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Fabrication and Characterization of Kevlar Fiber Reinforced Polypropylene Based Composite for Civil Applications

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Abstract: Composite is one of the most widely used materials because of their adaptability to different situations. Composites have gained popularity in high performance products to take harsh loading conditions such as, tails, wings, propellers, scull hulls because of their low costs, ease in designing and production of functional parts etc. Selection of the materials for fabricating composites was made from the final nature of the component, the volume required, apart from cost effectiveness and mechanical strength. In this study, It was envisioned to develop Kevlar fiber reinforced polypropylene based composites for structural components and systems with better strength, serviceability, durability and cost effectiveness. Composites of Kevlar and polypropylene (PP) barring five total fiber percentages (5, 10, 20, 30 and 40% by weight) were prepared by compression molding technique. The molded composite specimens were characterized by physical, mechanical and thermal properties. The highest change in tensile strength (TS) and elastic modulus (EM) were 550% and 140% respectively comparative to the matrix materials and 40% fiber containing composites. The analysis results were supported by scanning electron microscope images. However, based on the SEM image of the fracture surface, it was found that the interfacial interaction between the matrix and fiber was moderate.

Keywords: Kevlar, Polypropylene, Civil Application, Thermal Effect, Mechanical Property, Microscopic Image

1. Introduction

Composites are the materials which made up of more than one phase and contain more two or more materials. Composite materials are preferred as single materials cannot fulfill all the required conditions for different application. Considering the application the matrix and the continuous phases are changed for the desired properties. For this reason, scientist and other users of different materials for different applications are showing their interest in the composite materials. [1-4]. However, there are a number of materials for the preparation of composite and synthetic fiber reinforced composite is the most widely used. Different synthetic fibers can be used for the composite preparation, but fiber is very good for its high mechanical strength. For the matrix materials different synthetic polymer can be used such as polypropylene, polyethylene, low density polyethylene, different types of resin etc. Most widely used matrix material is polypropylene. Polypropylene (PP) is the fastest growing turnover polymers [5].

Polypropylene (PP) is an amorphous thermoplastic polymer. It also has wide applications as engineering material as well as civil application. PP has different vital properties such as high heat distortion temperature, transparency, flame resistance, dimensional stability, and high impact strength. PP is also very suitable for matrix materials for different types of composite materials as well as civil applications. Having such properties PP is thought to be one of the best thermoplastic matrix materials for composite fabrication. [6-8]. Composite materials have a wide range of applications. They possess applications in buildings and public works (chimneys, housing cells, door panel, windows, partitions, swimming pools), road transports (body components, complete body, wheel, bows and arrows, protection helmets, golf clubs and oars), general mechanical components (gears, bearings, robot arms, flywheels, furniture and bathrooms); electrical and electronics (insulation for electrical construction, armour, boxes, covers, cable tracks, antennas, tops of television towers, and wind mills); weaving machine rods, pipes, components of drawing table) etc.[9-10]. The carbon fibre reinforced composites can be a good replacement of typical construction materials.

Carbon Kevlar is one of the most heat resistant synthetic fiber, which was first synthesized in 1973 by condensation reaction of 1, 4-phenylene-diamine (para-phenylenediamine) and terephthaloyl chloride. Kevlar has high tensile strength, low specific gravity, low thermal conductivity, etc. Kevlar is one of the most widely used synthetic material which can keep its properties at the cryogenic (liquefaction temperature of nitrogen gas) temperature. The applications include protection (cryogenics, armour, personal protection), sports(personal protection, equipment shoes, cycle tires) music (audio equipment), fire dancing, frying pans, rope, cable, sheath, electricity generation, building construction, brakes, expansion joints and hoses, particle physics, smartphones etc. The use of the Kevlar in the construction sector is limited because of its high cost. That is why it is needed to find some low cost materials which can be used with it to reduce cost. Polypropylene is one of the low cost materials. This is the main reasons to use PP with Kevlar for construction materials [11-14].

Kevlar reinforced polypropylene based composites contain both properties of polypropylene and Kevlar like other composite materials. There is no natural material in Kevlar reinforced PP based composite. The mechanical properties of the polypropylene are no so good relative to the Kevlar fibre. But the cost of the Kevlar is so high that it cannot be used in all cases or applications. Sometimes so high mechanical properties are not in used, then to reduce the cost as well as to obtain moderate mechanical properties it is good to use Kevlar reinforced composites. Considering the cost and moderate mechanical properties, Kevlar reinforced polypropylene based composites can be very useful in different applications. In this paper it was tried to fabricate a composite material for civil application containing Carbon Kevlar and polypropylene. It was also tried to find some physico-mechanical properties of the prepared composites.

