The Effect of Water Absorption on Mechanical Properties of Hemp Fibre/Polyolefin's Composites.

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Abstract

The main objective of this research was to study the effect of water absorption on mechanical properties of hemp fibre reinforcement for polyolefin's (PP & HDPE) composites. The poor resistance towards water absorption is one of the drawbacks of natural fibres which make it more important. Hemp fibre-polyolefin's (PP & HDPE) composites were subjected to water immersion tests in order to study the effects of water absorption on the mechanical properties. Composites specimens containing 20% and 30% fibre weight were prepared. Water absorption tests were conducted by immersion specimens in a plastic container with normal tap water at room temperature for different time durations. The tensile, flexural and impact properties of dry and water immersion composite specimens were investigated. The percentage of moisture uptake increased as the fibre loading increased due to the high cellulose content. In order to improve compatibility of the natural hemp fibre and polyolefin's matrix, two commercial malamaleated polypropylene and polyethylene were used. The tensile, flexural and impact properties of hemp fibre/polyolefin's (PP & HDPE) composite specimens were found to increased with compatibilizer. The dry and water immersion specimens of the PP composites was shows better mechanical properties. The better understanding between fibre and matrix interface were investigated by Scanning Electron Microscopy.

Key words: Hemp fibre/PP and HDPE composites; compatibilizers; water absorption; mechanical properties; fracture analysis.

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 hemp fibre reinforcement polyolefin's (PP and HDPE) composites.

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, Taxas Eastman Division, USA. The hemp fibre supplied by Fibre & Textiles, Port Elizabeth, South Africa. The fibres were decorticated and mechanically treated for obtaining long fibres for injection moulding.

PREPARATION OF THE COMPOSITE SAMPLES:

Hemp fibre reinforced polyolefin's (PP and HDPE) composites were prepared by compression, extrusion and injection moulding processes. The fibre and matrix were dried in oven at 50^0C for one day. Polypropylene and 5 % of compatabilizer (PP-*g*-MA and PE-*g*-MA) was extruded to form pellets. The temperatures of the different chambers of extruder were 190^0C, 180^0C, 180^0C and 170^0C. Screw speed was maintained at 50 rpm. This blend was mixed with hemp fibre 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 TEST

The effect of water absorption on hemp 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 50^0C 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, 504 and 672 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 hemp 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

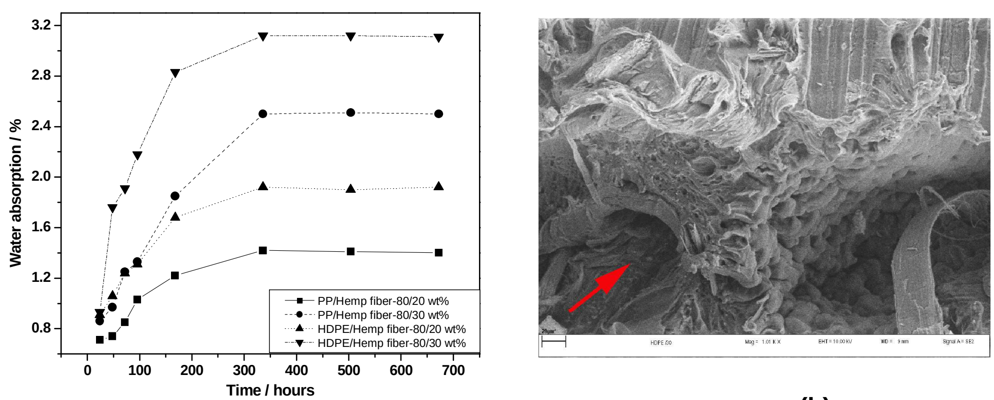
Effect of fibre loading

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.

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

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 hemp fibre/PP and HDPE composites for melt mixed composites as a function of time for different fibre loadings are presented in Figure.1(a). It is 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 hemp fibre compared to the PP and HDPE matrix and the greater interfacial area (capillary effect). The amount of water uptake by PP and HDPE is negligible as it is hydrophobic.



