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Full Length Research Paper

Influence of natural long fiber in mechanical, thermal and recycling properties of thermoplastic composites in automotive components

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Natural fiber thermoplastic components in the automotive industry can afford the advantages of weight, cost reduction and recyclability, compared to conventional materials. Handlings of natural fibers in automotive exterior and interior components are essential to recover eco-efficiency and renewability. Natural fibers have recently become affordable to automotive industry as an alternative reinforcement for glass fiber reinforced thermoplastics. The best way to boost the fuel efficiency without sacrificing safety is to employ fiber reinforced composite materials in the body of the cars so that weight reduction can be achieved. The goals are to amplify the performance of the long fiber thermoplastics (LFRT) components by replacing the glass fibers with natural kenaf fiber and also to trim down the production cost. This research is focused on development of partially eco-friendly injection molded hybrid long fiber reinforced thermo plastics with natural kenaf fiber by impregnation process to improve the desired mechanical, thermal properties and recycling of the automotive components.

Key words: Long fiber reinforced thermoplastics, kenaf fiber, hybrid, impregnation process.

INTRODUCTION

The application of the long fiber reinforced thermoplastics (LFRT) materials in an automotive industry is evolving rapidly due to their high performance in terms of mechanical properties, low cost, processing advantages and low density. The custom of the LFRT plastics can be extended up to the bumper beams, front end modules, instrument panel carrier, door modules and under body shields of the automobiles. They have an edge over traditional materials such as steel and aluminum due to their high specific strength good damping capacity, simple manufacturing process and corrosion resistance (Cheon et al., 1995). The matrix in the thermoplastic composites is generally comprised of poly propylene (PP), polyethylene (PE), nylon or other inexpensive polymers. E glass fiber is a commonly used reinforced material.

The natural fibers have some advantages over traditional reinforcement materials such as synthetic glass fiber in terms of cost, density, renewability, recyclability, abrasiveness and biodegradability. In modern years the overblown prices for plastics can be reduced by adding natural fibers to thermoplastics which provides both cost reduction and weight reduction. To augment the eco-friendly plastics in automotives the usage of the natural fibers were essential to enhance the degradability and recycling. The accessibility of the kenaf plant source is plenty in Indian rural areas; as a result this sustainable source can be consumed to improve the ecological compatibility (Saravana bavan and Mohankumar, 2010).

The main advantages of using the annual-growth natural kenaf bast fibers in thermoplastics along with polypropylene (pp) are high mechanical properties, thermal properties and recyclability (Sanadi et al., 1994). Using natural fibers helps to diminish the component weight compared to the glass fiber reinforced composites (Broge, 2000).

The fiber length in long glass fiber thermo plastics composites is very important for its higher mechanical properties and thermal properties. Fiber loading in thermoplastics decides the whole functioning of the long

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fiber thermoplastics (Bigg et al., 1988). The efficiency of the natural fiber reinforced composites depends on the fiber to matrix interface and the capability to adhesion over the matrix to the fiber. This can be maximized by increasing the bonding between fiber and matrix and also changing short fiber length to long fiber length of the composites. Influence of fiber length and fiber distribution having more impact while developing natural fiber thermoplastics composites using injection molding or extrusion process (Davoodi et al., 2008). While using short fibers in the composites the efficiency and performance is less, compared with long fiber composites due to the fiber orientation and distribution of fibers.

The same natural fibres can be used in automotive components by considering automotive safety legislation, crash-worthiness and safety; more importance should be given for material selection and light weighting the automotive parts (Feng and Feng, 2002). Apart from mechanical properties and thermal properties, recyclability of the materials should be considered for developing the natural fiber thermoplastics to save the green environment. To poise the cost and performance of the thermoplastic composites kenaf fiber were chosen as reinforcement in thermoplastics. The kenaf fiber has demanding mechanical properties and thermal properties compared to the other types of natural fibers (Mohanty et al., 2000).

