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EFFECTS OF RECYCLING ON THE PROPERTIES OF GLASS FIBRE REINFORCED POLYPROPYLENE

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Abstract

Recycled polymers are considered low performance materials because their properties are expected to reduce drastically with recycling. The objective of the present study was to characterize 30 wt. % glass fibre reinforced polypropylene (GFRPP) recycled for four generations. Samples for tensile testing of virgin and four recycled generation of GFRPP were prepared by injection moulding techniques and tested using Instron 20 KN. Differential Scanning Calorimetry (DSC) was also carried out to study the thermal properties of recycled and virgin samples of glass fibre reinforced polypropylene. Results showed that the thermal properties especially the transition temperature of GFRPP was not affected at all by the recycling process. In contrast the tensile strength decreased as number of recycling generations of glass fibres reinforced polypropylene increased. This research work demonstrates that 100% recycled GFRPP can be used effectively only for two recycle generations. However, some modifications/treatments are necessary for GFRPP to use it more efficiently for further recycles.

Key Words: Recycled Polymers, Glass Fibre, Reinforced, Polypropylene, Injection Molding

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1. Introduction

Plastics are widely used as an alternative to natural materials and have become the most useful part of human life[1]. The use of plastics is increasing day by day due to their important properties, such aseasy form ability, light weight, resistance to various chemical materials, low electrical conductivity and ability to be transparent. Moreover, they can be produced at low cost and coloured by mixing with some other materials. The addition of materials like glass fibre to plastics also improves its chemical mechanical properties[2, 3].

Due to their versatility plastic materials are used widely in both low performance products like wrapping products, bottles, toys, and high performance products like car components, bulletproof suits and a large number of other industrial products. Hence, plastic demand has increased exponentially in the past few decades. It is a common practice that plastic materials are disposed in landfills after their use. The disposal of plastic creates environmental and space problems because they are not very biodegradable and occupy a large volume [4, 5]. It is, therefore, suggested [6,7] that recycling is a viable option to conserve plastic materials.

Even minor changes in the processing parameters can influence the properties of the plastics. These parameters make them very important material for various applications. Therefore, it is shown by the researcher [1, 8,9] that by controlling the process parameters the plastic can be tailored according to the requirements. Fibre and particulate reinforcements can improve the mechanical properties of plastics with less costas compared to the materials of similar strength [9]. Mechanical properties of the composites of plastics and fibers depend on the fibre size, fibre density, fibre fraction, mode of distribution in the structure, working temperature and fibre–plastic adhesion forces [9, 10].

Glass fibre reinforced polypropylene (GFRPP) is a widely used cost-effective composite material. The success of these composites relies on the unique performance/cost ratio of polypropylene among various engineering plastics as well as that of glass fibres among different fibrous reinforcements. The properties of the glass fibre reinforced polypropylene can be tailored by adjusting the volume fraction of glass and the length of the fibre. Increase in the fibre contents and fibre length results in improving the impact strength and tensile strength but lowers the process ability of the composite. Another important advantage is the possibility of recycling these composites [11, 12]. Abdul Kadir G et. al. [12] are of the view that during tensile testing of the reinforced plastics, the load applied to the matrix is transferred to the glass fibres. In order to improve the strength of the composites, a strong interface bonding between the fibres and plastic is required. They also observed that humidity reduces the bonding force between the plastic and reinforcement element. GFRPP shows good resistance against acid and salt solutions but bad resistance against alkali solutions [13].

In the present work, the effects of recycling using injection moulding on the thermal and tensile properties of polypropylene with 30 wt. % glass fibre were investigated. This composition was selected on the basis of the work of H. Liang [14], who studied the effects of the glass fiber contents in GFRPP on their mechanical properties. They found that optimum mechanical properties such as impact strength, tensile strength and bending strength were found in GFRPP containing 30 wt. % glass fiber. The possible reason suggested by them is that the increase in glass fiber contents beyond 30 wt. % result in reduction in matrix contents. So it may cause the poor liquidity of glass fibers during injection molding and even result in agglomeration of glass fibers, thus it reduces the mechanical properties of GFRPP.

