

EFFECT OF WATER ABSORPTION ON MECHANICAL PROPERTIES OF FLAX FIBRE REINFORCED COMPOSITES

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ABSTRACT

Scutched and line flax fibres, with mean linear density of about 19.5 decitex, were utilized for this study. Mechanical properties of fibre and resin were measured for assessing their contribution in the composite matrix. Polypropylene (PP)/short flax fibre composites were prepared by compounding, extrusion and injection moulding techniques. Polypropylene-*graft*-Maleic anhydride (PP-*g*-MA, Grade: G-3015) and Polyethylene-*graft*-Maleic anhydride (PE-*g*-MA, Grade: G-2608) were used as compatibilizer for improving the adhesion between fibre and matrix. The mechanical properties, such as tensile, flexural and Izod impact, of the composites were investigated before and after water absorption. The moisture uptake of the resultant composite material was studied daily and their properties were measured after 7, 14 and 21 days at room temperature. The fracture morphology of the composites was characterized by Scanning Electron Microscopy (SEM). This paper presents the results of this ongoing project.

KEY WORDS: Flax fibre/PP composites; compatibilizers; water absorption; mechanical properties

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INTRODUCTION:

The use of natural plant fibres as reinforcement in polymer composites for making low cost engineering materials has generated much interest in recent years. New environmental legislation as well as consumer pressure has forced manufacturing industries (particularly automotive, construction and packaging) to search for new materials that can substitute for conventional non-renewable reinforcing materials such as glass fibre [1]. The advantages of natural plant fibres over traditional glass fibres are acceptable as good specific strengths and modulus, economical viability, low density, reduced tool wear, enhanced energy recovery, and reduced dermal and respiratory irritation and good biodegradability [2]. Natural plant fibre reinforced polymeric composites, also have some disadvantages such as the incompatibility between the hydrophilic natural fibres and hydrophobic thermoplastic and thermoset matrices requiring appropriate use of physical and chemical treatment to enhance the adhesion between fibre and the matrix [3]. Recently, car manufacturers have started manufacturing non-structural components using flax and hemp fibres due to their higher specific strength and lower price compared to conventional reinforcements [4].

All polymer composites absorb moisture in humid atmosphere and when immersed in water. The effect of absorption of moisture leads to the degradation of fibre-matrix interface region creating poor stress transfer efficiencies resulting in a reduction of mechanical and dimensional properties [5]. One of the main concerns for the use of natural fibre reinforced composite materials is their susceptibility to moisture absorption and the effect on physical, mechanical and thermal properties [6]. It is important therefore that this problem is addressed in order that natural fibre may be considered as a viable reinforcement in composite materials. Several studies in the use of natural fibre reinforced polymeric composites have shown that the sensitivity of certain mechanical and thermal properties to moisture uptake can be reduced by the use of coupling agents and fibre surface treatments [7,8].

Moisture diffusion in polymeric composites has shown to be governed by three different mechanisms [9, 10]. The first involves diffusion of water molecules inside the micro gaps between polymer chains. The second involves capillary transport into the gaps and flaws at the interfaces between fibre and the matrix. This is a result of poor wetting and impregnation during the initial manufacturing state. The third involves transport of micro-cracks in the matrix arising from the swelling of fibres (particularly in the case of natural fibre composites).

The objective of this work was to compare the influence of fibre content, compatibilizer and water uptake on mechanical properties of flax fibre reinforcement polypropylene

MATERIALS AND METHODS:

The matrix materials used in this study was based on a commercially available polypropylene, Trade name HNR 100_P supplied by Sasol company in South Africa The polypropylene-g-maleic anhydride (Epolene™ G-3015) and polyethylene-g-maleic anhydride (Epolene™ G-2608) was used as a compatibilizers, supplied by EASTMAN chemical company, Texas Eastman Division, USA. The South African grown flax fibres were utilized in this study. The fibres were decorticated and mechanically treated for obtaining long fibres for injection moulding.

Same fibres were further subjected to mechanical cottonisation for preparing nonwoven bat for moulding into composites.