2. Experimental

2.1. Materials

Polypropylene was purchased from MITSUIPET Company. The Kevlar fiber was collected from the Nasim Plastics, Bangladesh.

2.2. Preparation of PP Sheets

Kevlar reinforced polypropylene (PP) based composites were prepared after the preparation of the polypropylene sheets. There are three steps in PP sheet formation (a) weighing of polypropylene granules (b) Pressing and (c) Cooling. For the preparation of different weighted polypropylene sheets, weighing of PP granules was done first by an electric balance. 10 grams and 20 grams of PP granules were weighted for preparing PP sheets. Weighted PP granules were first placed on silicon paper which was on the steel plate. Properly arranged steel plates were placed into a heat press machine that pressed the granules at a temperature 190°C for about 5 minutes with a pressure of 2 tons in order to prepare PP sheets of desired size. After 5 minutes of pressing, steel plates containing hot PP sheet were drawn from the heat press machine to cool the plates by using ice at a room temperature. Then cooled PP sheet was separated from the silicon paper.

2.3. Preparation of Composites

There are four steps in preparing the composite materials as (a) weighing of Kevlar, (b) Layering of n Kevlar and PP sheets, (c) Pressing, (d) Cooling. Desired sized Kevlar was first cut from the Kevlar fabric and weighed by an electric balance. Layering of Kevlar and PP sheets were varied according to the percentage of the Kevlar in the composites to be prepared. Different types of composites were prepared with various formulation as, 5%(1 gm Kevlar+20 gm 6 PP), 10%(1 gm Kevlar+10 gm 6 PP) , 20% (1 gm Kevlar+10 gm 4 PP, 30% (3 gm Kevlar+10 gm 4 PP) of Kevlar with PP. Layer of Kevlar and PP were first placed on silicon paper which was on the steel plate. Properly arranged steel plates were placed into a heat press machine that pressed the layers at a temperature 190°C for about 5 minutes with a pressure of 2N in order to prepare composites of desired percentage of Kevlar. After 5 minutes of pressing, steel plates containing hot composite were drawn from the heat press machine to cool the plates by using ice at a room temperature. Then cooled PP sheet was separated from the silicon paper.

2.4. Tensile Testing

Tensile tests were performed using a Hounsfield series S testing machine (UK) with a cross-head speed of 1 mm/s. The specimen dimension and shape was in accordance with ASTM D-638. The tests were done at room temperature and the extensometer jaw grip was set at 20 mm. Minimum of seven specimens per batch were tested to get the best reproducible results. For each batch of specimen, the average values of Young's modulus (YM), tensile strength (TS) and percentage of elongation (%EB) were calculated by the software from the stress over strain curve obtained. At different temperatures (-20, 24, 30, 50°C) the prepared composites were tested for mechanical properties flowing the previously discussed methods.

2.5. SEM Analysis

SEM analyses have been carried out in the Centre for Advanced Research in Sciences (CARS), university of

Dhaka. A JEOL JSM-6490LA Scanning Electron Microscopy for image analysis. The JSM-6490LA is a high performance scanning electron microscope with an embedded Energy Dispersive X-ray analyzer (EDS) which allows for seamless observation and EDS analysis. The JEOL JSM-6490LA has a high resolution of 3.0 nm. The sample was non-conductive, so graphite coating was applied one surface for the best images.

3. Results

Five composite systems were produced in this study under a specific manufacturing procedure and with target constituent fractions. The composite system fabricated for this study was all classified as bidirectional composite laminates, consisting of seven layers. The composites were put through a rigorous characterization program, including tensile, thermal, water absorption and SEM testing. The results of these tests were analyzed to determine the potential of the systems for application as load bearing structural materials. Additionally, the test results were compared to determine the best composite for application. From this comparison, several key parameters, necessary for increased composite performance, were identified. From the average of five samples of each type, one datum was taken.