2. Experimental Set Up

2.1 Sample Preparation

The composite material used for the present study was 30 wt. % glass fibre mixed in polypropylene resin. Samples were produced for four different recycle generations (RG). The selected materials were produced by injection molding using a shredding and blending process. The samples for determining the thermal and tensile properties were fabricated using injection molding for both virgin and recycled materials. Each of the proposed five generations (one virgin and four recycled), a total of 10 samples for each cycle were prepared for thermal and tensile testing. The feed size for the virgin material for GFRPP was 3.7x 3.2x 2.5mm. The temperature (230 ^{0}C) and pressure(800 bars) during the fabrication of all the samples was kept constant. After injection molding, the same material was grinded for the next generation without exposing to the temperature and humidity. After grinding, the feed was of mixed size, however, the difference in the range of particles size was within excepted limits. The regrind material was injection molded to produce the 1st recycled generation sample. These steps were repeated to produce samples for 2nd, 3rd and 4th recycle generations. During injection molding, the temperature and pressure for all the regeneration cycles were kept same.

2.2 Evaluation of Thermal Properties

Each sample of one virgin and four recycled generations was analyzed using a Differential Scanning Calorimeter (DSC Shimadzu DSC-50). To measure thermal properties, 5 mg of each sample was taken and heated at a constant rate of 0.5 ^{0}C/min. for all the samples. Tests were performed at least three times to account for measurement errors. Main importance was given to measure the glass transition temperature.

2.3 Evaluation of Tensile Properties

Standard tensile test specimens, as shown in Figure 1, were produced using injection molding process. The tensile samples produced from virgin and recycled material were tested using tensile testing machine (Instron 20 KN). At least five samples were tested for each experimental conditionto measure the maximum load and fracture load.

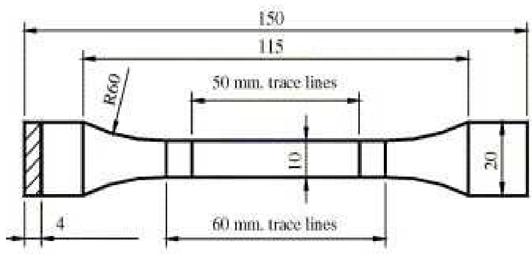


Figure 1: Standard tensile testing specimen [12].

3. Results And Discussion

3.1 Visual Observations

After the samples preparation, it was observed that there is almost no color difference in the injection molded products of virgin material and recycled material for GFRPP till four recycling generations.

3.2 Thermal Properties

Differential Scanning Calorimetric (DSC) results of glass fibre reinforced polypropylene (GFRPP) recycled for four generations and in virgin conditions are presented in Figure 2. The insignificant changes in the data indicate that chain length remains fairly constant during the thermal cycle. The polymer chain length was not measured in the initial stage. For GFRPP the values of glass transition temperature remained almost same (168 ^{0}C) for all the samples including virgin material, as shown in Figure 2. It can, therefore, be concluded that thermal properties (i.e. Tg) of GFRPP were not affected at all during the recycling process.

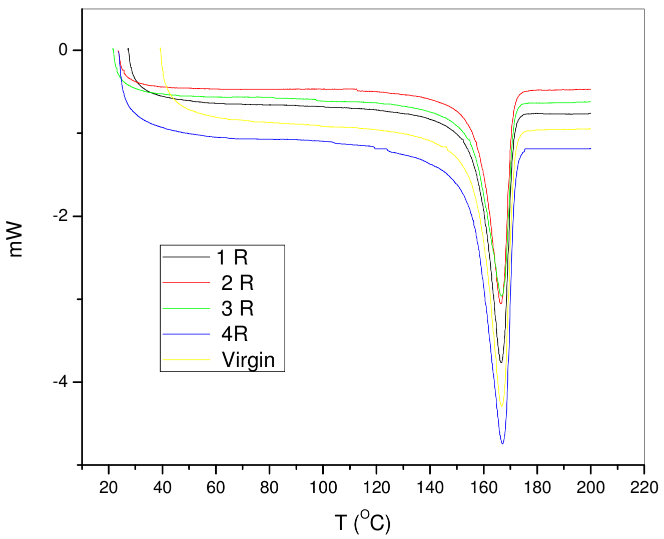


Figure 2: DSC of GFRPP samples showing no variations in Tg with recycling.

3.3 Tensile Properties

Five samples of the virgin and four recycled generations were tested, respectively, for each experimental conditions. The averaged load-extension curves of virgin and four recycled generation are presented in Figure 3 and also summarized in Table 1. All the curves showing average breaking load for each virgin and recycled samples have been plotted in one graph for comparison.

