Tribological and mechanical investigation of coir-silk reinforced polypropylene based matrix composites.

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Abstract: Silane treated natural fibers such as silk, coconut coir is reinforced into the polypropylene (PP) with a varying weight fraction of fibers and matrices are developed in twin screw extruder at a constant temperature followed by the hot compression molding. Totally three different weight percentage of the polymer composites are developed. Such as silk fiber reinforced composites (S-PP), coir fiber reinforced composites (C-PP) and silk along with coir fiber reinforced composites (S-C-PP). The developed composites are then subjected to various tests. The water absorption capabilities of the all three composites are investigated. The composites are tending to abrasive wear test as per the ASTM standards. Design of experiments L-9 orthogonal array was introduced to identify the optimal wear condition of the composites developed. From the results it is observed that the tricholo vinyl silane chemical treatment to the coir and silk fibers enhances the tribo-mechanical properties of the fiber reinforced polymer composites. Also, the wear life of the composites was increased by 35% and water absorption capability increased by 42%. The scanning electron microscopy helped in identifying the impact of wear test over the surface of the composites at higher magnifications. The detailed surface morphology was executed in order to identify the behavior of the composites upon application of load.

Keywords: Silane treatment, Design of experiments, Twin screw extruder, Tribology, Polymer matrix composites.

1. Introduction

Natural fiber reinforced composites manufacturing is becoming one of the important development in the recent decades. These natural fibers are easily available and less in cost. The mass production of natural fibre reinforced composites helps in economical production and recycling of the materials[1-4]. Polymer matrix composites are having multiple engineering applications as they
possess promising tribo-mechanical properties. As polymer composites are built with variety of continuous and short fibres which helps in transferring the loads between Matrix and the fibres[5-8]. In the recent years lot of research work is done to develop polymer composites in order to fulfill the industrial needs. In fact many researchers have proved that natural fibre reinforced polymer matrix composites are having potential to replace many industrial materials. The tribological and the mechanical characteristics of these composites exhibited promising results. Also, when these natural fibres are chemically treated they will release the moisture [9-12]. And when moisture content is reduced in the fibres this will help in proper bonding with the matrix material. Coconut coir comes under the category of natural fibers. They are drawn out from the outer husk of coconut and are used in making several daily use products. Coir has fibrous properties found between the hard-inner shell and the external coat of a coconut. Coir has the most upraised cluster of lignin, resulting in stronger yet less flexible than cotton and undesirable for coloring [13-15]. The elasticity of coir is less as compared to abaca. However, it has considerable protection from “microbial action and saltwater harm”. A coarse, short fiber is found in ropes, sleeping mattress, brushes, geotextiles and vehicle seats. It is a natural fiber which have a biomechanical property obligatory to initially stabilize the linkage, its fiber is a nonstop string of extraordinary rigidity estimating from 500 to 1500 meters lengthy, having a diameter varying from approximately (10 to 13) microns. In woven silk, the fiber's three-sided structure goes about like a prism which refracts light, resulting in silk fabric and is exceptionally valued "normal shimmer". It also has great permeability, less conductivity and dyes without any problem [16-18].

In this experimental investigation different weight fraction of natural fibers were reinforced with the polypropylene matrix materials. The natural fibers were treated chemically in order to reduce the moisture content and for the better reinforcement in the matrix material. This paper shows an assessment of the different utilization of coconut coir and silk natural cellulosic fibers for the plan & assembling of composite materials [19-24].

2. Materials and method:

Commercially available polypropylene is utilized as matrix material and naturally procured coconut coir and silk fibers are used as reinforcements. The matrix polypropylene granules are fed in the twin-screw extruder at a temperature of 160 degree Celsius, followed by the compression molding process. The silane treated natural fibers are chopped for the length of 1mm – 2mm and are fed into the twin screw extruder which is followed by the compression molding. The below table 1.1 shows the weight fraction of various materials used in this work. The fibers are distributed randomly all over the matrix and for the uniform mixing fibers are fed into the twin screw extruder.

| Composite | Coconut coir fiber weight percentage | Silk fiber weight percentage | Polypropylene matrix weight percentage | Total |
|----------|-------------------------------------|-----------------------------|--------------------------------------|-------|
| C1       | 20                                  | 80                          | 100                                  |       |
| C2       | 20                                  | 80                          | 100                                  |       |
| C3       | 20                                  | 60                          | 100                                  |       |

2.1. Twin-screw extruder

This is a process where two or more components are mixed together made to form a compound. This is more suitable for extruding reactive polymer materials. This process has two identical screws which are kept engaged and are mounted on shafts and are made to rotate in the same direction inside a closed container. These screws rotate with or against each other and this motion provide a special mixing form such as kneading block, forward and reverse capabilities, etc. Their movement indicates the characteristic of mixing.
3. Results & Discussion

3.1. Design of experiments

To identify the optimal wear rate of the polymer matrix composite samples prepared, L-9 orthogonal array was implemented. As shown in the table 1.2 it is a 3-factor and 3-level investigation. From the Taguchi’s approach L-9 orthogonal array was derived and it is having 9 rows and 3 columns. The column 1 designated for weight fraction of the composites, column 2 designated for the load in N and it is varied from 5N to 15N, column 3 is designated for speed of disc rotation varying from 200RPM to 600RPM. And from the MINITAB software the analysis of the experiment was done.