(a)

(b)

Figure 1. (a) The variation in the water uptake of the PP and HDPE / hemp fibre composites
(b) The fracture morphology of PP/hemp (30% loading) composite

The maximum percentage weight gain for 20 and 30% (by wt) hemp fibre reinforced specimens at room temperature for 672 h is 1.4 and 2.51% for PP/hemp fibre composites, 1.92 and 3.11% for HDPE/hemp 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 hemp fibre. When the composite is exposed to moisture, the hydrophilic hemp fibre swells. The high cellulose content in the hemp 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.1 (b) support this explanation. The red arrow shows void area in the water immersion composite specimen.

Effect of compatibilizer:

The purpose of polymer modification is to improve the interfacial bonding between fibre and matrix. Fig. 2 shows clearly the effect of polymer modification on the water absorption characteristics of hemp/PP and HDPE composites with 20 and 30% fibre loading. It can be seen that the modified PP and HDPE/hemp fibre composites exhibits decreased rate of water absorption compared to unmodified polymer 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 hemp 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 [13,14] internal strains, porosity and environmental degradation.

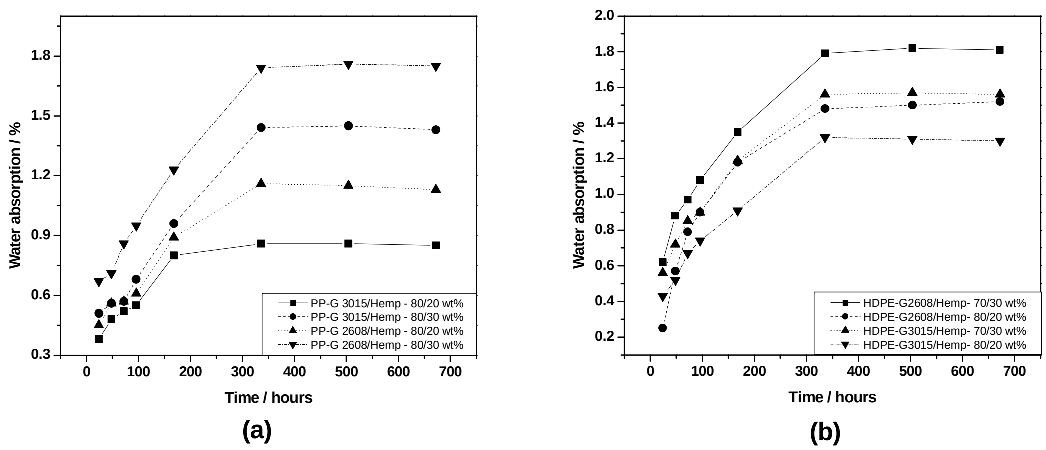


Figure.2. The variation of water absorption on PP and HDPE/hemp fibre composites with different compatibilizers, (a) PP/hemp fibre composites and (b) HDPE/hemp fibre composites

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

MECHANICAL PROPERTIES

The tensile and flexural properties of the hemp/PP and HDPE composites as a function of fibre loading and two different types of compatibilizers, before and after water immersion samples are presented in Figure 3 and 4. The effect of fibre loading on the tensile strength and modulus of the composites can be seen Fig.3 (a and b). As would be expected, an increase in the fibre content produces a corresponding increase in the tensile strength and modulus for both composites (PP/hemp and HDPE/hemp fibre composites). However, the polypropylene-grafted-maleic anhydride compatibilizer is shows higher tensile strength and modulus of the composites for both composites (PP/hemp and HDPE/hemp composites)