The primary practice of the natural fibers in thermoplastics were restricted due to inability to withstand high temperature during processing and moisture absorption .These limitations can be over come by proper selection of natural fibers, selection of fillers, separation methods of fibers from bast, processing techniques of fiber, fiber-matrix bonding, and selection of manufacturing process of components like injection molding, extrusion, compression molding etc (Ramakrishna et al., 2010).

In this research we used a natural kenaf long fiber instead of synthetic long glass fiber as reinforcements. In order to use kenaf fiber as reinforcement it is necessary to know the property of the fibers. Kenaf is extracted from the bast of the annual fast growing plant named Hibiscus cannabinus. The main constituents of kenaf are cellulose (45 to 57 wt.%), hemicelluloses (21.5 wt.%), lignin (8 to 13 wt.%) and pectin (3 to 5 wt.%). Normally kenaf fibers having discrete individual fibers 2mm to 6mm long filament and individual fiber properties can vary widely depending on the source, age, separating method, moisture content, speed of testing etc. The polypropylene (pp) is an outstanding matrix used to progress the properties of the natural fibers (Xue et al., 2009). Amongst eco-compatible polymer composites, special attention has been given to pp. It takes an important place in eco-composite materials to substitute the glass fibers to natural kenaf fibers (Mohanty et al., 2000, 2005).

This paper is focused on developing hybrid long fiber thermoplastics with kenaf fiber composite material to be used for automotive applications. The mechanical properties, thermal properties and important environment factor such as recyclability were analyzed and compared with commercial long fiber reinforced thermoplastics (LFRT) which is used by the automotive industry.

MATERIALS AND METHODS

The raw materials used in this research were
Polymer: Commercial grade polypropylene (PP)
Reinforcement: Twisted kenaf fiber
Compatibillizer: Maleated polypropylene (MAPP)
Formulation of composites used in this research has abbreviations as follows:

1. 40% wt of natural twisted kenaf fiber + polypropylene + compatibillizer; KLFRT.
2. 30% wt of twisted kenaf fiber +10% wt of glass fiber + polypropylene + compatibillizer; HYBRID PP.
3. 40% long glass fiber filled, (GF-PP), which is available commercially; LFRT. Separation of the kenaf fiber from the bast is an important step to ensure the high quality of composites. For this research, processed kenaf fibers were used; the fibers were soaked in 6% NaOH and 80% distilled water solution for 3 h. After finishing the soaking process, the fibers were taken out and washed in running water and dried and heated up to 140°C to remove the moisture content of the fibers.

Chemical treatment with NaOH removes the moisture content from the fibers, thereby increasing its strength. Chemical treatment also enhances the flexural rigidity of the fibers. This treatment clears all the impurities in the fiber material and also stabilizes the molecular orientation; a hot melt impregnation process was used to fabricate impregnated kenaf fiber pallets. The entire manufacturing processes of kenaf long fiber thermoplastic composite were detailed in Figure 1.

In this impregnation process kenaf fiber roving were used instead of synthetic glass roving. The Kenaf fibers were twisted manually to multiply the strength and made in to roving. The twisted kenaf fibers were made in to fine roving in the rollers. The natural kenaf fiber tows were sent along through the dye to make the pp impregnated matrix over the kenaf fiber. Tows were protruded with kenaf twisted fiber through a heated dye during which the individual filaments are coated with matrix pp. The pultruded tow impregnated with the pp matrix was cooled and then chopped in to KLFRT pallets approximately 10 to 11 mm in length and 3 mm diameter. The KENAF fiber content % by weight 40, HYBRID PP pallets were produced by 30% kenaf fiber and 10% synthetic glass fibers were jointly sent along the dye to get the pallets.

For this research three different composites (KLFRT, HYBRID PP, and LFRT) were cut as pallets and used as a starting material for injection molding process. The specimens were molded according to the ASTM standards (Davoodi et al., 2010) using injection molding process. The orientation of fibers in the course of action is anistropic and the flow axis is longitudinal. The mechanical properties of the standard glass fibers and kenaf fiber were listed in Table 1.

