Tensile Strength Improvement Using Human Hair Reinforcement in Recycled High Density Polyethylene

G Ragul1*, V Jayakumar2, S U Sha3, R Biswas1 and C Kumar4

1Department of Mechanical Engineering, Budge Budge Institute of Technology, Kolkata, India
2Department of Mechanical Engineering, Saveetha School of Engineering, Saveetha University, Chennai, India
3Department of Mechanical Engineering, Anna University, Chennai, India
4Department of Civil Engineering, Budge Budge Institute of Technology, Kolkata, India

Received 22 May 2017; revised 16 December 2017; accepted 07 May 2018

One way to reduce the harmful destruction of our ecosystem is to have policies encouraging the use of natural fiber. Human hair disposal has become a growing concern as it is non-degradable. Considerable research is being done regarding the alternative uses of the same. But the high tensile strength of human hair can be harnessed in productive ways. Another area of study aims at increasing the productivity of recycled plastics. This work aims at making use of this non-degradable material for increasing the strength of recycled plastic. Human hair (HH) is used as reinforcement in high density polyethylene (HDPE) forming a polymer matrix composite. Composite samples were made using 3%, 5% and 10% of human hair by weight and the mechanical properties of them were evaluated. The fabricated HH-HDPE polymer matrix composite samples have given encouraging results of improved tensile strength and tensile modulus.

Keywords: High Density Polyethylene, HDPE, Human Hair Fiber, Polymer Matrix Composite

Introduction

Human hair is found in abundance all over the globe and often considered useless in most societies and is therefore found in municipal waste streams. As the degradation time is slow, it stays as a waste for a long time occupying large volumes of space. In recent times, biological fibers such as human hair are being attempted as alternative reinforcement for FRP (fiber reinforced polymer) composites, due to their low cost, fairly good mechanical properties and high aspect strength. Varma et al. presented a review paper on the current scenario of human hair as biological composite fiber and its application in various fields1. In their work, they reported the various experimental studies carried out to examine the effect of human hair as a composite fiber in different matrixes. Ashish Kumar Dwivedi et al. carried out fabrication and properties evaluation of human hair reinforced polypropylene composite and reported that composite with 8% human hair and 92% polypropylene had yielded the compressive strength of 40.54 MPa2. Nila et al. have used the waste human hair with the concrete in different compositions to enhance the compressive and impact strength and also to reduce the crack in the walls3. Wajit Ali Butt et al. investigated on strength properties of clayey soil reinforced with human air fiber. They randomly distributed human hair fiber in clayey soil samples and tested for its engineering properties by performing CBR and tri-axial test on a number of samples by using the different percentage of fibres and comparing the results with the non-reinforced soil. Their test result revealed that the strength significantly improves with the inclusion of HHF and also prevents the sample from cracking4. Many research works have been reported on fabrication, characterization and applications of human hair reinforced composites5-12. In this paper, human hair reinforcements in HDPE are investigated to improve the tensile strength and tensile modulus properties of the material.

Experimental works

The human hair was selected as reinforced material and high density polyethylene (HDPE) was selected as matrix in the present investigation. Hair fibers were collected from a local barber shop. It was repeatedly cleaned using distilled water and then kept for drying under atmospheric conditions for about 24 hours. To
ensure the maximum removal of moisture, the hair fibers were kept in a hot air oven at 55°C for 2 hours. Treatment of the fibers with an alkaline medium like NaOH was also suggested as it forms –[OH] bonds increasing the bonding. High-density polyethylene (HDPE) is a thermoplastic material composed of carbon and hydrogen atoms joined together forming high molecular weight products. The availability, low moisture absorption, ease of forming, better chemical resistance, low shrinkage and highest strength-to-weight ratio attracted the selection of High Density Polyethylene as matrix material in the present investigation. The high density polyethylene used for the experiment was black in colour. We chose it purposefully, considering the aesthetic appearance of the composite material to be fabricated. It is as coloured as it contains carbon black.

Four type of samples were made with different composition as below.

- **Composite 1** - 0% Human hair (0 g) + 100% HDPE (300 g)
- **Composite 2** - 3% Human hair (9 g) + 97% HDPE (291 g)
- **Composite 3** - 5% Human hair (15 g) + 95% HDPE (285 g)
- **Composite 4** - 10% Human hair (30 g) + 90% HDPE (270 g)

