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Physico-mechanical properties of coir and jute fibre reinforced hybrid polyethylene composites

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ABSTRACT

Composite materials are materials made from two or more constituent materials with significantly different physical or chemical properties, that when combined, produce a material with characteristics different from the individual components. A hybrid composite refers to a special type of composite which contains more than one fibre material as reinforcing filler. Multiple fibre reinforced composites give a wide variety of mechanical properties with respect to a single fibre containing composite. The eco-friendly nature as well as the processing advantage, light weight and low cost have enhanced the attraction and interest of the natural fibre reinforced composite. The objective of the present research is to study the mechanical properties of the jute-coir fibre reinforced hybrid polyethylene composite. Composites were manufactured by using a hot press machine at three levels of fibre loading (5, 10 and 15 wt%). The tensile, flexural, impact and hardness tests were conducted for the purpose of mechanical characterisation. A water absorption and scanning electron microscopic analysis was carried out as part of the physical evaluation. The tensile test of the composite showed a decreasing trend of tensile strength and an increasing trend for Young's modulus with an increasing fibre content. During the flexural, impact and hardness tests, the flexural strength, flexural modulus, impact strength and hardness were found to be increased with the increasing fibre loading. Water absorption increased with the increase in fibre loading. The scanning electron microscopic analysis showed the strongest adhesion between the fibre and the matrix in the 15% fibre reinforced composite. Based on the fibre loading used in this study, the 15% fibre reinforced composite exhibited the best set of mechanical properties.

***Keywords*: Mechanical properties; SEM; jute; coir; polyethylene; hybrid composite.**

INTRODUCTION

"Hybrid composite" is a popular denomination nowadays because of its capability of providing various types of properties that cannot be attained in binary systems containing one type of fibre dispersed in a matrix. Both synthetic and natural fibres can be used as filler material. The replacement of the conventional synthetic fibres with natural fibres as reinforcement in the polymer matrix composites could lead to a green, renewable path of applications [1, 2]. Natural fibres have received great attention from researchers and industrialists due to their biodegradability, better mechanical properties, easy manufacturing, and overall cost effective quality [3, 4]. Apart from this, the lignocellulosic fibres are lightweight, reduce wear in the equipment used for their production, are easily available, renewable, non-abrasive, require less energy for processing, reduce the density of furnished products and absorb CO_2 during their growth [5-7]. The lignocellulosic fibres can be mixed either with the thermosetting or thermoplastic polymer matrix to produce composite**s** [8]. The composite using a thermosetting polymer shows brittleness and an incapacity to repair. Many of the thermoplastic-based composites offer excellent resistance to impact loading, the possibility of thermoforming and shaping at elevated temperatures and the potential for thermal joining and repair as well as recycling. Among various natural fibres, both coir and jute fibres are widely available and cheap in the current economic context of Bangladesh. Coir and jute are lignocellulosic fibres mainly consisting of cellulose, lignin and hemicelluloses. A high content of lignin in coir than in the jute fibre has made it highly weather resistant [9]. The coir fibre is relatively water-proof and is one of the few natural fibres resistant to damage by salt water. They absorb water to a lesser extent compared to all the other natural fibres including jute due to its reduced cellulose content. Both fibres are biodegradable and recyclable. These are renewable resources and these materials are CO_2 neutral. These fibres also possess much higher strength and stiffness as compared to the matrices [10]. The objective of the present research is to develop a hybrid composite by using inexpensive and ecofriendly jute and coir fibres, thus improving a new era of eco-friendly composites. The physical and mechanical properties of the composites were subsequently characterised.

MATERIALS AND METHODS

Materials

A commercial grade polyethylene (PE), coir and jute were used in this study. All of them were collected from the local market. The PE was white in colour and granular in form having a melting point of 135^{o}C. The jute fibre was extracted from bundle and the coir fibre was collected from coconut. The jute fibre consisted of 65.2% cellulose, 22.2% hemi-cellulose and 12.5% lignin. On the other hand, the coir fibre had 43.4% cellulose, 0.50% hemi-cellulose and 45.9% lignin. The die (Figure 1) used to prepare the composite was made of aluminium. It was made by machining an aluminium plate to a desired shape (25.4 cm x 18.8 cm) and depth of 0.8 cm.

Figure 1. Picture of the die that was used to prepare the composites.