Experimental and testing

Mechanical properties

Density and mechanical properties such as tensile strength, tensile modulus, flexural strength, flexural modulus, impact strength were tested according to the ASTM (American Society for Testing and

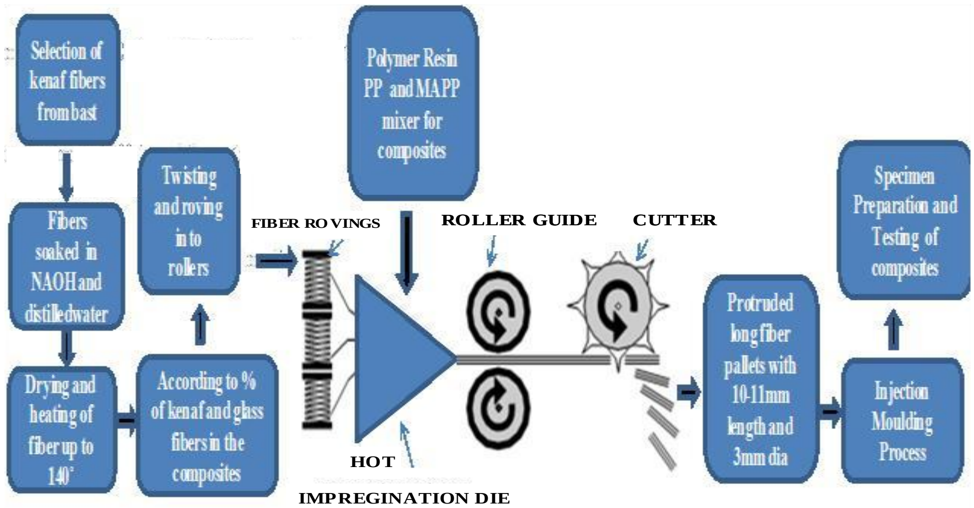

Figure 1. The process flow chart of manufacturing kenaf long fiber thermoplastic composites by hot impregnation process.

Table 1. Material properties of hybrid materials.

Property	Kenaf	Glass
Density	1.4	2.5
Strength	284 - 800	2000 - 3000
Modulus (Gpa)	21 - 60	70
Elongation at break (%)	1.6	2.5

Materials) standards (Davoodi et al., 2010). For density – ASTM D 792, tensile properties – ASTM D3039, flexural properties – ASTM D790, impact strength – ASTM D 256 were implied. Tests were carried out with five set of specimens of KLFRT, HYBRID PP and LFRT, the tested specimens are shown in Figure 2. The values of the KLFRT and HYBRID PP were compared with commercial LFRT composites (Matsuda et al., 2002).

Thermal properties

The application of the thermoplastics in automobile is normally for interior and exterior parts of the automobiles having chances to face various temperature changes. Hence it is important to have evaluation of these properties while designing the materials for automobiles. In heat deflection temperature (HDT), the temperature is being continuously increased were materials can deflect by 0.25 mm at an applied force, when the specimens were placed in three point bending mode. The thermal testing of the specimens was taken according to ASTM Standards (Suhara et al., 2006). For HDT test ASTM D 648 specimen was tested with load of 1.08 Mpa to monitor the dimensional stability of the specimens. Then heat aging of the specimens was monitored. Aging of the tensile test specimens were kept in an air oven at 120ºC for 1000 h, as per ASTM standard D3045, testing was performed after 24 h.

Recycling of composites

Kenaf fibers are less brittle and softer than glass fibers and are likely to result in composites that are easier to recycle than mineral based fibers. Thermoplastics have more recyclability compared to thermosetting plastics. Grinding reprocessing is a general method to recycle the thermoplastics. This recycling process is efficient and economic compared to other recycling methods like chemical recycling, particle recycling and energy recycling (Chu and Sullivan, 1996). To analyze the recycling property, KLFRT, LFRT and HYBRID PP materials went through a process of regrinding followed by injection molding process. The regrinding and injection molding process was repeated twice for better comparison of properties like tensile properties. The values of the recycled tensile properties were compared with virgin values of the composite.