PREPARATION OF THE COMPOSITE SAMPLES:

Flax fibre reinforced polypropylene composites were prepared by compression, extrusion and injection moulding processes. The fibre and matrix were dried in oven at 50⁰C for one day. Polypropylene and 5 % of compatibilizer (PP-g-MA and PE-g-MA) was extruded to form pellets. The temperatures of the different chambers of extruder were 190⁰C, 180⁰C, 180⁰C and 170⁰C. Screw speed was maintained at 50 rpm. This blend was mixed with flax fiber and was compression moulded at 170 °C for 5 minutes. The composite sheets formed were cut into small pieces and grinded by MASKIN grinder. This was then injection moulded to form the specimen composite.

WATER ABSORPTION TESTS

The effect of water absorption on flax fibre reinforced polypropylene and high density polyethylene composites were investigated in accordance with BS EN ISO 62: 1999 [11]. The specimens were dried in an oven at 50⁰C and then were allowed them to cool to room temperature in a desiccator before weighing them to the nearest 0.1 mg. This process was repeated until the mass of the specimens were reached constant. Water absorption tests were conducted by immersing the composite specimens in distilled water in beaker at room temperature for different time durations. After immersion for 24 h, the specimens were taken out from the water and all surface water was removed with a clean dry cloth or tissue paper. The specimens were reweighed to the nearest 0.1 mg within 1 min of removing them from the water. The specimens were weighed regularly at 24, 48, 72, 96, 168, 336 and 504 h exposure. The moisture absorption was calculated by the weight difference. The percentage weight gain of the samples was measured at different time intervals.

MECHANICAL TESTS

Tensile testing of the flax fibre reinforced composite specimens before and after water immersion was carried out according to ISO R 527 standards, using an Instron universal testing machine model 4303 at a cross head speed of 5 mm/min and a gauge length of 50 mm. The tensile strength and modulus of the composites were calculated from the load/displacement curve. Seven specimens were tested for each set of samples and the mean values were reported.

The flexural strength and modulus of the composite before and after water immersion was determined using three-point bending test according ISO 178, using an Instron universal testing machine model 4303 at a cross head speed of 5 mm/min and span length of 60 mm. Five specimens were tested for each set of samples and the mean values were reported.

The Izod impact test was carried out according to ISO 180 standards. Samples having width 10 mm, length 80 mm, thickness 4 mm and notch depth 2 mm (V notch) were used for impact testing. At least four specimens were tested for each set of samples and the mean values were reported.

MORPHOLOGY

In order to understand the effect of compatibilizer on the microstructure of composites, samples were examined using a scanning electron microscope (SEM) JSM 6100.

RESULTS AND DISCUSSION

Effect of fibre loading

The percentage of water absorption in the composites was calculated by weight difference between the samples immersed in water and the dry samples using the following equation.

$$\Delta M(t) = \frac{m_t - m_0}{m_0} \times 100$$

Where $\Delta M(t)$ is moisture uptake, M_0 and M_t are the mass of the specimen before and during immersion in water respectively.

The variation in water uptake of flax fibre/PP composites for melt mixed composites as a function of time for different fibre loadings are presented in Figure.1. It is clearly evident that the initial rate of water uptake increases with increase in fibre content. The increasing water absorption is caused, among other factors by the hydrophilic nature of flax fibre compared to the PP matrix and the greater interfacial area (capillary effect). The amount of water uptake by PP is negligible as it is hydrophobic.

