was observed. There appears to be a similar trend in the general behaviour of glass fiber reinforced composites [20], irrespective of orientation. Joshi, *et al.* [9] also reported that the epoxy resin could easily be degraded by moisture, resulting in the weakening of the interfacial structure that exists in the glassy structure.

Figure 5 shows the plots for 10%-30% fiber content at 0° orientation and it can be seen that the thickness swelling increased with time but decreased with fiber contents with affirmed the hydrophobic character of the reinforcing fibers. This shows that thickness swelling increases with immersion time, until a specific value is attained where no defined thickness swelling occurred.

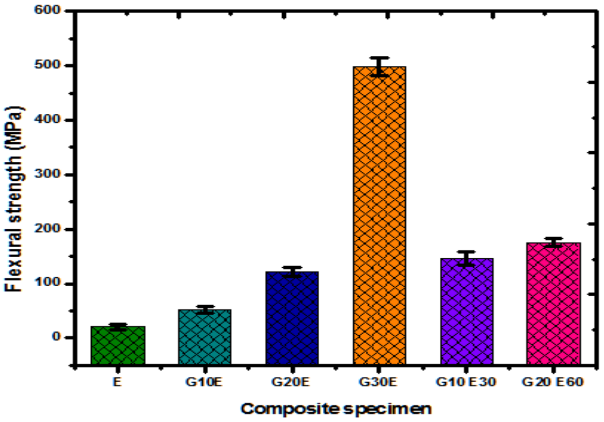

Figure 6: Impact of fiber content on flexural strength of reinforced composites.

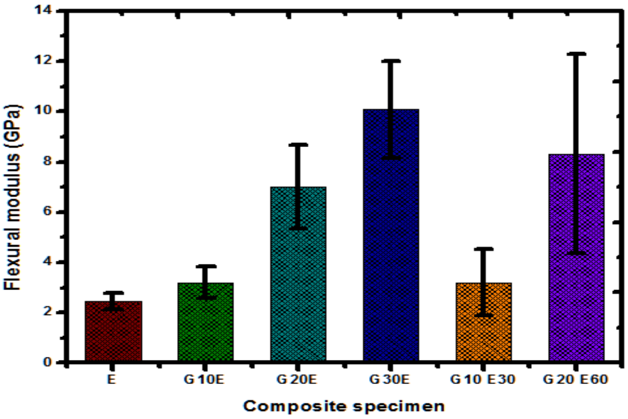

Figure 7: Impact of fiber content on flexural modulus of reinforced composites.

The thickness swelling of oriented reinforced composite specimens can also be seen Figure 5 and it can be seen that composite panel at 30^{o} orientation was more vulnerable to swelling tendency, which may be as a result of the poor interfacial adhesion occasioned by the large amount of adjoining area between the reinforcing filler and the hydrophobic matrix polymer.

The effect of successive fiber enhancement on the flexural modulus and strength of glass fiber reinforced epoxy resin specimen is discussed in this section. Considering the composite specimen at 0^{o} (Figure 6), it can be seen that there was ~2,390% improvement in the flexural strength of the $G_{30}E$ specimen and ~400% increment in the flexural modulus of the $G_{30}E$ specimen (Figure 7) when compared with the flexural strength and the modulus of the neat epoxy resin (E). The same trend was also observed with respect to the oriented reinforced composite, where the improvement in the flexural strength of the $G_{20}E_{60}$ specimen is ~20% for and ~160% in the tensile modulus when compared with the $G_{10}E_{30}$ specimen.

4. CONCLUSION

In this work, we have established the water absorption properties of five composite specimen taking into consideration oriented and unoriented reinforced composites. The research work has shown that as the fiber content increases, so also the resistant properties of these composite increases irrespective of fiber loading and orientation. This point to the fact that orientation of the fiber may not influence the resistant property of the composite. For any composite to be applicable for refrigerated vehicle wall, the moisture tendency of the composite material must be relatively low in view of the interactive nature of the refrigerated chamber and the body wall. From the analysis presented above, $G_{30}E$ appears suitable for refrigerated body wall with increased 30% fiber content in the epoxy resin. The other composite specimens show significant moisture resistance if compared with natural fiber reinforced composite materials even with enchanced fiber content. This fact may not be unconnected with hydroscopic nature of natural fiber. In a similar manner, thickness swelling properties of the composite specimens also followed the same pattern demonstrated by absorption plots. Generally, the thickness swelling decreases as the fiber contents increases which is also in variance with natural fiber reinforced composite. The flexural properties of these specimen are also reported in this study. The results showed over 2000% improvement in the flexural strength of $G_{30}E$ when compared with the neat resin. The same pattern of flexural strength and modulus are also noticed in all the plots most importantly as we increase the fiber contents.

5. ACKNOWLEDGEMENT.

The lead author would like to appreciate Tshwane university of Technology, Pretoria, South Africa and CSIR-IBS for providing the fund to embark on this work.

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