Manufacturing of Composites

The hybrid composites of the polyethylene matrix with a varying amount of jute and coir fibre were manufactured using the hot press technique in a 25.4 cm × 18.8 cm ×

0.8 cm die (Figure 1) mentioned in the previous section. A hydraulic type machine having a maximum load of 35 kN and a maximum temperature of 300 °C was utilised. The fibre loading was varied at 5, 10 and 15 wt% with a ratio of jute to coir of 1:1. Fibres were cut to a 3-5 mm length. At first, the required amount of fibres and PE were weighted in a balance. Then to allow the removal of moisture, fibres and polyethylene were dried in an oven at 80 °C for 20 minutes before preparing each composite. In some cases, they were mixed properly in a container by applying heat from a hot plate. The application of heat (much below the melting point of PE) during mixing enables the fibres to adhere with the PE granules, since no additional adhesive had been used. A mould releasing agent was sprayed on it uniformly for an easy removal of the composite. The fibre and PE mixture was then placed inside the die. The fibre matrix mixture was allowed to press at 30kN pressure. The temperature was initially raised to 120 °C and held there for around 12-15 minutes, after that the temperature was raised to (150-160)°C depending on the thickness required. The water cooling system was used for the slow cooling of the system. The PE composite specimen was then carefully discharged from the mould after cooling it to room temperature. Since the compression temperature was higher than the melting point of PE (135°C), the matrix melted but the fibres (melting point > 220°C) remained intact. Figure 2 shows a composite and its raw materials.

Coir Jute PE Composite

Figure 2. Preparation of the composite.

(a) (b)

Figure 3. Picture of the (a) flexural and (b) tensile test setup with workpiece.

Mechanical Testing

Tensile, impact, flexural and hardness tests were carried out in this study. In each case, five samples were tested and the average values were taken. The tensile tests were conducted according to ASTM D 638-01 [2] using a universal testing machine at a crosshead speed of 4mm/min (Figure 3). Each test was continued until tensile failure. The dynamic charpy impact test of the composite was conducted using an impact tester MT 3016 according to ASTM D 6110-97 [11]. Static flexural tests were carried out according to ASTM D 790-00 [12] by using a universal testing machine

(Figure 3). The hardness of the composite was measured using a shore hardness testing machine.

Water Absorption Testing

The water absorption test was also performed using rectangular specimens having a dimension of 39 mm × 10 mm × 4.1 mm. The specimens were dried in an oven at 105 ^oC, cooled in a desiccator using silica gel and immediately weighted. A Denver Instron balance was used for the weight measurement. The dried and weighted specimens were immersed in hot distilled water according to ASTM D 570-99 [13] for 2 hours. After immersion, the excess water on the surface of the specimens was removed using a soft cloth. The final weight of the specimens was then taken. The increase in the weight of the specimens was then calculated.

Scanning Electron Microscopy

The interfacial bonding between the fibres and PE matrix in the manufactured composites and tensile fracture surfaces of the same composites were examined using a Scanning Electron Microscope (Philips XL 30). The composite surface was initially made conductive by applying gold coating using a sputtering machine. The composite was then taken inside SEM, a vacuum was created and micrographs were taken. The micrographs are presented in the Results and Discussion section.

RESULTS AND DISCUSSION

Tensile Properties

The tensile properties of the composite samples were measured for each fibre content value (5, 10 and 15%) with the help of the stress/strain curves. The tensile strength and Young's modulus of the raw coir and jute fibre (Jute: Coir=l:l) reinforced hybrid polyethylene composites at different fibre loadings are summarised in Figure 4. The tensile strength decreased with an increase in the fibre loading. As the fibre loading increased, the interfacial area between the fibre and matrix increased, which was weak because of the worsening interfacial bonding between the cellulose based hydrophilic filler (jute and coir) and the hydrophobic PE matrix [9]. This consequently decreased the tensile strength [6]. The same trend was also observed by other researchers in their work [14-17].

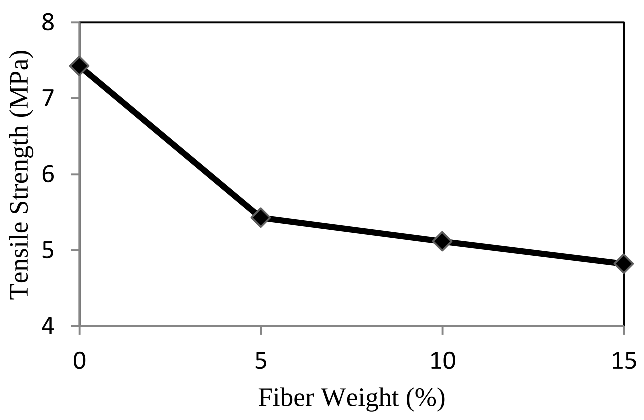

Figure 4. Variation of tensile strength against fibre loading.