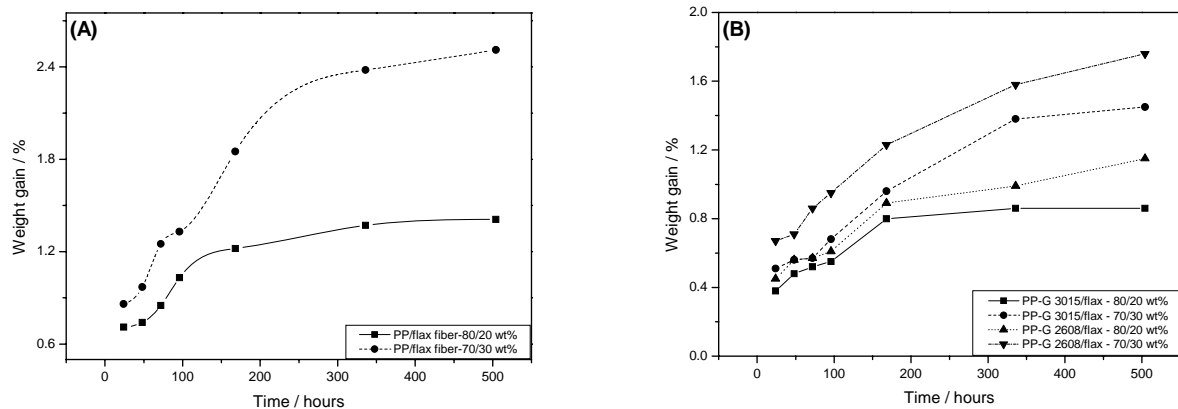


Figure 1. The variation in the water uptake of the PP/flax fibre composites (A) without compatibilizer (B) with compatibilizer

The maximum percentage weight gain for 20 and 30% (by wt) flax fibre reinforced specimens at room temperature for 504 h is 1.41 and 2.51% for PP/flax fibre composites. The initial rate of water absorption and the maximum water uptake increases for all composite specimens as fibre content increases in the composites. This phenomenon can be explained by considering the water uptake characteristics of flax fibre. When the composite is exposed to moisture, the hydrophilic flax fibre swells. (Fig.2). The high cellulose content in the flax fibre, further contributes to more water penetrating in to the interface through the voids induced by swelling of fibres creating swelling stresses leading to composite failure [12]. The SEM micrographs in Fig.2 support this explanation.

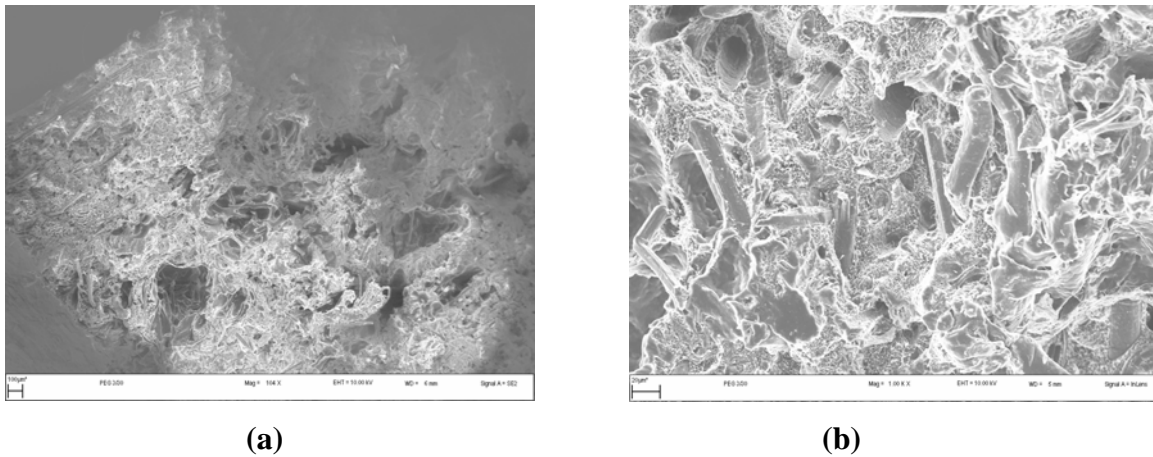


Figure.2. The SEM micrographs of fracture composites a) PP/flax fibre (30%) low magnification and b) PP/flax fibre (30%) high magnification.