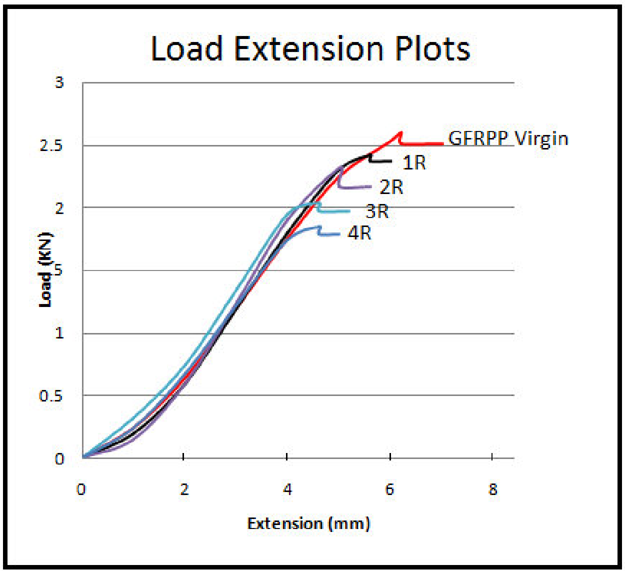


Figure 3: The average load – extension curves of virgin and four recycled generations.

Table 1: Tensile properties data for various GFRPP samples.

Specimen	Average Load maximum, KN	Average Load at break, KN	% age variation in max. load for different recycles	%age difference in max. load between the virgin and 4th recycle generation
GFRPP Virgin	2.6066	2.5144	- - -	**29.07**
1 R	2.4265	2.3697	6.91	
2 R	2.3207	2.1704	4.36	
3 R	2.0377	1.9694	12.19	
4 R	1.8488	1.7845	9.27	

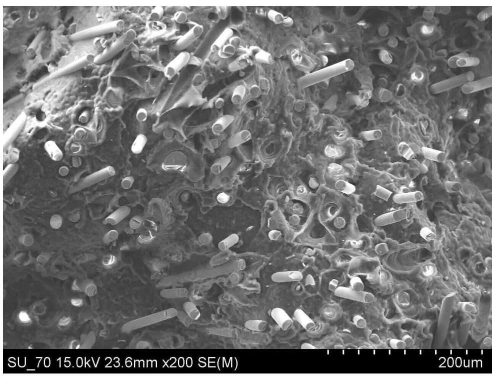
The decreasing trend in the values of the maximum load and breaking load with increasing the number of recycles can be seen in Table 1. The decrease in the values is more in case of third and fourth recycles as compared to the first and second recycled generations i.e. 6.91 %, and 4.36 % as compared to 12.19 % and 9.27 %, respectively. These values will remain same even if they are converted into ultimate tensile strength (UTS), since area is same for all the samples.

For better understanding regarding the decrease in the tensile properties of GFRPP, fractured samples were analyzed using a scanning electron microscope. Figures4.1 and 4.2 show the fractured surface of virgin material specimen prepared by injection molding. It can be observed from Figures 4.1 and 4.2 that the fibre and matrix seems to have very good adhesion and most of the fibres are aligned well. Figures 4.3 and 4.4 are the scanning micrographs of the fracture surfaces of first recycle (1R)specimens. Figures4.5 and 4.6 are scanning micrographs of second recycle (2R), Figures4.7 and 4.8 are scanning micrographs of third recycle (3R) and Figures4.9 and 4.10 are scanning micrographs of fourth recycle (4R).InFigures4.3 – 4.10, it can be seen that the fibres are of non-uniform size, more randomly orientated and pulled outward from the matrix. This can be related to feed size and adhesion of fibres with matrix.

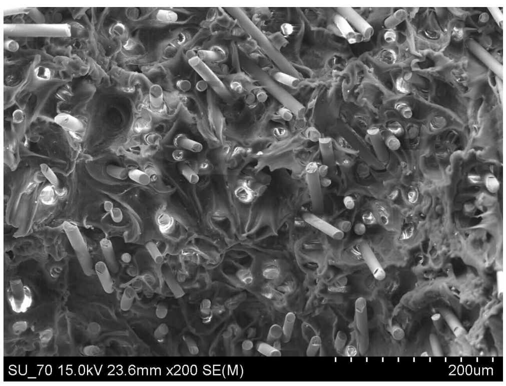
The feed material for the virgin polymer is of uniform size, whereas for recycled material when grinding (shredding) was done, the feed was not of uniform size (mixture of large and small sizes because of the grinding operation). This is in agreement with the work of Abdul Kadir G et. al. [12] who observed that increase in fibre length improved the tensile strength. They also observed that during recycling humidity reduces the bonding force between the plastic and reinforcement element. In the third and fourth recycle generation SEM micrographs, more holes can be seen which are because of the fibres pulled out from the matrix. So, the decrease in the tensile strength can be related to the poor adhesion between matrix and fibres in the third and fourth recycle generations which may be due to humidity absorbed during recycling.