3.1. Mechanical Properties

Synthetic fibers are strongly hydrophobic materials and composites made from two or more synthetic materials have different mechanical properties than those of its constituents. Any alteration of the characteristics of the cell wall, either chemical or morphological, has an effect on the mechanical properties of the fibers.

3.1.1. Tensile Strength

The figure 1 shows the tensile strength of composites with different percentage of Kevlar. It could be seen that the maximum value of the tensile strength was obtained, for the composite having 40% Kevlar, which was 162.3 MPa & the lowest was for the composite having 5% Kevlar which was 24.67 MPa. Tensile strength of composites increased with increasing the percentage of Kevlar in composites as the TS of the CK fiber was high relative to the PP matrix. But the increase of tensile strength from 30% to 40% was not so high as compared with other percentages. High percentage of Kevlar in composite made the composite more costly as the cost of CK fiber is high. So, composite with 30% Kevlar may be considered as a favorable composite for any construction materials considering the strength and the cost.

3.1.2. Young's Modulus

The figure 2 shows that Young's modulus of composites. The YM increased with increasing percentage of CK fiber in composites as desired like TS properties. But the increase of Young's modulus of composites having Kevlar percentage from 30% to 40% was not so highly similar to the TS. Therefore, composites of 30% Kevlar was taken as optimized percentage considering the TS and YM.

3.1.3. Percentage Elongation

From the figure 3, it can be seen that percentage elongation of composites decreases with increasing percentage of Kevlar in the composite samples. The %EB of the PP matrix was very high as shown in the figure 3, but the value was very low for the CK fiber. As the percentage of the matrix, PP was decreasing and the fiber percentage was increasing the elongation at break was decreasing. At the 40% fiber the value was very low so it was not shown this in the figure and the 30% fiber was taken as optimized percentage.

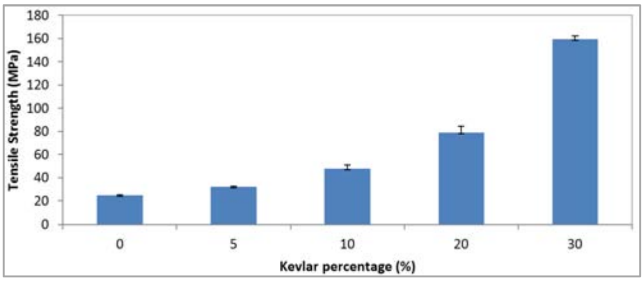


Figure 1. Change of tensile strength with Kevlar percentage in composite.

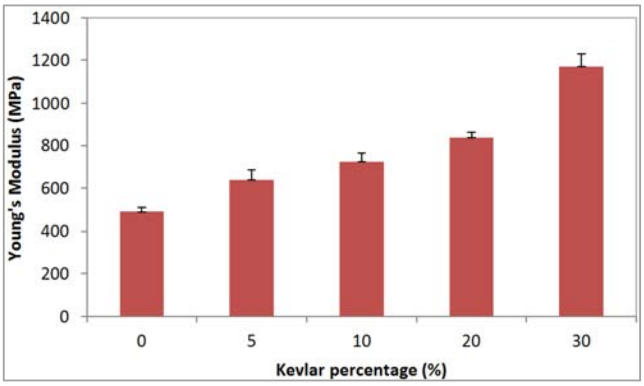


Figure 2. Change of young's modulus with Kevlar percentage in composite.

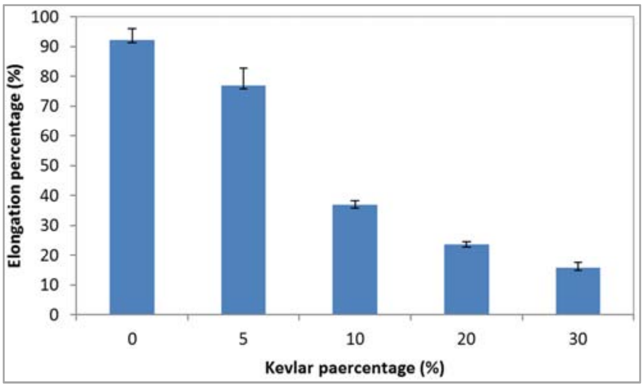


Figure 3. Change of elongation percentage with Kevlar percentage in composite.

