American Journal of Engineering Research (AJER)
e-ISSN: 2320-0847 p-ISSN : 2320-0936
Volume-8, Issue-3, pp-275-281
www.ajer.org
Research Paper Open Access

Water Absorption Capacity and Thermal Properties of Waste and Virgin Acrylics Fibres Reinforced Epoxy Composites

C. M. Ojo[1], B. M. Dauda[2], A. S. Lawal[2] And U. S. Ishiaku[2]
1- Department of Home Economics, Federal College of Education, Zaria, Kaduna State, Nigeria.
2- Department of Polymer and Textile Engineering, Ahmadu Bello University, Zaria, Kaduna State, Nigeria.
Corresponding Author: C. M. Ojo

ABSTRACT: *In this research work, acrylic waste fabrics were shredded into fibre, spun into yarn and woven into fabrics using table loom. The fibre, yarn and fabrics were made into composite using epoxy as the matrix. The virgin acrylics undergo the same process alongside with the waste samples. The composites produced through hand lay-up method were subjected to thermal and water absorption analysis. A careful observation of the weight loss profile show that at the initial decomposition temperature range where the acrylic component was volatilized, the virgin fabric composite showed a slightly more rapid loss in weight. This trend was again noted at around 400^{o}C to 600^{o}C, so that at the end, while the virgin composite showed a residual weight of 12 %, the waste composite exhibited a residual weight loss of 10 %. The water absorption capacity of waste composites was found to be higher than that of the virgin composites.*
KEY WORDS: *Acrylics, waste fabric, shredded, composite, thermal and water absorption capacity.*

Date of Submission: 25-02-2019 Date of acceptance: 18-03-2019

I. INTRODUCTION

Composites are the most important materials to be adopted for aviation since the use of aluminum in the 1920s. Composites are materials that are combinations of two or more organic or inorganic components. One material serves as a "matrix", which is the material that holds everything together, while the other material serves as reinforcement, in the form of fibres embedded in the matrix. Until recently, the most common matrix materials were "thermosetting" materials such as epoxy and unsaturated polyester. The reinforce materials can be glass fibre, boron fibre, carbon fibre or other more exotic mixtures. A composite material usually has characteristics that are not depicted by any of its components in isolation (Kaw, 2006 and Al-Mosawi, Ammash & Salaman, 2012).

According to Awad, Aravinthan, Zhuge, & Gonzalez, (2012), fibre reinforced polymer composite or more easily referred to as FRP is a relatively new material in the construction industry as compared to steel and concrete.The commonly used synthetic fibres are glass, aramid and carbon (Hollaway, 2010). The advantages of natural fibres over its synthetic counterparts include low weight, low cost, low density, biodegradable, availability from renewable resources, and good thermal and acoustic insulation properties (Dittenber and GangaRao, 2012, Liu, Takagi, Osugi, & Yang, 2012, Araújo, Waldman, & De Paoli, 2008). Temperature plays an influential role in the thermal stability of natural fibre composite where it causes direct thermal expansion or contraction and affects rate and volume of moisture absorption that leads to fibre swelling (Wang, Sain, & Cooper, 2005). The degradation process of natural fibres includes dehydration combined with emission of volatile components initiating at a temperature of about 260 °C, and rapid weight loss due to oxidative decomposition corresponding to the formation of char as the temperature increased (Beg and Pickering, 2008).

Thermo gravimetric analysis is one of the methods used to study the thermal degradation behaviour of natural fibre/polymer composites and its constituents. Approximately 60% of the thermal decomposition of most natural fibres occurred within a temperature range between 215 and 310 °C with an apparent activation energy of 160-170 kJ/mol (Yao, Wu, Lei, Guo, & Xu, 2008). For example, fibres from water hyacinth, reed, sisal and roselle decompose at 290-490 °C (Methacanon, Weerawatsophon, Sumransin, Prahsarn, & Bergado, 2010) while bamboo fibres degrade at 250-420 °C (Lee and Wang, 2006).

Water absorption is used to determine the amount of water absorbed under specified conditions. Factors affecting water absorption include: type of matrix, filler used, filler content, temperature and length of

exposure. The data obtained usually sheds light on the performance of the materials in water or humid environments.