The Young's modulus values of the coir and jute fibre reinforced polyethylene composites for different fibre loadings are shown in Figure 5. It is observed that the Young's modulus increased with an increase in fibre loading. This is because with an increase in the fibre content, the brittleness of the composite increased and the stress/strain curves became steeper [9]. Poor interfacial bonding creates partially separated micro spaces, which obstruct the stress propagation between the fibre and the matrix. As the fibre loading increases, the degree of obstruction increases, which in turn increased the stiffness [17]. Other researchers also found the same trend in their research [5, 6, 14, 18].

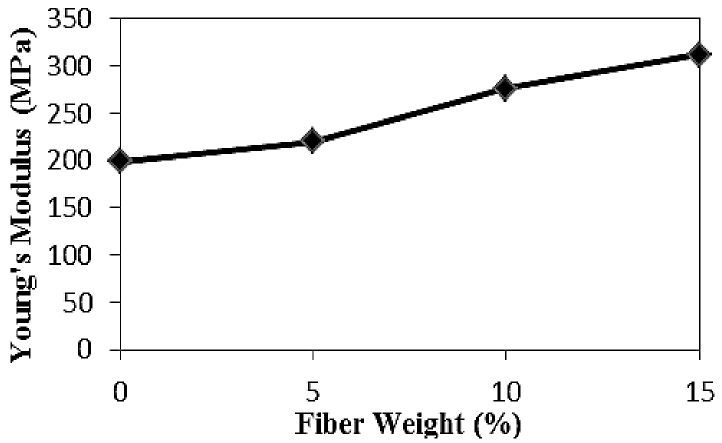

Figure 5. Variation of Young's modulus against fibre loading.

The percentage elongation at break of the composites against fibre loading is shown in Figure 6. This figure reveals that the elongation at break was reduced considerably with the enhancement of the fibre fraction. Both coir and jute fibres were stiffer than the polyethylene matrix, thus they had a lower percentage of elongation at break than the PE matrix. As a result, the elongation at break decreased with the increase in the fibre content of the PE composites.

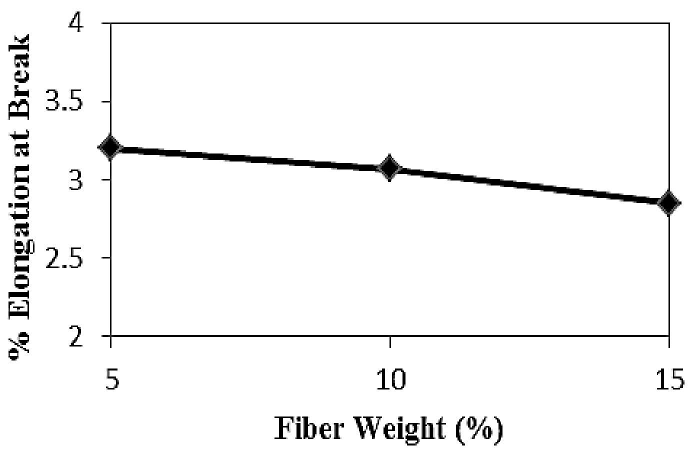

Figure 6. Variation of the percentage of the elongation at break against fibre loading.

Flexural Properties

The flexural properties (flexural strength and flexural modulus) were measured for samples of each fibre content with the help of the flexural stress/strain curves and respective equations. The flexural strength of the raw coir and jute fibre reinforced hybrid polyethylene composites at different fibre loading values is shown in Figure 7. The flexural strength increased with an increase in the fibre loading, which is in agreement with the findings of other researchers. This may be due to the favourable entanglement of the polymer chain with the filler, which has overcome the weak filler matrix adhesion with an increasing filler content [16]. The same trend was observed in previous research [5, 15, 19].