3.2. Thermal Properties

Thermal Properties of the composite showed the withstanding power of composites under temperature variation. Tensile properties of composites were measured after exposing the composites at four different temperatures and as a result, tensile properties varied with temperature change. By these variations it can be assumed about the thermal behavior of composites.

3.2.1. Tensile Strength

The value of the TS decreased with increasing temperature and increased with the increment of temperature. TS of composite was the highest at (minus) -20°C temperature and the lowest TS was at 50°C temperature. This changing trend was due to the molecular effects of the polymer matrix and fiber. With the increment of temperature the molecular energy increased and thus the rotation, vibration and movement were increased. Thus, the molecular distance was increased, with the increment of temperature. On the other hand, when the temperature was decreased the molecular energy decreased and hence the molecules were close to each other. The figure 4 shows the tensile strength of the composites with the variation of temperature.

3.2.2. Young's Modulus

The figure 5 shows the temperature effect on the Young's modulus of composite samples. The YM value decreased with increasing temperatures and increased with the increment of temperature. The reason of changing YM with temperature was as similar of tensile strength and is described in the previous section.

3.2.3. Percentage Elongation

In case of percentage of elongation the opposite behavior of TS and YM was observed. As with the increment of the temperature the molecule trend to move away and thus the flexibility increased. On the other hand, with the increment of temperature the molecule trend to keep closer and the flexibility decreased. For this reason the more the temperature the more the percentage of elongation. Figure 6 shows the percentage of elongation change at different temperature.

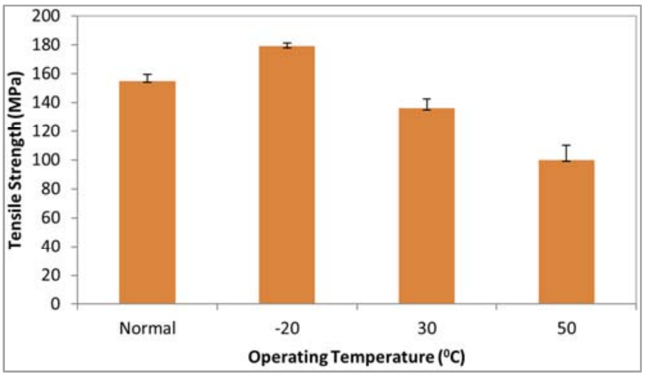


Figure 4. *Change of tensile strength with temperature.*

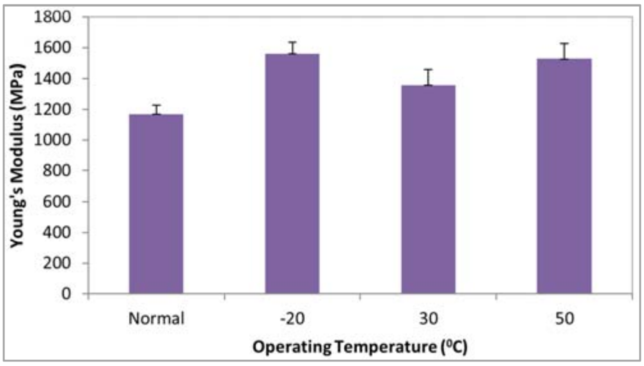


Figure 5. *Change of young's modulus with temperature.*

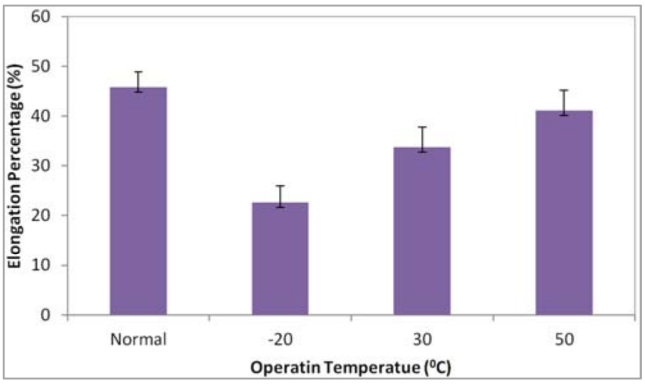


Figure 6. *Change of elongation percentage with temperature.*

3.3. Water Uptake Test

Water uptake of any materials shows the hydrophilc and hydrophobic nature. Low water uptake property indicated the hydrophobic nature. In our prepared composite low water uptake was observed, just only 3% of the total composite mass. So it can be said that our prepared composite was hydrophobic composite as the raw materials (PP and Kevlar) were hydrophobic. The water uptake was almost constant over time, in this case up to 408 hours (17 days). Within five minutes the composites absorbed, about 2.5% of water. This may be some vacant space in the prepared composites between the fiber and fiber as well as the matrix. Water uptake of Kevlar reinforced composite is shown in figure 7.