Effect of compatibilizer:

The purpose of chemical treatment is to reduce the hydrophilic nature of the fibre, there by a strong interface is established between the fibre and the polymer matrix [13]. Fig.1B shows clearly the effect of chemical treatment on the water absorption characteristics of flax/PP composites with 20 and 30% fibre content. It can be seen that that treated flax/PP composite exhibits decreased rate of water absorption compared to untreated fibre composites. The compatibilizer builds up chemical bonds and hydrogen bonds which reduce the moisture-caused fibre/matrix debonding. It is found that all the modifications reduce the hydrophilic nature of the flax fibre thereby favouring a strong interfacial adhesion between the fibre and matrix. This in turn reduces the extent of water absorption. A strong adhesion at the interface is needed for an effective transfer of stress and load distribution throughout the interface. The lack of interfacial interactions lead to [14,15] internal strains, porosity and environmental degradation.

It can be seen observed that the composite containing PP-g-MA(G3015) exhibits lower water uptake compared to G2608. This can be attributed to better interfacial bonding in the former.

MECHANICAL PROPERTIES

The tensile and flexural strength of the flax fibre/PP composites as a function of fibre content and different compatibilizers, before and after water immersion samples are presented in figure... The effect of fibre content on the tensile strength of the composites can be seen Fig.3 (a). As would be expected, an increase in the fibre content produces a corresponding increase in the tensile strength. Similar results can be observed in Fig.3 (b) for flexural strength. The maximum

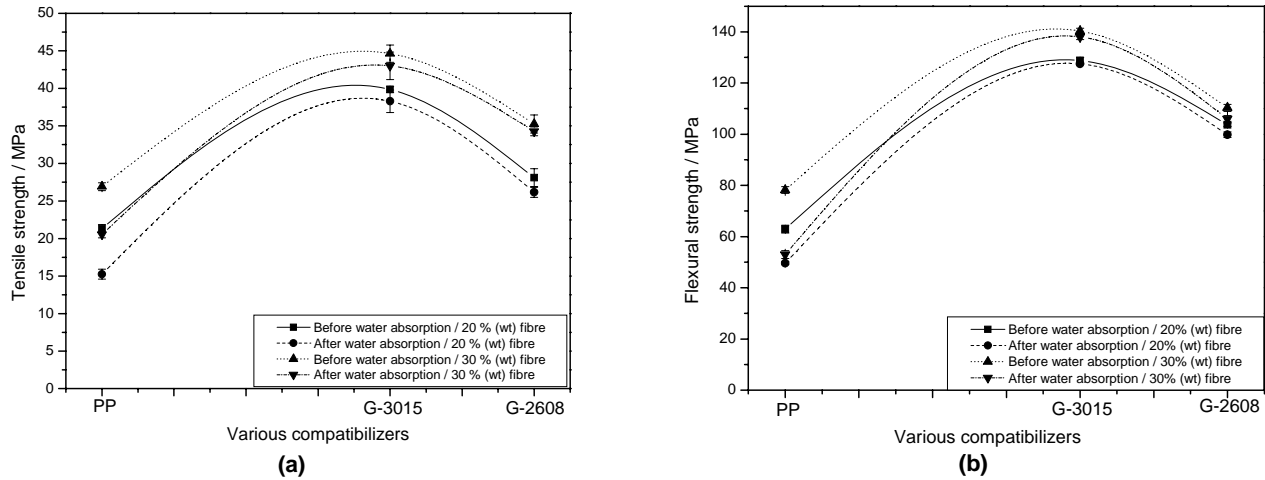


Figure 3. The various of the strength of PP /flax fibre composites before and after water immersion a) Tensile strength with compatibilizer and b) Flexural strength with compatibilizer

strength (tensile and flexural) of the composites was found at 30% fibre content. The ultimate stress of any composites depends on several factors, chief among them being the properties of the reinforcement and matrix and the fibre content [16]. The PP-g-MA (G3015) compatibilizer composites showed the best tensile and flexural strength properties at 30% fibre content (43 MPa for tensile and 140 MPa for flexural).