The total weight was maintained at 300 g. The fiber and recycled HDPE granules were hand-mixed thoroughly in a container before adding it to a two roll mill. The rollers consisted of a working width of 230 mm with a roll diameter 150 mm rotating at 45 rpm and held at 185°C. The HDPE touching the roller surface turned to be a semi-solid material which paved the way for proper mixing with fibers and thereby a homogeneous mix was obtained. Figure 1 depicts the various stages of the experimental work carried out to manufacture the human hair composite specimen. The so obtained mix was placed in the mold chamber of the lower plate of a compression molding machine and the upper plate is brought downwards to maintain a pressure of 65 psi with 200°C temperature of both the plates. After compression molding, the mold was taken out and was kept for 15 minutes to cool down before taking out the composite. The mold was then cleaned with silicone spray. As the composite 1 contains no hair fibers, it was not subjected to milling; the HDPE granules were directly placed in the die for compression molding. The compression molding gave us a sheet of 20 cm in both length and breadth and 3 mm in thickness. The sheet was then cut using a die using a specimen die punch cutter to obtain dumbbell shaped specimens. The Computerized Universal Testing Machine (Capacity: 1000 kN & Make: Fine UTM manufactures limited), equipped with a 10 kN load cell was used to perform the tensile tests according to ASTM D 638 standard. Five dumbbell shaped samples with size 165 x 13 x 3 mm³ were tested for each case, setting the cross-head speed to 1 mm/min and the average value is noted as the tensile strength of respective composite samples. The tensile test results for the four composites are given in Table 1. One of the most common of tensile testing requirement is the determination of break strength. It is generally the tensile load required to fracture the sample to fail. The sharp break is referred to the measurement when load or force drops by 5% from its peak load measurement. A thermo plastic material is likely to have a load drop of 5%, and the breaking load is the break strength. The break strength of 18.1 kgf/cm², 31.7 kgf/cm², 29.1 kgf/cm² and 25.6 kgf/cm²
were obtained for four different combinations and the resulting loads vs. displacement diagrams are shown in Figure 2.

**Results and Discussion**

This experiment involved the fabrication of four composites: (i) Composite 1 with 0% human hair and 100% HDPE (actually it cannot be termed as a composite as it contains no hair fibers); (ii) Composite 2 with 3% human hair and 97% HDPE; (iii) Composite 3 with 5% human hair and 95% HDPE and (iv) Composite 4 with 10% human hair and 90% HDPE. The virgin sample showed poor results for the tensile strength and modulus. As the composition is varied by reducing 9 grams of HDPE and adding the corresponding weight of human hair, the strength shot up exhibiting a value of 191.889 kgf/cm$^2$, which is the peak strength obtained. The addition of 5% and 10% of hair fibers in HDPE reduced the tensile strength of composites significantly due to reason that the matrix is unable to carry the load transferred to it after the fibers have failed, and therefore, the matrix fails immediately after the fiber failure. However, at low fiber volume fraction, it is possible that the matrix will be able to carry additional load even after the fibers have failed. The 3% of HH is the critical fiber content in the present investigation. As the fiber content is increased to 5% and at last to 10% and correspondingly reducing the matrix content, the rigidity of the composite shot up and the peak value of tensile modulus was exhibited by composite 4 and it is 304.2 MPa. The test results show that the composite 2 exhibits a tensile strength of 191.889 kgf/cm$^2$ at break load which turns out to be the best composition as far the strength is considered while the composite 4 turns out to be the best composition as far the rigidity of composite is considered exhibiting a tensile modulus of 304.2 MPa. The variation of tensile modulus and tensile strength values obtained for the four composites are presented graphically in Figure 3.

<table>
<thead>
<tr>
<th>Composition</th>
<th>Break Load (kgf)</th>
<th>Tensile Strength (kgf/cm$^2$)</th>
<th>Tensile Modulus (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0% HH + 100% HDPE</td>
<td>18.1</td>
<td>94.271</td>
<td>153.231</td>
</tr>
<tr>
<td>3% HH + 97% HDPE</td>
<td>31.7</td>
<td>191.889</td>
<td>252.294</td>
</tr>
<tr>
<td>5% HH + 95% HDPE</td>
<td>29.1</td>
<td>179.63</td>
<td>287.546</td>
</tr>
<tr>
<td>10% HH + 90% HDPE</td>
<td>25.6</td>
<td>158.819</td>
<td>304.2</td>
</tr>
</tbody>
</table>

![Fig. 2 — Load vs. Displacement diagram for (a) virgin specimen, (b) composite 2, (c) composite 3, (d) composite 4](image-url)
Conclusions

The compression molding and tensile strength evaluation of pure HDPE and three other human hair added variants were done according to ASTM D638 standards. The relevance of the work can be justified by the peak strength of 191.889 kgf/cm² shown by composite 2 containing 3% human hair and 97% HDPE which is more than double the strength of the virgin sample. This work also points out that the increase in fiber content increased the rigidness of the composite and a peak modulus value of 304.2 MPa was obtained for composite 4 containing 10% human hair and 90% HDPE. This composite can find applications in sewage pipes, plastic lumber, coaxial cables and other areas where sufficient elasticity and tensile strength in HDPE is required. Thus the fabricated HH-HDPE polymer matrix composites have given encouraging results of improved tensile strength and tensile modulus and more works may be attempted in reinforcing recycled plastics for specific applications.

Acknowledgement

We thank the editor and reviewers for their insightful comments and suggestions, which helped us to improve the paper.