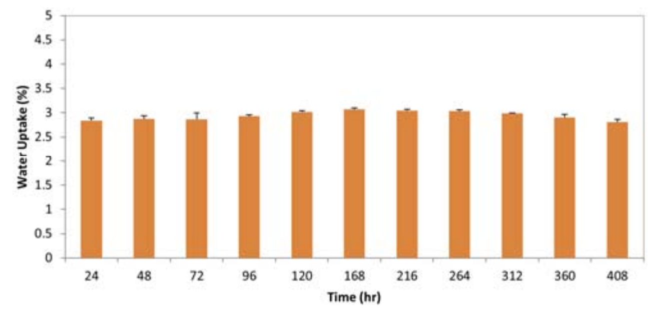
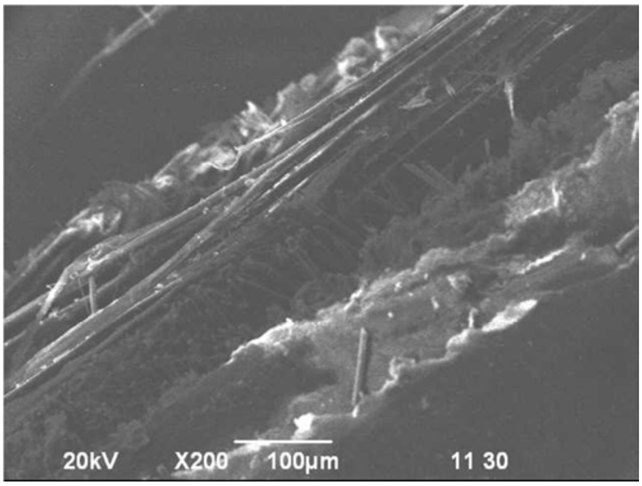
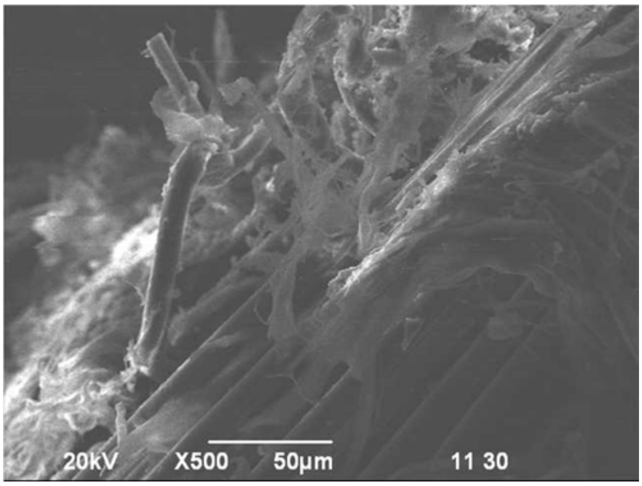


Figure 7. *Water uptake percentage of composites with 30% Kevlar within seventeen (408 hours) days.*

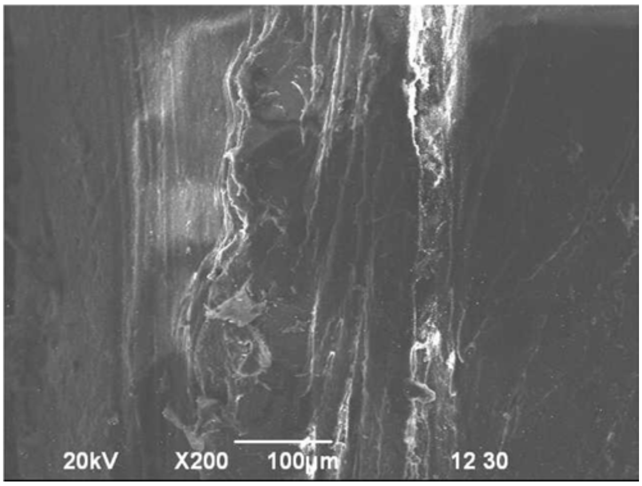
3.4. Scanning Electron Microscope (SEM) analysis



