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Development and Mechanical Behaviour Analysis of Human Hair Fibre-Reinforced Polypropylene Composites

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Abstract - In recent years, natural bio-fibres have attracted considerable attention from researchers, engineers, and scientists as potential alternatives to synthetic reinforcements in fibre-reinforced polymer (FRP) composites. Their low cost, acceptable mechanical properties, lightweight nature, and favourable aspect ratio make them promising reinforcement materials. In India, approximately three to four tonnes of human hair waste are generated annually, creating significant environmental disposal challenges. Therefore, utilizing waste human hair fibres as reinforcement in polymer composites provides an opportunity for sustainable material development and value-added applications.

In this study, polypropylene (PP)-based composites were developed using waste human hair fibres as reinforcement. The human hair fibres were incorporated into the polypropylene matrix at different weight fractions of 3%, 5%, 10%, and 15% using a two-roll mill mixing process. The prepared composites were subsequently fabricated through compression moulding under controlled temperature and processing time conditions. The results indicated that the incorporation of human hair fibres improved the flexural and impact strength of the polypropylene composites compared with neat PP. However, the tensile strength of the hair fibre-reinforced polypropylene composites showed a reduction compared with pure polypropylene.

Keyword : *human hair fibre, composite, mechanical properties, polypropylene*

I. INTRODUCTION

Composite are combination of two or more than two materials in which one of the material, is reinforcing Composite materials are generally classified according to the type of matrix phase used, such as polymer, metal, or ceramic matrices, and the type of reinforcement incorporated. Among these, polymer matrix composites (PMCs) are the most widely manufactured commercial composites, where polymer resins act as the matrix phase and are reinforced with various materials to achieve improved performance. Polymer matrices are mainly categorized into two groups: thermoplastics, including polyethylene (PE), polypropylene (PP), polyether ether ketone (PEEK), polyvinyl chloride (PVC), polystyrene (PS), and other polyolefins, and thermosetting polymers such as epoxy, polyester, and phenol-formaldehyde resins. These polymer matrices can be reinforced with different types of fibres, including natural fibres (plant, animal, and mineral-based) and synthetic fibres, depending on the intended application [1–2].

Human hair fibres are primarily composed of keratin protein, which possesses an alpha-helix structural arrangement. Approximately 91% of human hair consists of proteins formed by long chains of amino acids connected through peptide bonds. The elemental composition of normal human hair includes approximately 45.68% carbon, 27.9% oxygen, 6.6% hydrogen, 15.72% nitrogen, and 5.03% sulphur. The major amino acids present in hair include cysteine, serine, glutamine, threonine, glycine, leucine, valine, and arginine. Natural fibres have gained attention as reinforcement materials in composite applications due to their advantages, including good mechanical strength, low cost, high toughness, and biodegradability. However, their application in advanced composites is limited by certain drawbacks, such as poor compatibility with hydrophobic polymer matrices, moisture sensitivity, fibre aggregation during processing, limited fibre length, and relatively large fibre diameter [3–5].

Colom *et al.* developed high-density polyethylene (HDPE)/wood fibre composites using a compounding process at 160 °C in a two-roll mill, followed by compression moulding at 150 °C for up to 20 minutes. Similarly, feather fibre-reinforced polypropylene composites were fabricated using an extrusion process at 200 °C.

In the present study, waste human hair fibres were incorporated into polypropylene at different concentrations of 3, 5, 10, and 15 wt%. The composite materials were prepared through mixing in a two-roll mill, followed by compression moulding to produce tensile specimens. The moulding process was carried out at temperatures ranging from 180 °C to 190 °C for processing times between 0 and 10 minutes. Neat polypropylene samples were also prepared under identical conditions for comparison [6–8].

EXPERIMENTAL

Materials: polypropylene homo polymer (PP) (1110MG, Density 0.903 gm/cm^3, MFI 11 gm /10min) supplied by Indian Oil Corporation limited Panipat, Haryana and India. Human hair (density 1.32 gm/cm^3 tensile strength 382 M pa) obtained from local market.

Compounding: The polypropylene are mixed into Human hair fibre at 3, 5, 10, 15 wt% using two roll mill and the compounding temperature is 190^{0}C.Table-1 shows sequential addition of PP and human hair.

Specimen preparation: The mould sample for testing were compression moulded using compression moulding at 190^{0}Cand 60mpa for 10 min. After pressing the sheet are removed from the press and cooled by water.

II. CHARACTERIZATION TECHNIQUES

Mechanical properties: The test specimen for analyzing the Mechanical properties was initially conditioned at 23$\pm$2^{0}C and 50$\pm$ 5%RH for 24 hr prior to testing.