Water absorption of composites is important in case the material that has been developed when used for applications comes in contact with water. There is much more information on interaction of water with structural resins. This scientific interest has arisen because water interactions with resins can degrade the mechanical properties of the resins (Low*et al*., 2007). Water can cause the resins to swell and produce what is called "crazing" of the surfaces. Water absorbed in the resins can reduce the glass transition temperature (Tg) of the polymers and make them weaker. The manner in which composite materials absorb water depends upon several factors such as temperature, fibre volume fraction, orientation of reinforcement, permeability nature of fibre, and area of exposed surfaces, diffusivity, reaction between water and matrix and surface protection.

II. MATERIALS AND METHODS

The research work was carried out in three stages; in the first stage, waste fabrics were collected and shredded into fibres. The fibres obtained were characterized and spun into yarns by Chellco Industries, Kaduna. The yarns were woven into fabrics with the use of a hand loom by the researcher. Similarly, the virgin fibres were spun into yarns and the yarns were woven into fabric using the same processing conditions. In the second stage, molds were produced, and various composites were fabricated using fibres, yarns and fabrics (virgin and waste) as the reinforcing materials, epoxy resin was used as the matrix. The composites were fabricated by hand-lay-up method. The third stage involved analysis of the fabricated composites for various mechanical and other properties. The samples were characterized for strength before using them to produce the composites. All samples used were conditioned under standard atmosphere for testing textile for 48 hours.

Epoxy Composite Preparation

The composites were prepared using hand lay-up method. The reinforcing agents were fibres, yarns and fabrics of waste and virgin acrylic fibre. The matrix used was epoxy resin which comes in twin form (epoxy and hardener). In the fabrication process, the epoxy resin and the hardener, with a ratio of 2:1, was uniformly mixed using hand lay-up method and poured into the mould and kept for curing at room temperature for 24 hours.

Thermal Gravimetric Analysis

The thermal study of the composite samples was performed on an SDTQ 600 Thermal instrument. Virgin and waste fibres, yarns and fabrics samples were contained within alumina crucibles and heated at a rate of 10^{o}C/min, from room temperature to 600^{o}C under flowing nitrogen at a rate of 75mL/min.

Water absorption test

The water absorption test was carried out in accordance with ASTM D570 of 2003. Water absorption is used to determine the amount of water absorbed under specified condition. The test specimens were weighed on a mettler balance before they were immersed in water. The materials were then immersed in water for 48 hours. Specimens were removed, parted dried with lint of free cloth and then weighed again. The change in weight was recorded and water absorption was then expressed as increase in weight percent.

$$\text{Percent Water Absorption} = \frac{(\text{Wet weight} - \text{Dry weight})}{\text{Dry weight}} \times 100$$

III. RESULT AND DISCUSSION

Thermal Gravimetric Analysis (TGA) of Various Composites

Thermo gravimetric analysis (TGA) is one of the members of the family of thermal analysis techniques used to characterize a wide variety of materials. TGA measures the amount and rate (velocity) of change in the mass of a sample as a function of temperature or time in a controlled atmosphere. The measurements are used primarily to determine the thermal and/or oxidative stabilities of materials as well as their compositional properties. The technique can analyze materials that exhibit either mass loss or gain due to decomposition, oxidation or loss of volatiles (such as moisture). It is especially useful for the study of polymeric materials, including thermoplastics, thermosets, elastomers,composites, films, fibres, coatings and paints. TGA measurements provide valuable information that can be used to select materials for certain end-use applications predict product performance and improve product quality.