Figures 5 (a) and (b) show, at a high magnification, the morphology of fractured fibres in injection molded virgin material and 4R material after the tensile tests, respectively. The fractured surfaces of the broken glass fibers in 4R sample show the degradation during recycling.

Many researchers have suggested that the tensile properties can be improved by mixing virgin material into recycled material. Moreover, the better control on the properties of glass fibre reinforced propylene may be achieved by proper control on the feed size (uniform size). This can be achieved by improving the regrinding step for recycled material which may be done by using a more powerful and sophisticated machine (11, 12 & 13).



(4.1)



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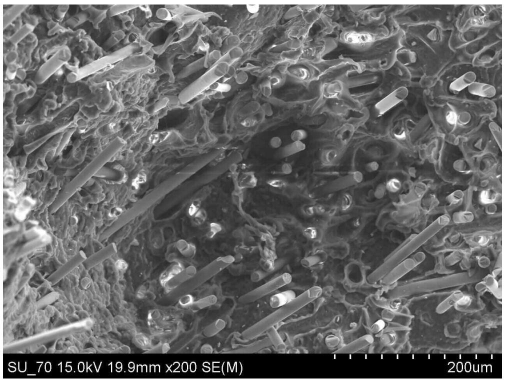
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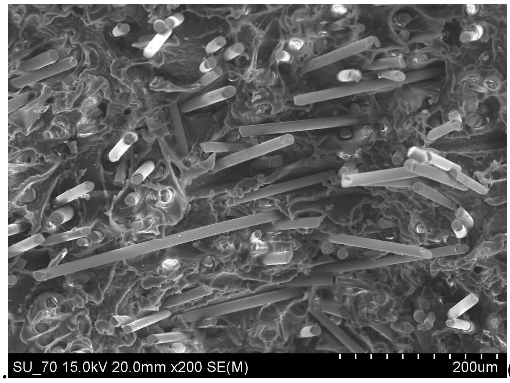
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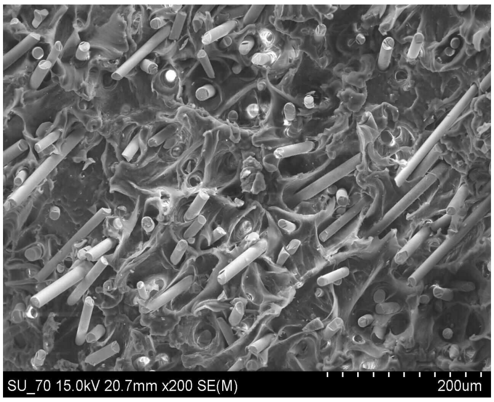
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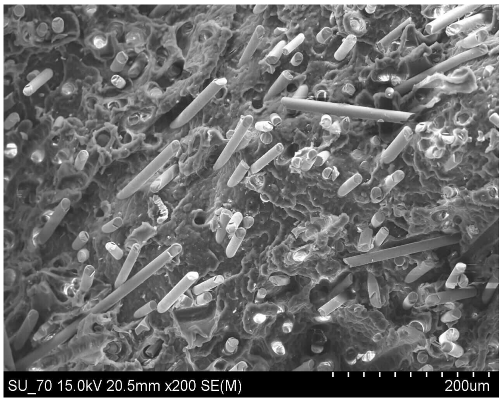
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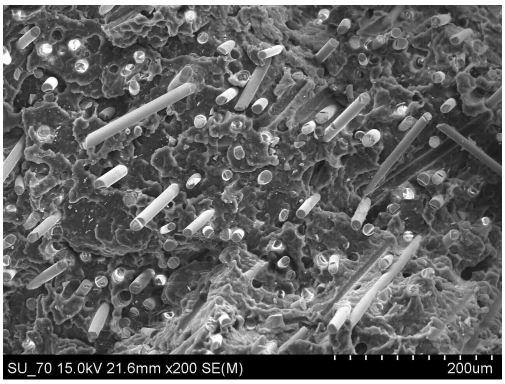
SU_70 15.0kV 21.6mm x200 SE(M)
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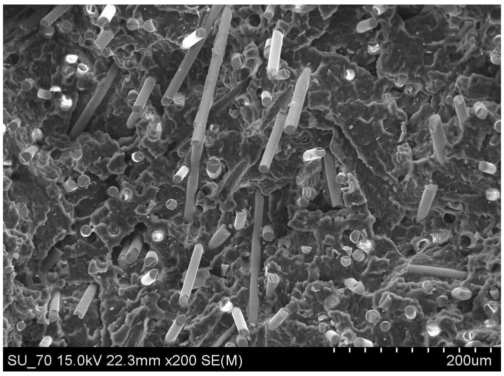