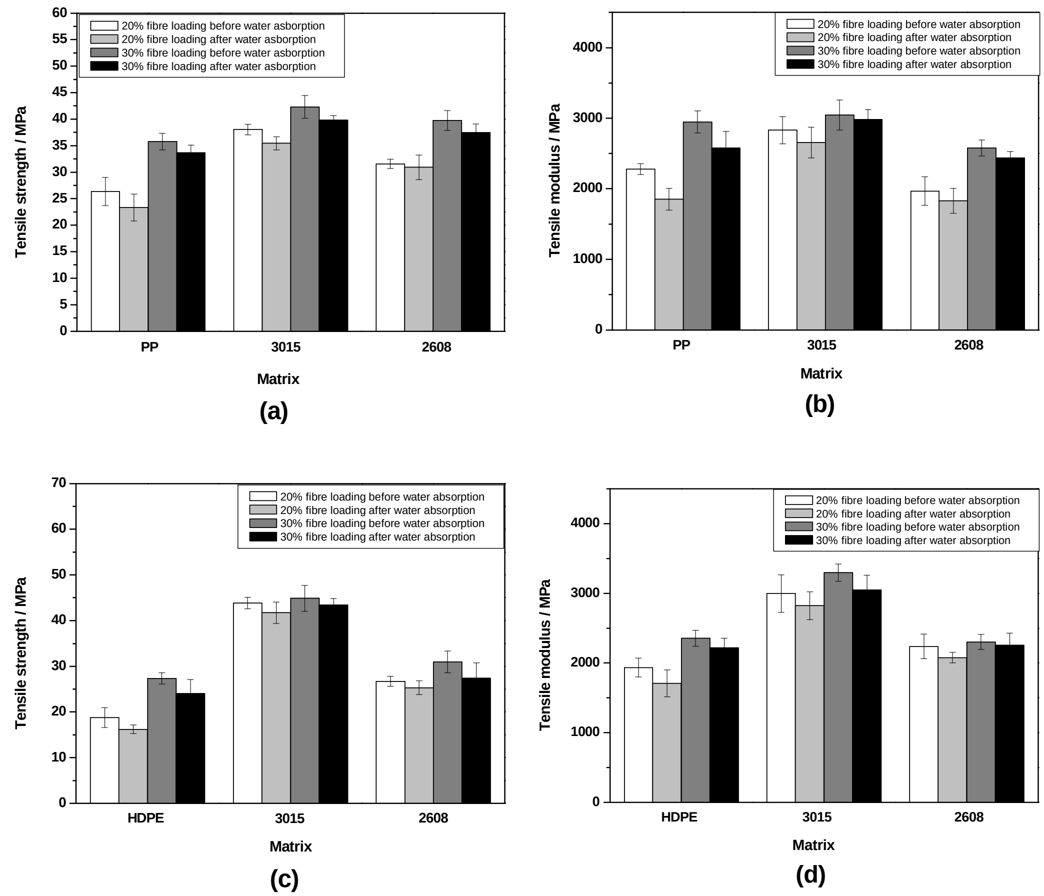


Figure 3. The variation of tensile properties of hemp/PP and HDPE composites, before and after water immersion with two different types of compatibilizers. (a) and (b) tensile strength and modulus of PP/hemp fibre composites; (c) and (d) flexural strength and modulus of the HDPE/hemp fibre composites .

The flexural strength and modulus of the composites before and after water immersion specimens for both composites are presented in Figure 4. From Fig.4 (a and b) shows, the flexural strength and modulus of the composites decreases with increase fibre loading. However, the PP/hemp fibre composites with polypropylene-grafted- maleic anhydride shows higher flexural properties that of the HDPE/hemp fibre composites with polyethylene-grafted-maleic anhydride. 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 [15]. The PP/hemp/PP-*g*-MA and HDPE/hemp/PP-*g*-MA composites showed the best tensile properties at 30% fibre content, 44 MPa and 3264 MPa tensile strength and modulus of the PP/hemp/PP-*g*-MA composites, 42 MPa and 3096 MPa tensile strength and modulus for HDPE/hemp/PP-*g*-MA.