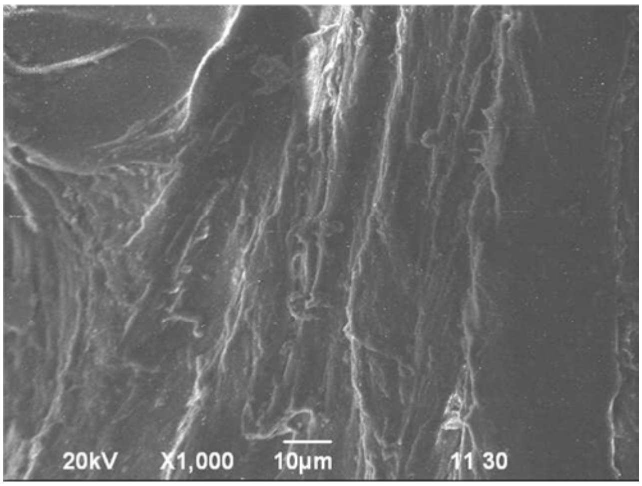
(a) At 200 micrometer magnification



(b) At 500 micrometer magnification



(c) At 200 micrometer magnification



(d) At 1000 micrometer magnification

Figure 8. *Fracture surface of composites at different magnification (a, c~ at 200 micrometer; b~at 500 micrometer and d~at 1000 micrometer).*

SEM images of the fracture surface of kevlar fiber reinforced PP based composites are shown in figure 8. This was clearly observed that the bonding between fiber and matrix was good. The polymer and the fiber were hydrophobic in nature and both are organic compounds. Thus the interaction between the CK fiber and matrix was good. In the mention figure it was tried to show the resolution of 200, 500 and 1000 micrometer. From the images it can be seen that the fiber matrix interaction of the composite was good and as a result the composite showed higher tensile strength, higher elastic modulus and lower elongation at break.

4. Discussion

The tensile strength and tensile modulus of the Kevlar fiber is higher than the polypropylene matrix, but the elongation at break was lower in Kevlar [15]. With the increment of fiber content the TS and TM generally increased. But when the fiber content increased from 30% to 40% the increment percentage was only about 4% and 2% respectively for TS and TM. Considering the cost of the construction materials the 40% fiber containing composites cannot be feasible. The motion of the particles of any material greatly influences the mechanical properties of that material. There are main two types of motions, namely rotational and vibrational motion, which is responsible for the variation of mechanical properties. When the temperature of the prepared composites was increased the rotational and vibrational motions were increased [16]. That is why the TS and TM were decreased in great extent, but the elongation at break was increased. At lower temperature the two motions were decreased and the molecular attraction was increased. Hence the TS and TM was increased and EB decreased. The hydrophobic and hydrophilic nature of any composite depends on the constituting materials. If the both materials are hydrophilic, then the prepared composites are also hydrophilic in nature on the other hand, if the both materials are hydrophobic, then the prepared composites are also hydrophobic. If the hydrophilic and hydrophobic materials are considered for the composite preparation, then the hydrophilic nature is the dominating nature in composite [17]. As, the both dispersed phase and continuous phase are hydrophobic, the composites also showed hydrophobic nature. In case of water uptake, there was minimum absorption of water (only 3%). As the water uptake was not changed significantly, the time for sorption was 17 (seventeen) days only [18]. In the SEM analysis, the adhesion between the fiber and matrix was good. This is another reason to be the better mechanical properties of the prepared composites [19].

5. Conclusion

The highest tensile strength was obtained from 30% Kevlar fiber containing composites containing. It can be said that, Stiffer composite had been made from Kevlar and Polypropylene. Composite containing 30% Kevlar showed less percent of elongation which means it was rigid in nature. Thermal analysis of composite showed that the tensile properties increased with decreasing temperature and decreased with increasing temperature. So it can be used up to a certain temperature for civil applications. The low water uptake property also increased the probability of the use of the composite materials as a surface material of many applications. From the SEM micrographs of clean fiber surface during fracture, it was found that the interfacial bonding between the fibers and the matrix was good. From the thermal and mechanical properties of the composites, it can be said that the Kevlar reinforced composite is very good for civil applications.

Statements

There is no conflict of interest regarding this manuscript.

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