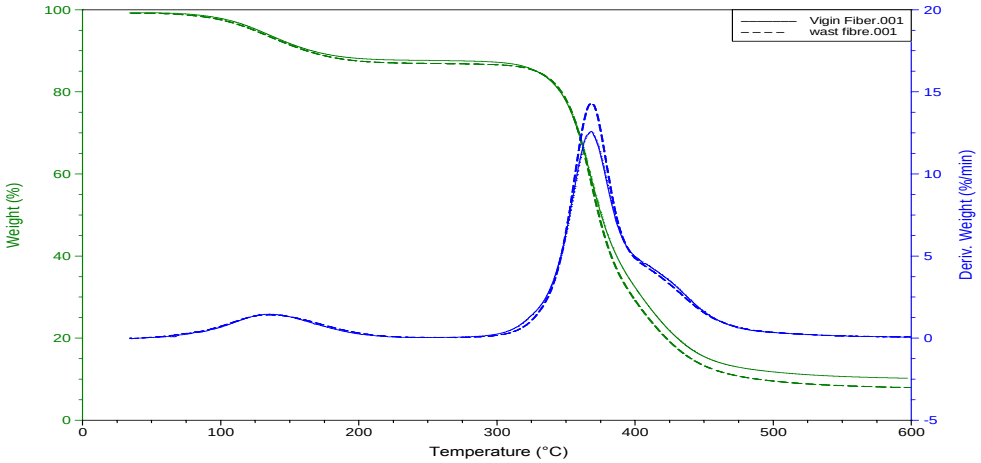

Figure 1: TGA ofvirgin and waste fibre composites

Figure 1 shows the thermo gravimetric (TGA) results generated on virgin and waste fibre composite. The plot shows the percent mass as a function of sample temperature for virgin and waste fibre composite under a nitrogen purge. Approximately 10 mg of sample was heated at a rate 10^{o}C/min with STDQ 600 thermal instrument.

At about 100^{o}C a gradual loss in mass begins. This can be traced to loss of moisture content of the composite. The loss in mass continued above 100^{o}C at a slightly faster rate and at about 160^{o}C, a loss in weight of 15 % was observed. Acrylic fibres is one of the very sensitive synthetic fibres that begins to degrade when heated near their melting point. Thus the loss in weight was as a result of polatilization of the acrylic fillers in the composite structure.

It was further observed in Figure 1 that the main onset of decomposition commenced at about 340^{o}C till the final decomposition at temperature of about 450^{o}C in which 83 % of the acrylic/epoxy fibre composite material have been lost. At 500^{o}C, 550^{o}C and 600^{o}C, the weight loss was 90 %, indicating that the composite material had experienced a total decomposition leaving 8 % residue (ashes).

A final observation from Figure 1 was that the waste fibre composite had a slightly higher weight loss compared with the virgin fibre composite. At the initial decomposition stage where the acrylic component melted and volatilized, the loss in weight for virgin fibre composite was 15 %, that of the waste composite was about 16 %. At the final decomposition stage at 600^{o}C, the virgin composite showed a weight loss of 90 % while the waste fibre composite showed a loss of 92 %. The probable reason for this was that the waste acrylic which has been depolymerized by UV radiation during use, volatilized more readily during the heating process compared with the virgin, acrylic fibre component.

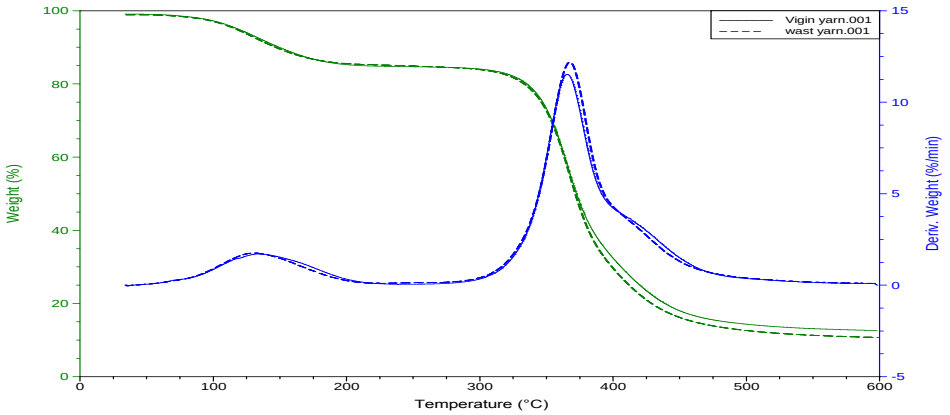

Figure 2: TGA of virgin and waste yarn composites

Figure 2 shows the thermo gravimetric (TGA) results generated on virgin and waste yarn composite. The plot shows the percent mass loss as a function of sample temperature for virgin and waste yarn composite under a nitrogen purge.