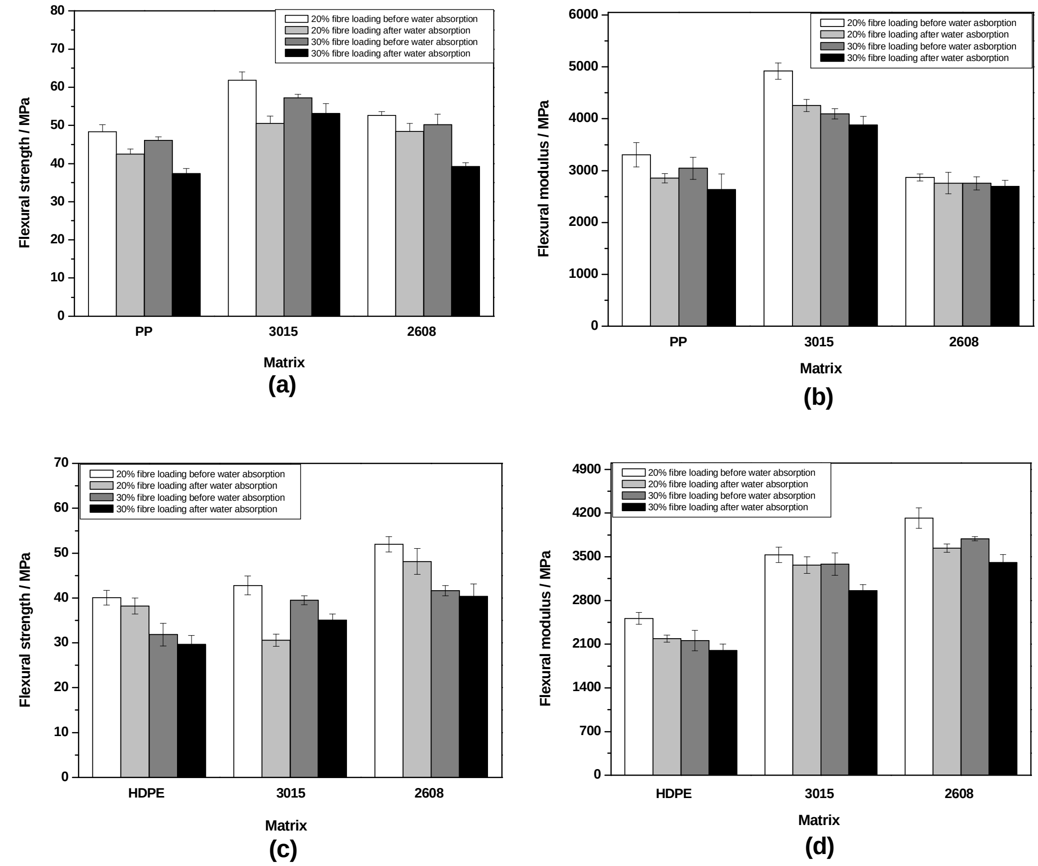
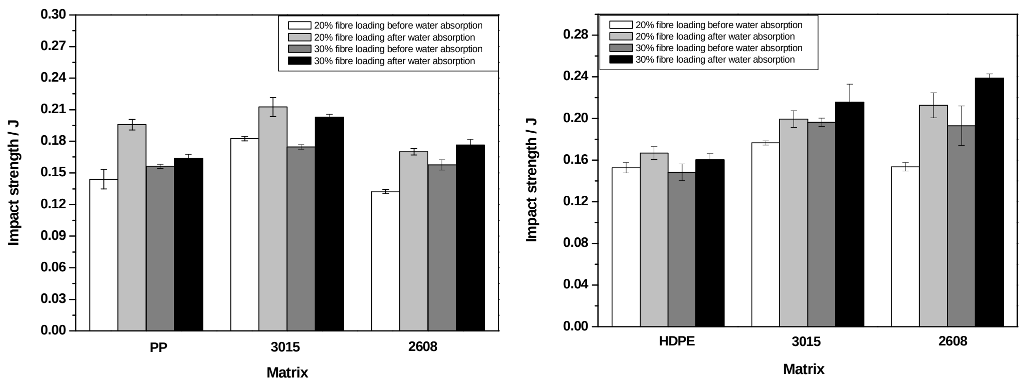


Figure 4. The variation of flexural properties of hemp/PP and HDPE composites, before and after water immersion with two different types of compatibilizers. (a) and (b) tensile strength and modulus of PP/hemp fibre composites; (c) and (d) flexural strength and modulus of the HDPE/hemp fibre composites

The effect of compatibilizer on the tensile and flexural strength of the PP/hemp fibre and HDPE/hemp fibre composites with compatibilizer after immersion in water at room temperature for 672 h is presented in Fig.3 (a and c) and 4 (a and c). It is clear from the figures 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 [16]. This is observed in the case of uncompatibilized composites whereas, in the case of PP-*g*-MA and PE-*g*-MA/hemp fibre composites, the hydrophilicity of the fibre can be reduced using MA-*g*-PP and MA-*g*-PE treatment due to the esterification reaction between hemp fibre hydroxyl groups and anhydride part of MA-*g*-PP and MA-*g*-PE.