RESULTS AND DISCUSSION

Tensile test

The tensile test were performed according to the ASTM D3039 standard five sets of specimens were tested by a calibrated AUTOGRAPH – AGS – 2003 testing machine as shown in Figure 3 with speed of 5 mm/min. Five sets of specimens with three different reinforcements were used for testing and the results were plotted in Figure 4. The tensile strength and the young's modulus of the KLFRT specimens were higher than common bumper beam materials such as LFRT. Tensile modulus of

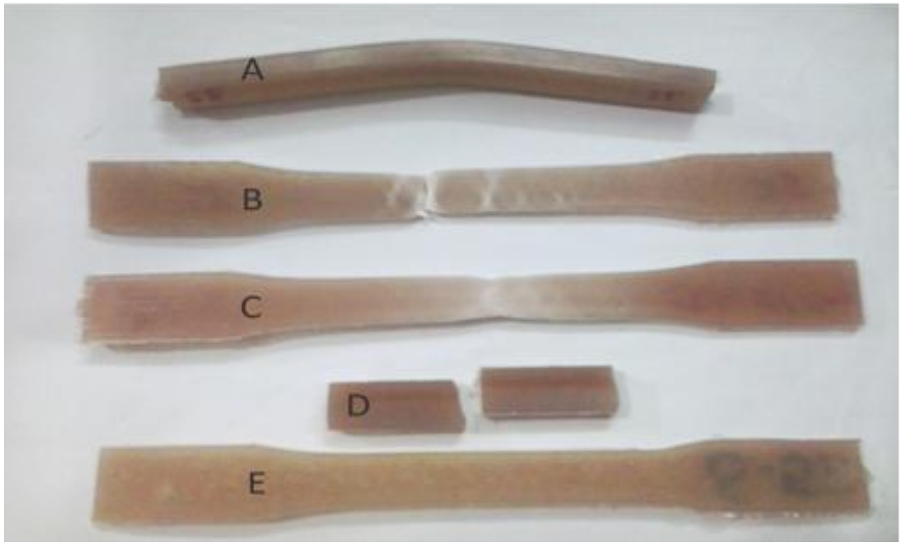

Figure 2. Samples of tested specimens. A-Flexural test, B, C-Tensile test, D-Impact test, E-Heat aging test.

Figure 3. Tensile strength testing of specimen.

HYBRID PP shows dramatic property improvement with LFRT and KLFRT, this is due to the good adhesion and bonding between the fibers/matrix interfaces in the material. Under a tensile load, the improved adhesion results in a more efficient stress transfer from the matrix to the reinforced fibers.

Flexural strength analysis

The specimens were tested using a calibrated AUTOGRAPH –AGS- 2003 testing machine as shown in Figure 5. The flexural strength was conducted according to the ASTM D790 (Three point bending) standard. The five specimens with velocity of 10 mm/min were tested for various span lengths like 100, 80 and 60 mm. The average flexural modulus and strength of five specimens are calculated and plotted as shown in Figure 6. The flexural strength and the flexural modulus of the LFRT material were almost similar to HYBRID PP. The KLFRT shows challenging values compared to the LFRT. This implies that the twisted kenaf fibers had better strength