The experimental conditions were the same as the fibre composite sample. At about 100^{o}C, slight onset weight loss started and this can be ascribed to loss in moisture contain in the composite. A relatively more rapid loss in weight was observed from 110^{o}C to about 170^{o}C during which the composite mass further reduced to 85 %. As explained earlier, the loss in mass after water vaporization, was due to melting and subsequent volatization of the acrylic component.

As was the case of fibre composite, here also the onset of main decomposition of the yarn composite was at around 340^{o}C till the final decomposition at around 440^{o}C. At this point the weight loss was about 84 %, with further slight weight loss at 500^{o}C, 550^{o}C and 600^{o}C of 85 %. Finally, it may be observed that at about 375^{o}C, a slightly higher weight loss was observed and this trend continues till 600^{o}C where the weight loss for the waste yarn composite was 88 % compared with that of virgin yarn composite at 85 %.

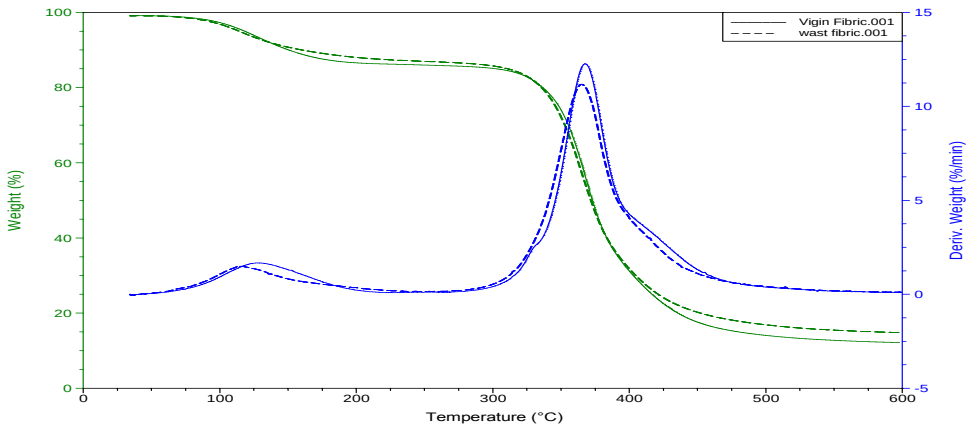

Figure 3: TGA of virgin and waste fabric composites

Figure 3 shows the thermosgravimetry (TGA) results generated on virgin and waste fabric composite. The plot shows the percent mass as a function of sample temperature for virgin and waste fabric composite under a nitrogen purge. Again, the experimental conditions were the same as highlighted in fibre composites.

Figure 3 shows that as temperature increases, at approximately 100^{o}C a slight reduction in weight was observed due to loss of moisture within the composite. Between 100^{o}C and 170^{o}C, a 15 % further loss in weight was observed, due to melting and vaporization of the acrylic component of the composite.The onset of major decomposition of the composite was observed at around 330^{o}C and over the next 100^{o}C rise in temperature, a total decomposition was observed at 450^{o}C, with a corresponding weight loss of 82 %. Over the next 150^{o}C rise in temperature, a further 8 % loss in weight was observed so that at 600^{o}C the residue weight remaining was 10 %.

A careful observation of the weight loss profile will show that at the initial decomposition temperature range where the acrylic component was volatilized, the virgin fabric composite showed a slightly more rapid loss in weight. This trend was again noted at around 400^{o}C to 600^{o}C, so that at the end, while the virgin composite showed a residual weight of 12 %, the waste composite exhibited a residual weight loss of 10 %.

Water absorption properties of fibre composites

Water absorption is used to determine the amount of water absorbed under specified condition. At low fibre contents, the matrix restrain expansion of the fibres while at high fibre content there is insufficient matrix to maintain this restrain and the fibre can take up more water than its weight in water (Hargital *et al*., 2006).