The variation in modulus of the composites with fibre content and compatiblizer, before and after water immersion of the composites are presented in Fig. 3 (b and d) and 4 (b and d). It is clear from the figures that all the composites samples showed a decrease in the modulus after water immersion due to plasticization effect [17]. 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. The PP/hemp/PP-*g*-MA composites showed superior tensile properties and flexural strength 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 evident that the impact strength of composites increases with increase in fibre loading. PP/hemp fibre composites with PP-g-MA compatiblizer exhibit better impact strength than PE-g-MA due to better interfacial adhesion between fibre and matrix. In case HDPE/hemp fibre composites with PE-*g*-MA compatibilizer shows higher impact strength.



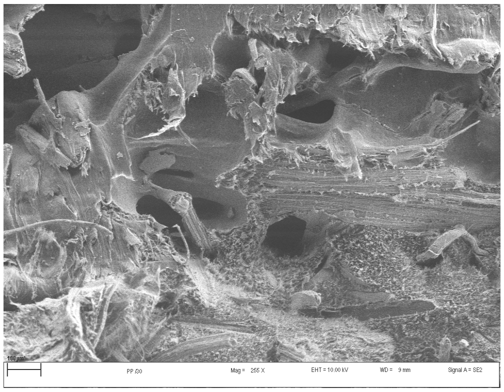
(a) (b)

Figure 5. The variation of impact strength of the composites before and after water immersion with two different types of compatibilizers (a) PP/hemp composites with PP-g-MA and PE-g-MA and (b) HDPE/hemp composites with PP-g-MA and PE-g-MA.

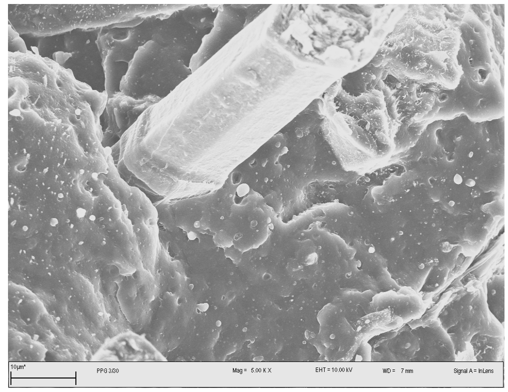
MORPHOLOGY

The SEM micrograph of PP/hemp fibre composites with 30% fibre is presented in Figure 6 (a). From the Fig. 6(a) is clearly shows, the random orientation of fibres produces lower mechanical properties compared to long unidirectional orientated fibres. This fibre entanglement can create resin rich areas, which can contribute to the formation of voids and porosity. Voids and porosity can act as stress concentrators leading to failure of composite samples [18].

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



(a)



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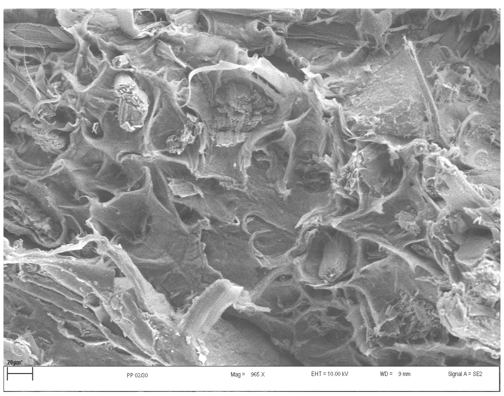
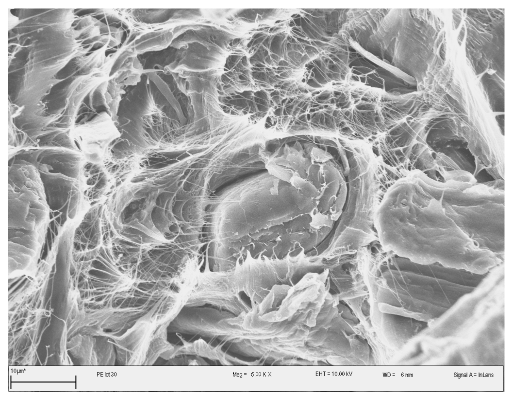


(c)



(d)

Figure 6. The SEM micrographs of hemp fibre composites, (a) and (b) 30% hemp fibre/PP composites and (c) and (d) 30% hemp fibre/PP composites with compatibilizer

CONCLUSIONS

The effect of water absorption on the mechanical properties of hemp fibre/PP and HDPE composites with compatiblizer 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 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. SEM macrographs also showed better bonding between fibre and matrix when compatibilizer was used.

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