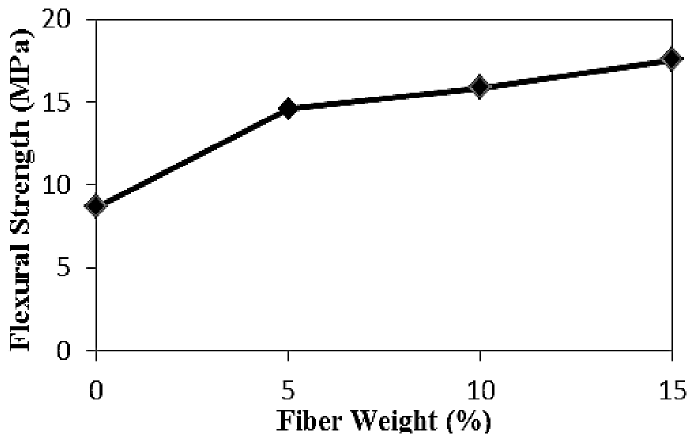

Figure 7. Variation of flexural strength against fibre loading.

The flexural modulus values of the raw coir and jute fibre reinforced hybrid polyethylene composites at different fibre loading values is shown in Figure 8. The flexural modulus increased with an increase in the fibre loading. Since both coir and jute are high modulus materials, a higher fibre concentration demands higher stress for the same deformation. So the incorporation of the filler (rigid coir and jute) into the soft polyethylene matrix results in an increase in the modulus [16]. Other researchers also found the same trend in their work [15, 18, 19].

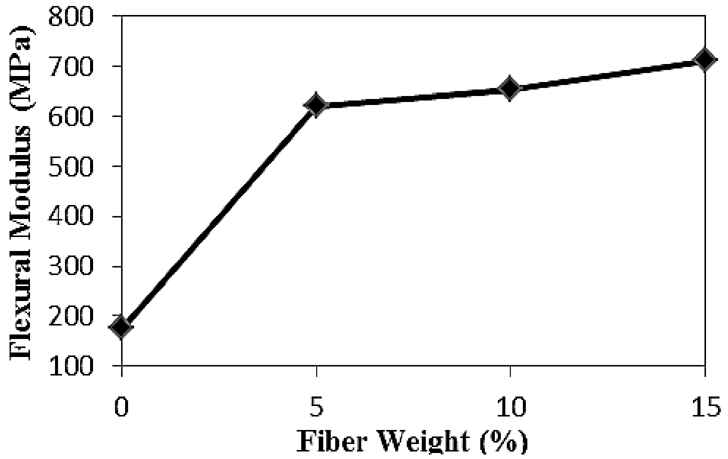

Figure 8. Variation of flexural modulus against fibre loading.

Impact Strength

The variation of the Charpy impact strength with different fibre loading for the raw coir and jute fibre reinforced hybrid composite is shown in Figure 9. The impact strength increased with the fibre loading. The impact strength of a material provides information regarding the energy required to break a specimen of a given dimension, the magnitude of which reflects the material's ability to resist a sudden impact. The impact strength of the fibre reinforced polymeric composites depends on the nature of the fibre, polymer and fibre-matrix interfacial bonding [20]. As presented in the figure, the impact strength of all composites increased with the fibre loading. This result suggests that the fibre was capable of absorbing energy because of the favourable entanglement of fibre and matrix [9]. Fibre pull out is found to be an important energy dissipation mechanism in fibre reinforced composites [17]. One of the factors influencing the impact failure of a composite is the fibre pull out. With the increase in fibre loading, a stronger force is required to pull out the fibres. This in turn increased the impact strength [17]. The same trend was observed in previous research [10, 14, 17].

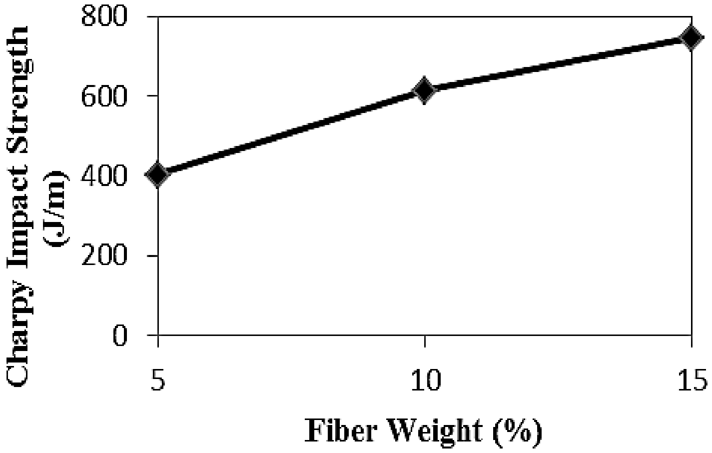

Figure 9. Variation of impact strength against fibre loading.