Tensile strength: Tensile properties were evaluated to ASTM D638 using dumbbell shaped samples and an INSTRON Universal testing machine model 3342 tensile tester with a cross head speed 5mm/min [9].

Flexural modulus: flexural properties are evaluated according to ASTM D790 using an INSTRON universal testing machine model 3342 with a cross head speed of
1.3 mm/min .the dimension of the specimen were 127mm in length,12.7mm in width and 3mm thickness[10].

Izod impact strength: Izod impact properties were evaluated according to ASTM D256 using impact tester model impact104 with a notch angle 45^{0}and depth of
2.54 mm .the dimension of the specimen were 63.5mm in length, 12.7mm in width and 3mm thickness[11].

III. RESULT AND DISCUSSION

The mechanical properties of human hair fibre-reinforced polypropylene (PP) composites, including impact strength, flexural strength, flexural modulus, tensile strength, and elongation at break, were evaluated as shown in Table 3. The results indicated that these properties improved with an increase in fibre content from 3 wt% to 5 wt%. However, further addition of fibre loading from 10 wt% to 15 wt% resulted in a reduction in mechanical performance. The improvement observed at lower fibre concentrations can be attributed to enhanced interfacial bonding between the fibre and polymer matrix, which facilitates effective stress transfer.

The overall performance of fibre-reinforced polymer composites is strongly influenced by the quality of the fibre–matrix interface. This interface depends on factors such as fibre surface morphology, chemical compatibility between the fibre and matrix, and the characteristics of the resin system. The incorporation of human hair fibres into polypropylene improved the interfacial adhesion, resulting in more efficient load transfer across the fibre–matrix boundary.

The increase in mechanical properties with increasing fibre content up to an optimum level is mainly due to the greater availability of reinforcement fibres for carrying applied loads. However, at higher fibre concentrations, the mechanical properties decreased due to increased fibre–fibre interactions, inadequate fibre alignment, poor dispersion within the polymer matrix, and increased void formation. The presence of residual moisture in the fibres may also contribute to void development, reducing interfacial strength and limiting effective stress transfer between the fibre and matrix. Consequently, excessive fibre loading leads to reduced composite efficiency and lower mechanical performance.

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Table-1 : Mechanical properties of the pure resin

	Flexural strength,Mpa	Flexural modulus.Mpa	Tensile strength,Mpa	Elongation at break%	Izod impact strength,j/m
Polypropylene	30.08	992.83	40.41	31.52	11.93

Table -2 : Mechanical properties of human hair fibre

	Linear density,gm/cm^3	Fibre length,mm	Tensile strength,Mpa	Elongation at break%
Human hair fibre	1.32	3-10	384.79	216.94

Table -3 : Mechanical properties of human hair fibre and PP reinforced polymeric composite

	0%	3%	5%	10%	15%
Tensile strength,Mpa	40.41	24.87	32.26	13.35	9.7
Elongation at break, mm	31.52	7.02	10.47	10.20	7.7
Flexural strength,Mpa	30.08	30.13	38.89	30.07	25.01
Flexural modulus,Mpa	992.83	1450.85	1539.25	1363.63	1064.91
Izod impact strength,j/m	11.93	6.20	12.55	5.08	5.02

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The tensile strength result of control (0%) and different fibre loaded composites were demonstrated and compared in fig.1. These results show that the control composites tensile properties were significantly higher when compared to the human hair fibre reinforced composites. In all cases the control (0%) composites had better tensile properties than the human hair reinforced composites. It was expected that when the fibre loading percentage increases some of the mechanical properties decreases due to the random short fibre distribution inside the composite matrix and also lack of adhesion between matrix and fibre. The main concern with short fibre reinforced composite is the difficulty in controlling.