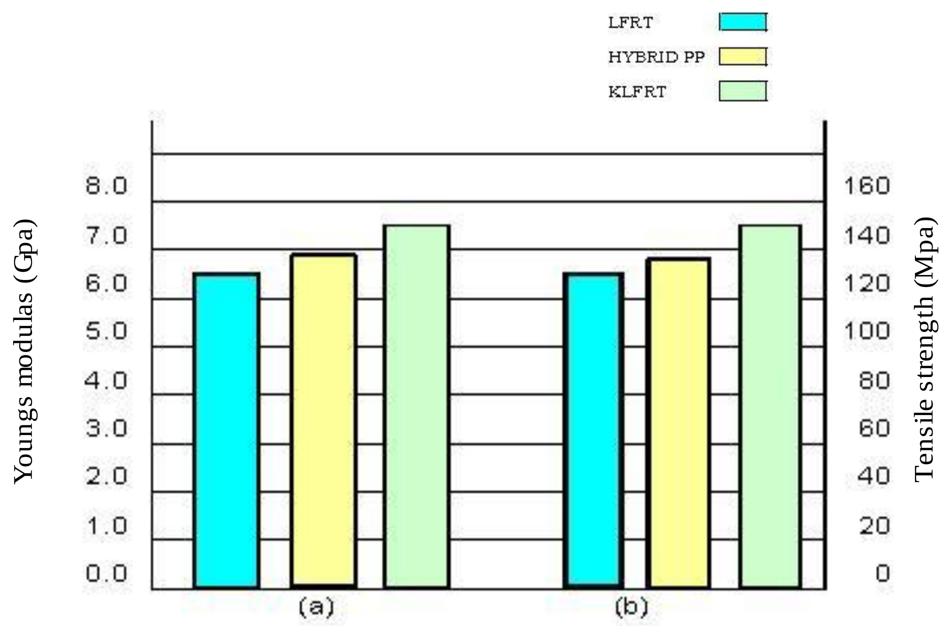

Figure 4. (a) Young's modulus (b) Tensile strength.

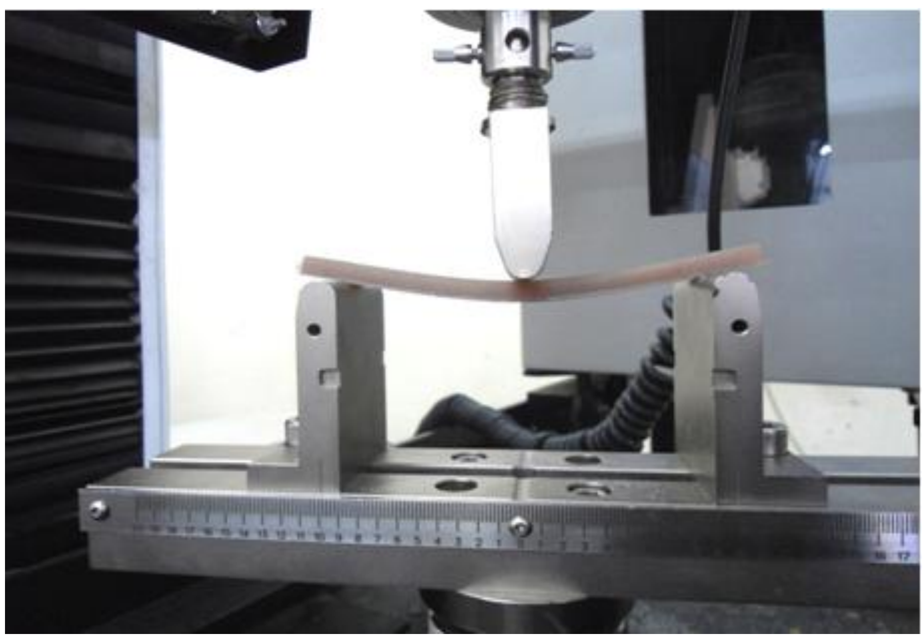

Figure 5. Flexural testing machine.

and the fiber distribution is good.

Impact test

Izod impact test methods were conducted according to the ASTM D256-04 standard. Six samples were prepared and the results were compared with LFRT composites as seen in Figure 7. The density of the HYBRID PP and KLFRT is slightly higher than LFRT; while comparing the izod test results, it is proven that the HYBRID PP has demanding strength to LFRT but the KLFRT impact strength is slightly lesser than the other two composites. The bumper materials should have higher impact strength to absorb heavy shock loads during collision. From the results it is clear that the HYBRID PP can