The effect of compatibilizer on the tensile and flexural strength of the composites after immersion in water at room temperature for 504 h is presented in Fig.3. It is clear from the figure that all composite samples showed a decrease in properties with exposure time. It is found that the compatibilized composites showed higher strength than uncompatibilized composites for all fibre content. This results in the development of shear stress at the interface which leads to the ultimate debonding of the fibres [17]. This is observed in the case of uncompatibilized composites whereas, in the case of PP-g-MA and PE-g-MA/flax fibre composites, the hydrophilicity of the fibre can be reduced using MAPP and MAPE treatment due to the esterification reaction between flax fibre hydroxyl groups and anhydride part of MAPP and MAPE.

The variations in modulus of the composites with fibre content and compatibilizer, before and after water immersion of the composites are presented in Fig.4. It is clear from the figure that all the composites samples showed a decrease in the modulus after water immersion due to plasticization effect [18]. That is the absorbed water molecules reduces the intermolecular hydrogen bonding between cellulose molecules in the fibre and establishes intermolecular hydrogen bonding between cellulose molecules in the fibre and water molecules, thereby reducing the interfacial adhesion between the fibre and the matrix. Fig.4 shows that the tensile and flexural modulus of the composites increases with increase in fibre loading.

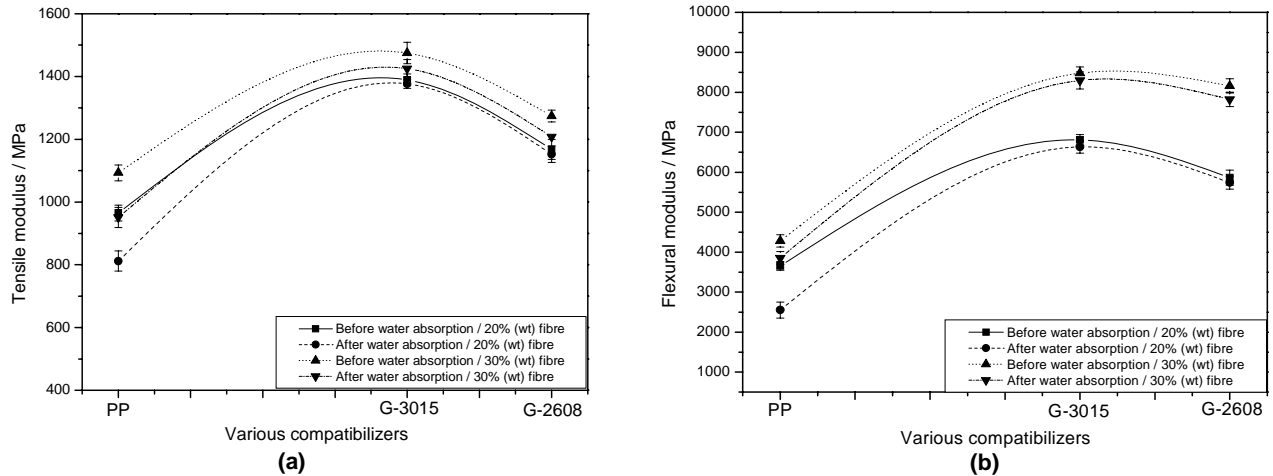


Figure 4. The various of the modulus of PP /flax fibre composites before and after water immersion a) Tensile modulus with compatibilizer and b) Flexural modulus with compatibilizer

The PP-g-MA composites showed superior tensile and flexural properties compared to PE-g-MA composites due to better interfacial adhesion between fibre and matrix.

The variation in impact properties of the composites with fibre content and compatibilizer before and after water immersion samples are presented in Fig.5. From the figure, it is clearly evident that the impact strength of composites increases with increase in fibre loading. PP-g-MA compatibilized composites exhibit better impact strength than PE-g-MA due to better interfacial adhesion between fibre and matrix.

MORPHOLOGY

The SEM micrographs of impact failure samples of the PP/flax fibre composites are presented in Fig.6. Figure 6 (a) exhibits fiber pull out due to poor bonding between fiber and matrix. In composite containing PP-g-MA, broken fiber ends can be seen indicating superior bonding. The fibres do not come out of the matrix but instead break off as seen in Figure 6 (b).