Hardness

The hardness of a composite depends on the distribution of the filler into the matrix. Usually, the presence of a more flexible matrix causes the resultant composites to exhibit lower hardness. As shown in Figure 10, the incorporation of the fibre into the PE matrix has reduced the flexibility of the matrix resulting in more rigid composites. Due to the increase of stiffness of the respective composite, the hardness of the jute-coir hybrid PE composites showed a slight increasing trend with an increase in the fibre content. A better dispersion of the filler into the matrix with a minimisation of the voids between the matrix and the filler also enhanced hardness [21].

Water Absorption Characteristics

Natural fibre has a tendency to absorb water due to the presence of hydrophilic hydroxyl groups of cellulose, hemicelluloses, and lignin. The water absorption characteristics are shown in Figure 11. With the increase in fibre loading, the amount of hydrophilic hydroxyl groups of cellulose, hemicelluloses, and lignin content of the overall composites increased. As a result, the water absorption of the coir and jute fibre reinforced polyethylene composites increased with the increase in the fibre content inside the PE [17].

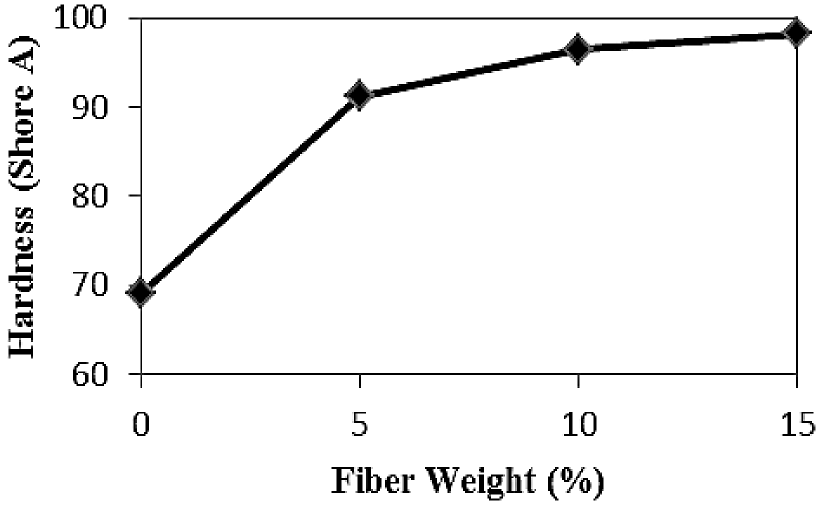

Figure 10. Variation of hardness against fibre loading.

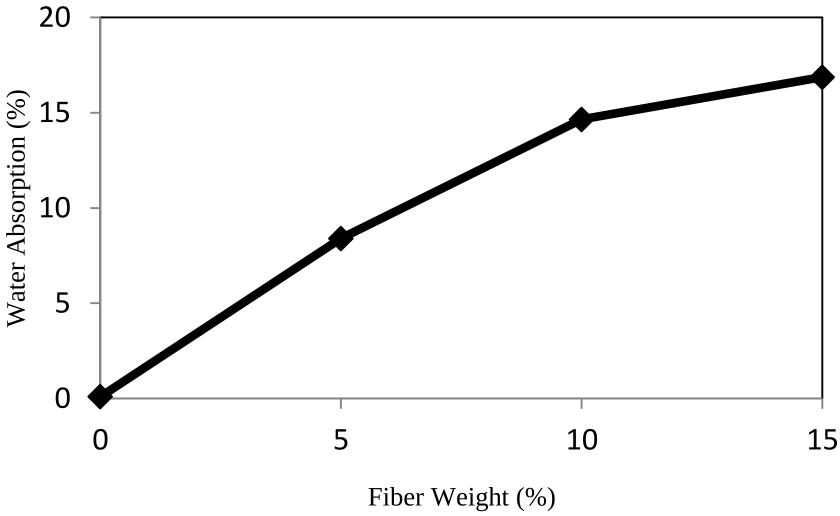

Figure 11. Variation of water absorption against fibre loading.

Surface Morphology

The tensile fracture surface of the 5, 10, 15 wt% coir-jute fibre reinforced hybrid polyethylene composites is shown in Figure 12**.** The figure shows the presence of both coir (comparatively larger diameter) and jute (comparatively smaller diameter) fibres in the polyethylene composite. The main reason for poor mechanical properties in raw fibre reinforced composites is the weak bonding between the fibre and the matrix [22]. This is evidential in the micrographs obtained from the scanning electron microscope. According to the scanning electron micrographs, the 15% fibre reinforced composites (Figure 12) show favourable entanglement between the fibre and the matrix among all manufactured composites. As a result, the 15% fibre reinforced composites yielded the best set of mechanical properties as compared to other fibre loaded composites [22].