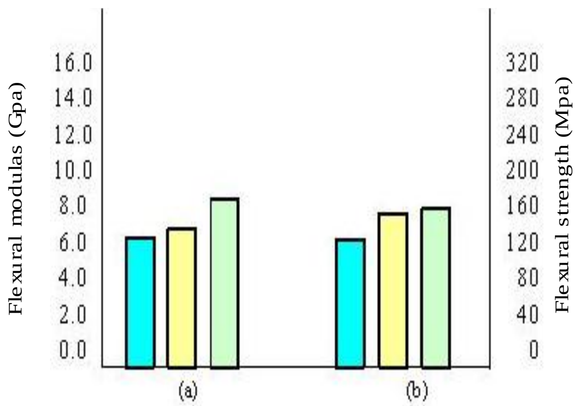

Figure 6. (a) Flexural modulus (b) Flexural strength.

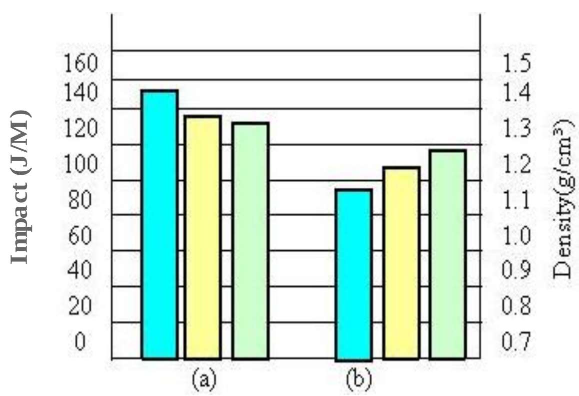

Figure 7. (a) Impact property (b) Density.

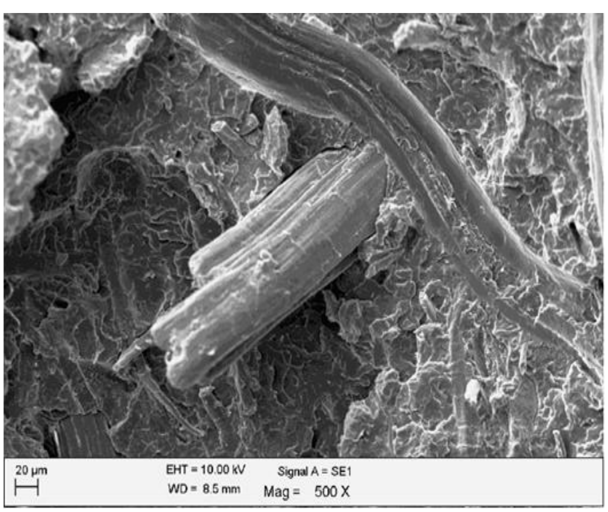

Figure 8. SEM image of Impact fractured surfaces of HYBRID PP composite.

replace the LFRT as a bumper beam. Scanning electron microscopic (SEM) analysis of the HYBRID PP specimen after impact test is shown in Figure 8.

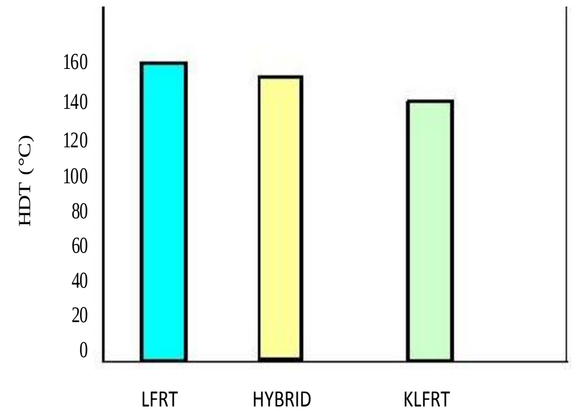

Figure 9. HDT of LFRT and KLFRT.

Thermal properties

Heat deflection temperature (HDT)

It is the basic property of the material to retain its stiffness at elevated temperatures. HDT of the LFRT, HYBRID PP and KLFRT specimens were compared and the graphs were plotted. Figure 9 shows an equivalent stiffness value with LFRT and HYBRID PP. LFRT shows corresponding values to the HYBRID PP and higher values to KLFRT composites. This result shows the dimensional stability of the kenaf long fiber composites, which is essential for automotive components.