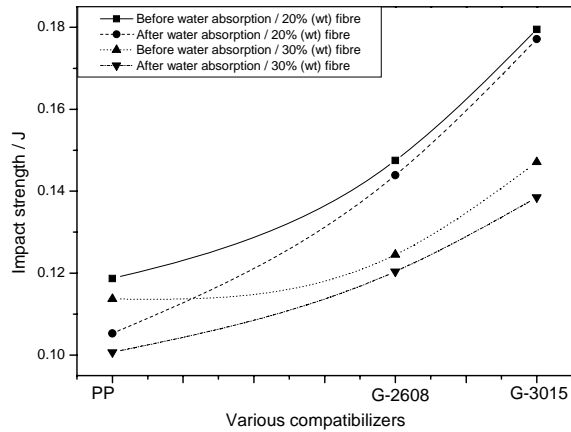


Figure 5. The impact strength of the flax fibre/PP composites before and after water immersion.

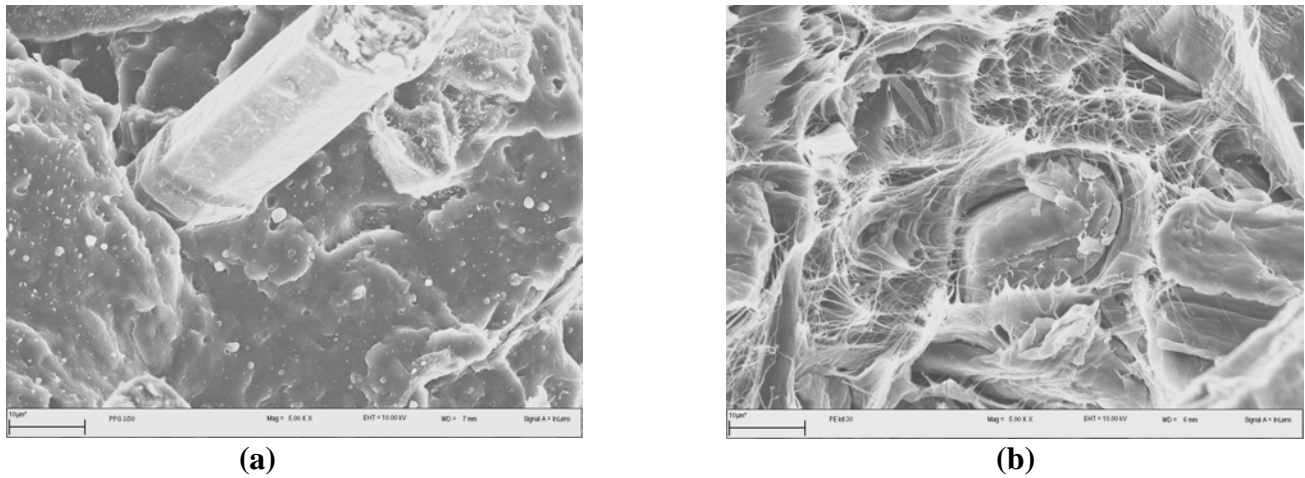


Figure.6. SEM micrographs of impact fracture flax fibre/PP composites a) PE-g-MA compatibilizer with 30% fibre loading and b) PP-g-MA compatibilizer with 30% fibre loading

CONCLUSIONS

The effect of water absorption on the mechanical properties of flax fibre/PP composites with compatibilizer has been studied. It was seen that moisture uptake increases with fibre loading due to increased voids and cellulosic content. Mechanical properties (tensile, flexural and impact) of the composites were determined after immersion in water for different periods of time with respect to fibre loading and compatibilizer. In all cases, reduction in mechanical properties was observed due to the plasticisation effect of water. The PP-g-MA compatibilizer showed (lower water uptake) and superior mechanical properties compared to the uncompatibilized composites.

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