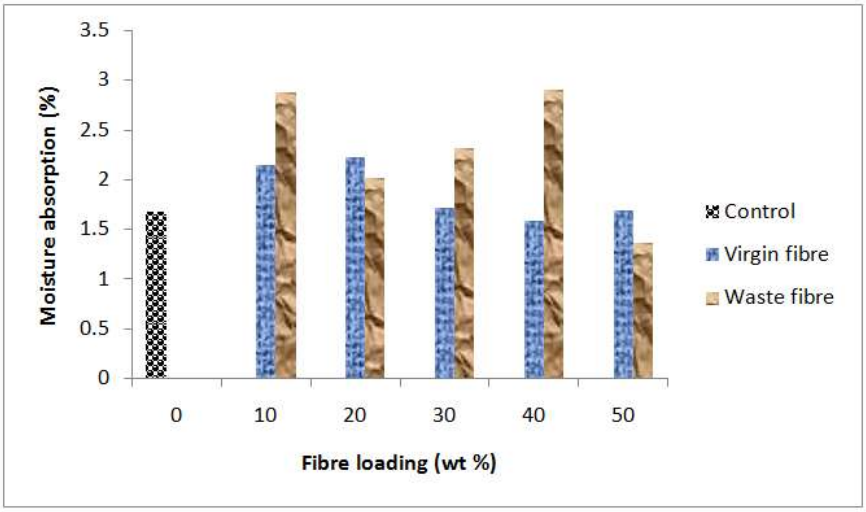

Figure 4: Moisture absorption versus fibre loading of fibre composites

% Moisture uptake result for fibre composite in the Figure 4 shows that waste fibre carries higher values in all fibre loading percent compositions except for 20 % fibre loading where the virgin composite has the higher values. Similar results were obtained by Yuan *et al*., (2002) and Babraukas, (1984). Because of high volume of short fibres in waste composites, it was expected that the amount of voids in the composite structure will be higher than that of the virgin fibre equivalent. This higher voids will act as capillaries within the composite which will aid percolation retention of water into the composite structure. Thus virgin fibre composites with lower void content would therefore absorb and retain less moisture.

Water absorption properties of yarn composites

Figure 5 shows that waste yarn composite has the higher % moisture absorption in all inter yarn spacing compositions. Here also the waste yarn composite show higher moisture absorption than the virgin yarn composite and the explanation above suffices.

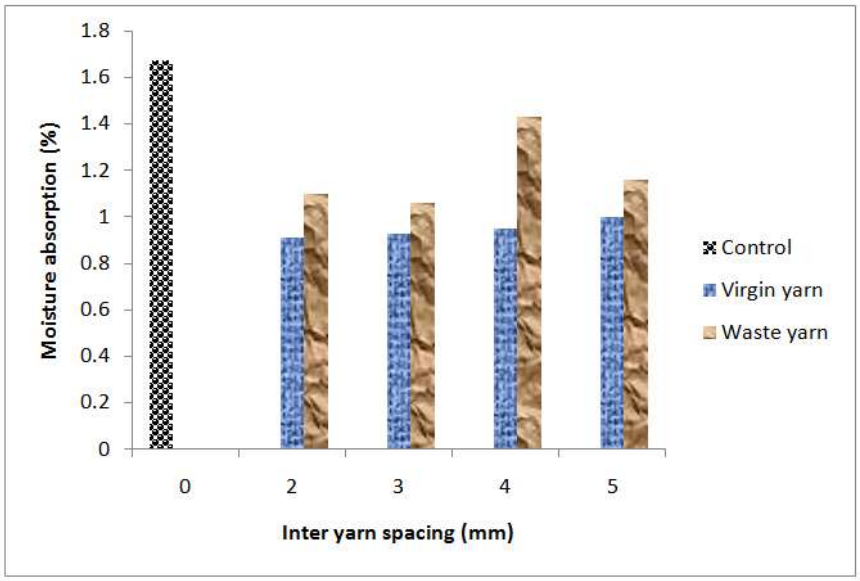

Figure 5: Moisture absorption versus inter yarn spacing of yarn composites

Water absorption properties of fabric (weft & warp directions) composites

The % moisture uptake results from Figures 6 and 7 shows that the waste fabric composite has the higher value than virgin fabric composite.