Table 1.2: L9 orthogonal array

| Sl No. | Composites | Load in N | Speed of the disc in RPM | Wear Rate * 10^3 | SNRA2  | MEAN2 |
|--------|------------|-----------|--------------------------|------------------|--------|-------|
| 1      | C1         | 5N        | 200RPM                   | 935              | -59.4162 | 935   |
| 2      | C1         | 10N       | 400RPM                   | 1150             | -61.214  | 1150  |
| 3      | C1         | 15N       | 600RPM                   | 1246             | -61.9104 | 1246  |
| 4      | C2         | 5N        | 400RPM                   | 1144             | -61.1685 | 1144  |
| 5      | C2         | 10N       | 600RPM                   | 1280             | -62.1442 | 1280  |
| 6      | C2         | 15N       | 200RPM                   | 1285             | -62.1781 | 1285  |
| 7      | C3         | 5N        | 600RPM                   | 801              | -58.0727 | 801   |
| 8      | C3         | 10N       | 200RPM                   | 867              | -58.7604 | 867   |
| 9      | C3         | 15N       | 400RPM                   | 950              | -59.5545 | 950   |

Table 1.3: Linear Model Analysis: SN ratios versus Composites, Load on the pin, Speed of the disc rotation. Estimated Model Coefficients for SN ratios.

| Term             | Coef SE | Coef | T    | P     |
|------------------|---------|------|------|-------|
| Constant         | -60.491 | 0.06972 | -867.687 | 0 |
| Composite C1     | -0.3559 | 0.09859 | -3.609 | 0.069 |
| Composite C2     | -1.3393 | 0.09859 | -13.584 | 0.005 |
| Load on 5N       | 0.9385  | 0.09859 | 9.519  | 0.011 |
| Load on 10N      | -0.2152 | 0.09859 | -2.183 | 0.161 |
| Speed of 100RPM  | 0.3728  | 0.09859 | 3.781  | 0.063 |
| Speed of 200RPM  | -0.1547 | 0.09859 | -1.569 | 0.257 |
S = 0.2091   R-Sq = 99.6%   R-Sq(adj) = 98.2%.

Table 1.4: Analysis of Variance for SN ratios:

| Source                  | DF | Seq SS   | Adj SS   | Adj MS   | F        | P     |
|-------------------------|----|----------|----------|----------|----------|-------|
| Composites              | 2  | 14.3815  | 14.3815  | 7.19075  | 164.39   | 0.006 |
| Load on the Pin         | 2  | 4.3509   | 4.3509   | 2.17546  | 49.73    | 0.02  |
| Speed of the disc rotation | 2  | 0.6313   | 0.6313   | 0.31565  | 7.22     | 0.122 |
| Residual Error          | 2  | 0.0875   | 0.0875   | 0.04374  |          |       |
| Total                   | 8  | 19.4512  |          |          |          |       |

Table 1.5: Response Table for Signal to Noise Ratios: Smaller is better.

| Level | Composites | Load On the Pin | Speed of the disc rotation |
|-------|------------|-----------------|---------------------------|
| 1     | -60.85     | -59.55          | -60.12                    |
| 2     | -61.83     | -60.71          | -60.65                    |
| 3     | -58.80     | -61.21          | -60.71                    |
| Delta | 3.03       | 1.66            | 0.59                      |
| Rank  | 1          | 2               | 3                         |

Table 1.5 is displaying the final results of the Taguchi’s design of experiment L-9 orthogonal array. To get the statistically significant reading 3 replicates were used for running each test. And the average wear rate is noted upon completion of each experiment. After this ANOVA used to know the significant factors affecting the major wear rate of the composites. From the table it is observed that the percentage of weight fraction of fibers in the composites is the most influencing factor followed by load and disc rotation speed respectively. Also, residual error of the entire experiment is only 0.8763%. From the figure it is observed that composites C2 are the least affected with respect to wear rates are concerned.
From the figure 1.1 and 1.2 it is observed that composites C2, silk fiber reinforced composites are tend to lose more when they are let to dry body abrasion wear test. Whereas the C3 composite, which is a combination of coir and silk fibers are tend to wear less upon higher load and distance.

3.2. Water absorption

Figure 1.3 shows the percentage of water absorption by each composite. From the figure it is seen that the composites C3 are good at absorbing higher amount of water content. This property is due to the chemical treatment given to the fibers before manufacturing. C3 composites are able to absorb 1.55% of water followed by C2 1.13% and C1 0.88%.
In this project, fiber reinforced polypropylene composites were used to study their tribo-mechanical properties. Coir fiber was chemically treated with alkali solution. Hot compression method was used in manufacturing the composite followed by twin-screw extrusion. The composites were prepared with different weight fraction compositions of coir and silk fiber. The composites were then let for the tribo-mechanical tests. Following are the conclusions drawn from the results:

- Twin screw extrusion method helps in producing good surface finish composites and this manufacturing process found effective.
- The wear life of the C3 composites was increased by 35% in comparison with the C1 and C2 composites.
- From the design of experiments it was observed that weight fraction of the composites are the major influencing factor followed by the load on pin and disc rotation speed.
- Water absorption capability of the C3 composites was increased by 42%. This is due to the tri chloro vinyl silane treatment to the composites.

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