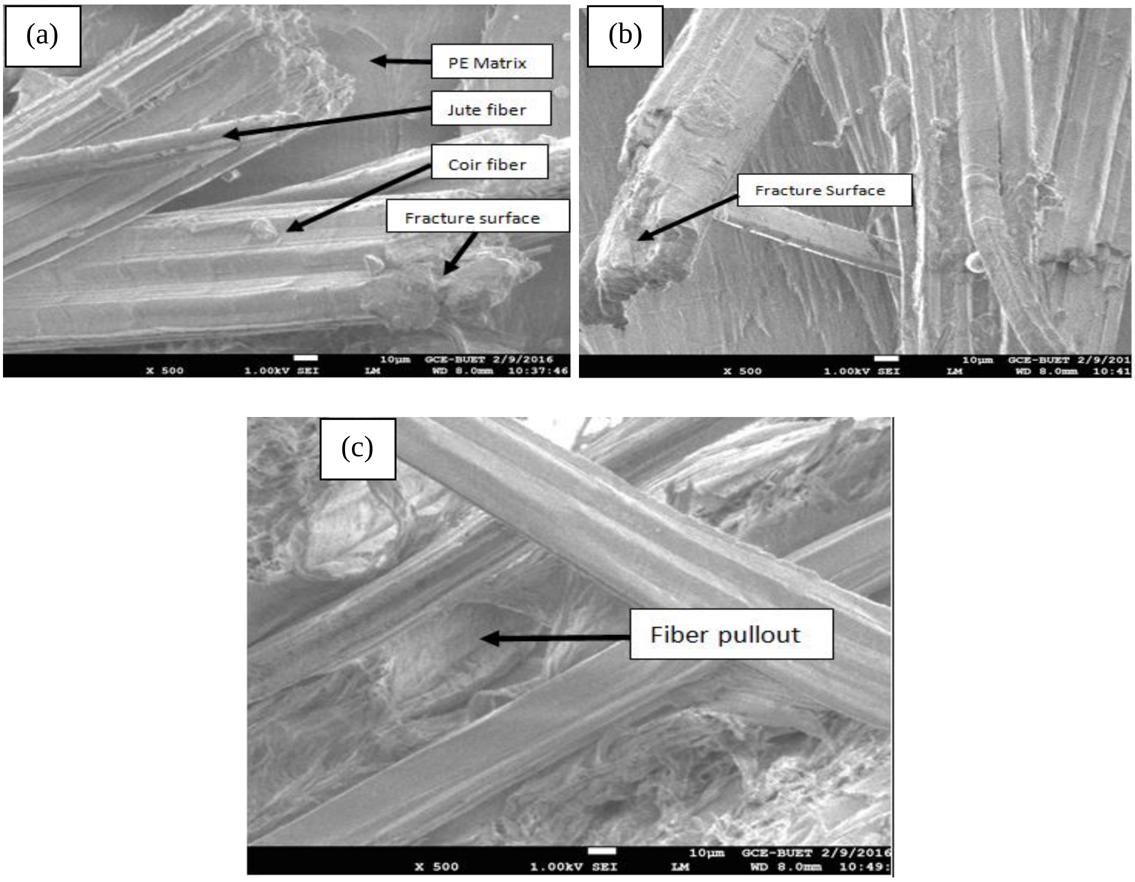

Figure 12. SEM micrographs of the tensile fracture surface of (a) 5%, (b) 10% and (c) 15% fibre reinforced PE composite

CONCLUSIONS

In this study, a jute and coir fibre reinforced hybrid polyethylene composite was manufactured using the hot press technique. The level of fibre loading was varied at 5, 10 and 15 wt%. The tensile strength of the composite decreased with an increase in fibre loading. Conversely, Young's modulus increased with the fibre loading. The flexural strength, flexural modulus, charpy impact strength and hardness values all increased with an increasing in fibre loading. The water absorption increased with the increase in fibre loading. The scanning electron microscopic analysis showed the strongest adhesion between the fibre and the matrix when the 15% fibre was reinforced into the polyethylene matrix. As a result, the 15% fibre composite yielded the best set of mechanical properties compared to other composites. A further modification can be implemented by treatment of the fibre and improving the fibre matrix inter-bonding.

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