Heat aging

Tensile properties of composites before and after aging at 120ºC for 1000 h are listed in Table 2. From the results, it is clear that after aging for long period there is a small reduction in tensile strength and modulus of KLFRT. The HYBRID PP also shows good reduction compared to the LFRT and the results obtained shows that the kenaf fibers in the composites have good thermal stability.

Recycling of composites

The percentage retention in tensile properties of LFRT, HYBRID PP and KLFRT is shown in Figure 10. It is clear that the strength of KLFRT after regrinding and further injection molding did not alter or deteriorate, while incorporation of glass fibers alter the recyclability strength of glass fibers decreased after the first regrinding (100 to 84%) itself and showed further decrease (70%) after second regrinding and may thwart during the next regrinding processes. From Figure 11, the modulus of the KLFRT improved after regrinding and injection molding while other composites showed a lower value. These results indicate the superiority of the natural fiber in KLFRT over LFRT and HYBRID PP with respect to

Table 2. Tensile properties of heat aging test.

Sample	Tensile strength (MPa)			Tensile modulus (Gpa)		
	Before	After	% Change	Before	After	%Change
KLFRT	86.6	82.3	-4.3	4.45	4.95	+2.5
Hybrid PP	93.2	90.5	-2.7	5.12	5.00	-4.85
LFRT	102.4	100.2	-2.2	5.63	5.12	-11.23

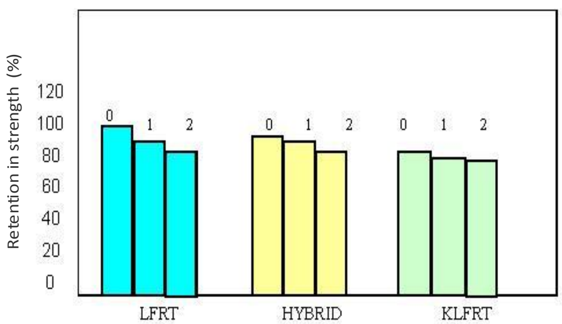

Figure 10. Retention strength during recycling. Key: 0-Origina, 1-1st regrind and 2-2nd regrind.

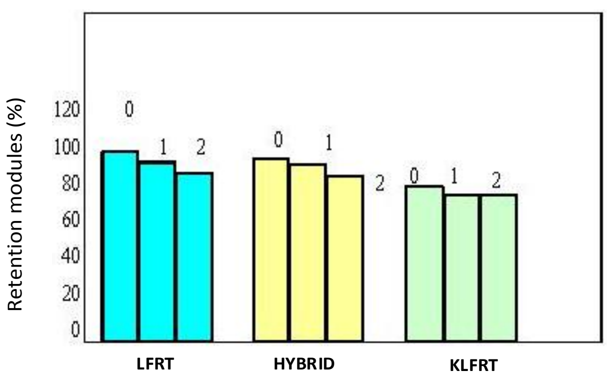

Figure 11. Retention modulus % during recycling process. Key: 0-Origina, 1-1st regrind and 2-2nd regrind.

recyclability. It is very clear that the natural fibers in thermoplastics leads to improved recycling of the composite. Recycling of the automotive thermoplastics having major impact over the environment, the results proven that the KLFRT composite can be used as a biopolymer for better degradation and ecofriendly materials.

Conclusion

This study concentrates on the mechanical, thermal and recycling properties of a kenaf long fiber reinforced composites for consumption in automotive components. A twisted kenaf hybrid material HYBRID PP, which is fabricated by hot impregnation method, presents a superior mechanical and thermal property associated to the commercial LFRT material. This implies that a natural kenaf long fiber reinforced composites could be utilized in automotive structural components such as bumper beams, front end modules and also in interiors of automobiles. More over recycling properties of KLFRT is immense compared to its mechanical and thermal properties. It is clear that the natural kenaf fiber composites can undeniably replace the commercial LFRT for automotive components.

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