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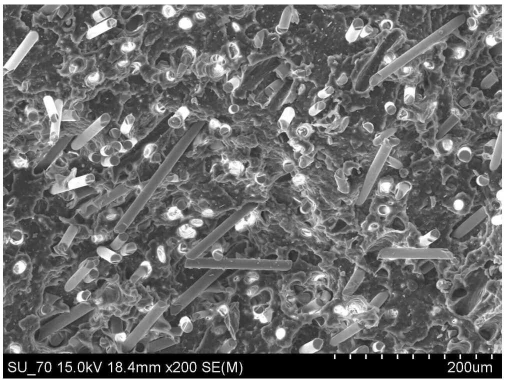
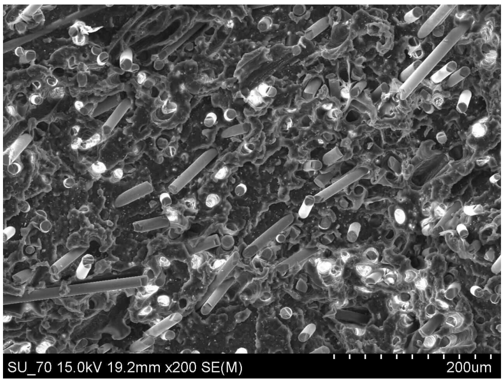
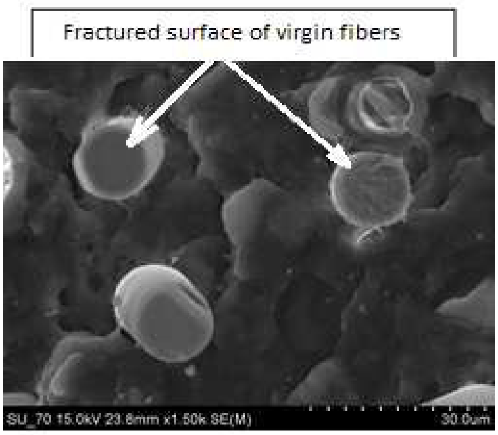
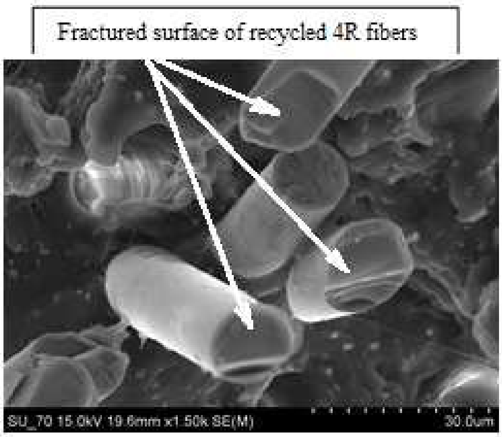




(4.9) (4.10)

Figure 4: 4.1-4.10 SEM micrographs of various GFRPP fractured specimens. 4.1 and4.2 for virgin material, 4.3 and 4.4 for 1 R, 4.5 and 4.6 for 2R, 4.7 and 4.8 for 3R, 4.9 and 4.10 for 4R.





(a) (b)

Figure 5: Fractured fibres in injection molded virgin material and 4R material after tensile test are shown in figures (a) and (b), respectively.

4. Conclusions

Based on the experimental data, it can be concluded that;

1. The glass transition temperature of GFRPP is not affected during recycling.
2. The tensile properties of GFRPP are significantly affected as a result of recycling. The decrease in tensile strength is more in case of third and fourth recycles as compared to first and second recycled generations.
3. The decrease in the tensile strength for virgin to 4^{th} recycle generation was about 29 %.
4. It is considered that the decrease in tensile strength due to recycling of GFRPP is possibly because of variation in the feed (mixed sizes) and less adhesion between matrix and fibres.

Acknowledgment
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