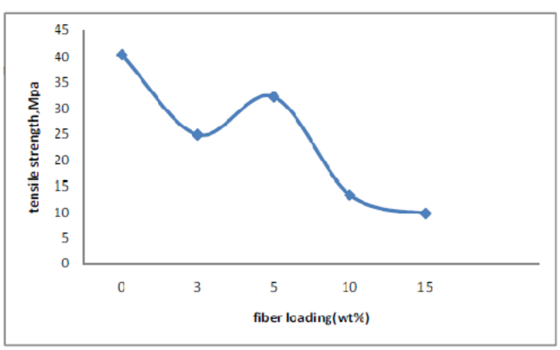

Fig. 1. Tensile strength result of composite

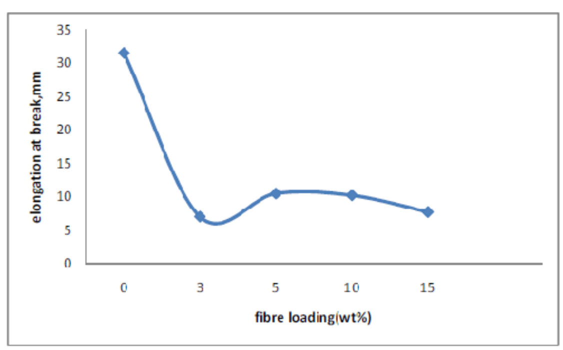

Fig.2 elongation at break result of composites

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The breaking elongation results of the composites are given in fig.2. The breaking elongation results were found to be similar to the tensile result, when fibre loading increased the breaking elongation decreased. Elongation at break for polypropylene is just above at
31.52mm at 0%fibre loading. The lowest breaking elongation occurred at the 15% human hair reinforced polypropylene composite which was 7.02 mm.

The flexural strength results are demonstrated in Fig-3 the flexural strength increase with the increase fibre loading from 3 to 5wt%. The flexural strength values are reduced from 10 to 15wt% due to random short fibre distribution inside the composite matrix

The flexural modulus values are illustrated in Fig.4. The flexural modulus values of human hair fibre reinforced composite increases up to 3 to 5% when the fibre loading percentage rises and then decreases from 10 to 15 wt%. PP control composites have lower.

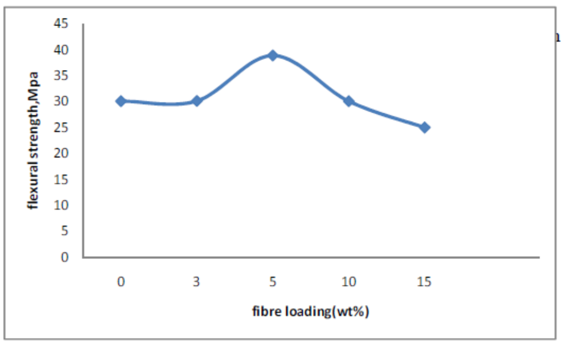

Fig.3. flexural strength result of composites

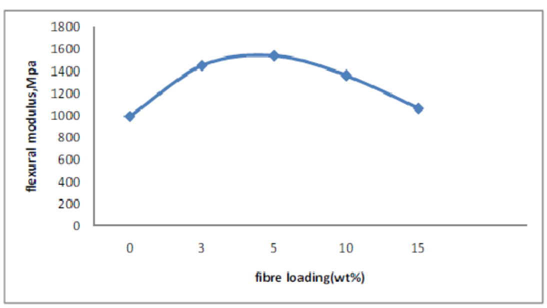

Fig .4.flexural modulus result of composite

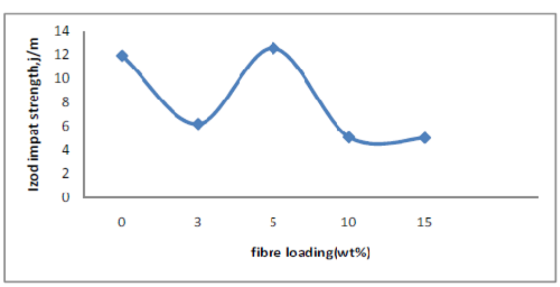

Fig-5 Izod impact result of composites.

The Izod impact values of composites increases with the fibre loading up to 3 to 5 wt% due to the test and the random short fibre reinforcement nature both the impact test and short fibre reinforcement have multidirectional (unidirectional) characteristics. Therefore if the unidirectional short fibre percentage increases for the composite structure, the impact values will increase for the composite structure, the impact values will increase in relation. The Izod impact values of composite decreases form 10 to 15 wt%.

IV. CONCLUSION

,This study demonstrates that human hair fibres can effectively function as reinforcement materials in a polypropylene (PP) matrix. The incorporation of 3–5 wt% human hair fibres resulted in improved flexural strength, flexural modulus, and Izod impact strength compared with unreinforced polypropylene. However, further increase in fibre content to 10–15 wt% led to a reduction in these properties, resulting in lower flexural strength, flexural modulus, and impact strength than the neat PP matrix. The tensile strength of the reinforced composites was also found to be lower than that of the unreinforced polypropylene, with tensile and flexural properties decreasing as the fibre loading increased beyond the optimum level.

The utilization of untreated whole human hair fibres as reinforcement provides advantages by reducing processing requirements, lowering production costs, and maintaining desirable composite characteristics. The mechanical performance of these composites can be further improved by optimizing fibre content, selecting suitable resin systems, and applying appropriate surface treatments to enhance the interfacial adhesion between the fibre and polymer matrix. Improved bonding at the fibre–matrix interface can contribute to better stress transfer and enhanced overall composite properties.

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