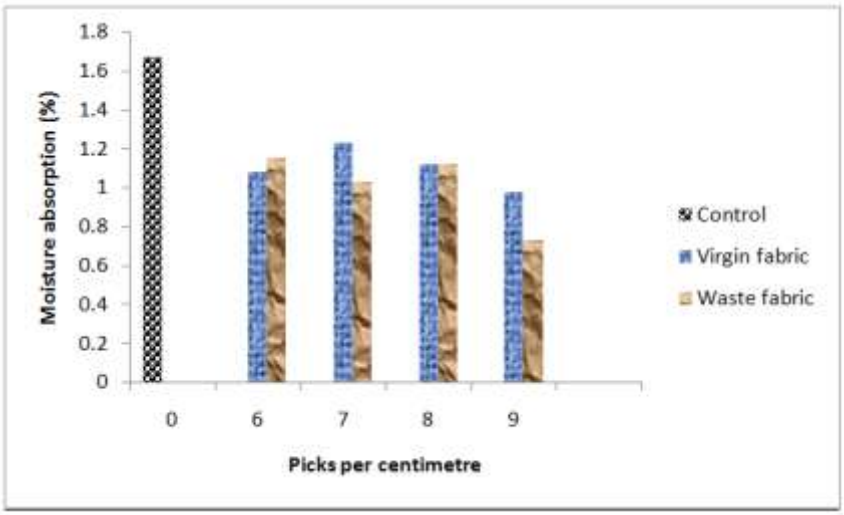

Figure 6: Moisture absorption versus picks per centimetre of fabric composites

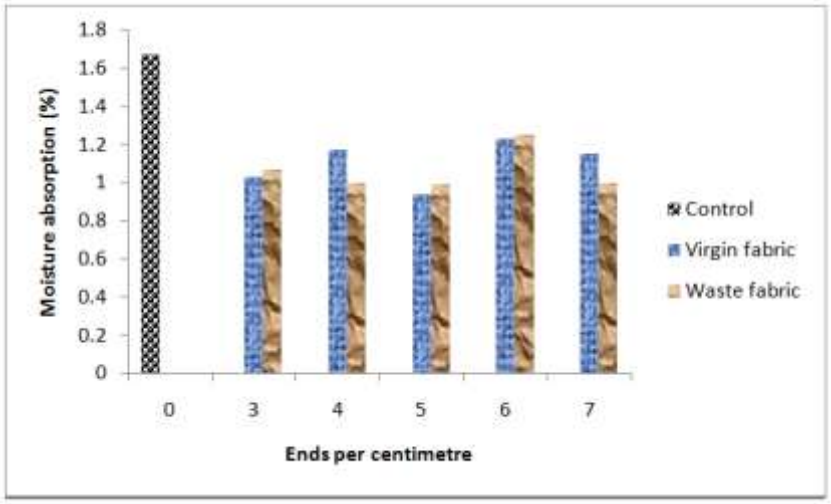

Figure 7: Moisture absorption versus ends per centimetre of fabric composites

Because of high volume of short fibres in waste composites, it was expected that the amount of voids in the composite structure will be higher than that of the virgin fibre equivalent. This higher voids will act as capillaries within the composite which will aid perculation retention of water into the composite structure. Thus virgin fibre composites with lower void content would therefore absorb and retain less moisture.

CONCLUSION

Waste and virgin fibres, yarns and fabrics epoxy composites were subjected to thermal degradation by means of Thermo Gravimetric Analysis (TGA) and water absorption test. From the study, it can be concluded that the addition of fibres, yarns and fabrics into the epoxy improves the thermal stability of the samples as well as its charring capability.No particular trend was noticed in moisture absorption with increasing ends per centimetre and picks per centimetre. However, as noted for fibre and yarn composites, the waste composite exhibited higher moisture absorption than virgin composites.

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C. M. Ojo. "Water Absorption Capacity and Thermal Properties of Waste and Virgin Acrylics Fibres Reinforced Epoxy Composites." American Journal of Engineering Research (AJER), vol.8, no.03, 2019, pp 275-281