Advanced Composite Materials
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/tacm20

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Version of record first published: 02 Apr 2012.

To cite this article: Teruo Kimura, Yoshiaki Kataoka, Yukie Kondo & Tetsuya Takahashi (1998): Tensile characteristics of polyolefin/glass composites using waste of polyolefin fibers as matrix material in injection molding, Advanced Composite Materials, 7:4, 403-409

To link to this article: http://dx.doi.org/10.1163/156855198X00282

Adv. Composite Mater., Vol. 7, No. 4, pp. 403–409 (1998)

FRP Award Winning Paper

Tensile characteristics of polyolefin/glass composites using waste of polyolefin fibers as matrix material in injection molding

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Received 25 June 1998; accepted 13 July 1998

Abstract—The tensile characteristics of polyolefin/glass composites using waste of polyolefin fibers as a matrix material were investigated. The waste of polypropylene non-woven fabrics and polyethylene fishing net was reused as matrix materials of composites. A simple molding method, in which waste of polyolefin and glass fiber was fed into the injection machine together with the spun maleic anhydride grafted PP, was used for the molding of the composites. The results suggest that the injection molding method described herein shows promise in contributing toward the material recycling of waste products of polyolefin resin.

Keywords: Polyolefin/glass composites; recycle; injection molding; tensile strength.

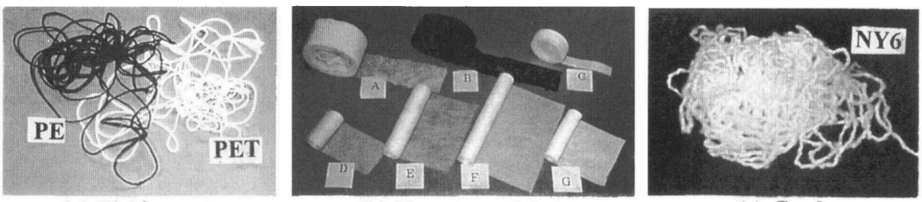
1. INTRODUCTION

Fibers are used not only as clothes but also as various industrial materials including fishing nets, ropes, tire chords and packages. In particular, the usage rate of fibers made of polyolefin resin such as polyethylene and polypropylene is high and their usage spans a wide range. The recent industrial trend is to use resin for common parts of automobiles and consumer electronics by taking recycling into consideration. Polypropylene resin is counted as one such candidate. It is thus expected that the amount of polyolefin resin waste will continue to increase in the near future which calls for the establishment of a proper recycling method. In this article, fiber waste which is often dumped in large quantity from fiber-related manufacturers is investigated as an example of polyolefin resin waste and an attempt is made to recycle the fiber waste as a matrix material for injection molding of fiber reinforced composites and to examine the mechanical properties in order to reuse polyolefin resin waste.

2. FIBER WASTE AND YARNS OF ADHESIVE RESIN

In this article, as polyolefin fiber waste among various fiber waste, high density polyethylene fishing net waste shown in Fig. 1a, polypropylene non-woven cloth cut waste shown in Fig. 1b-E and non-woven cut waste which is a mixture of polyethylene and polypropylene with a weight ratio of 25 to 75 shown in Fig. 1b-C were used as mold raw materials.

In addition, a mold material which is a mixture of polypropylene non-woven cut waste and nylon-6 fiber waste (selvage of woven clothes) which is non-polyolefin



(a) Fishing net (b) Nonwoven fabrics (c) Cord

Figure 1. Various wastes of synthetic fibers.

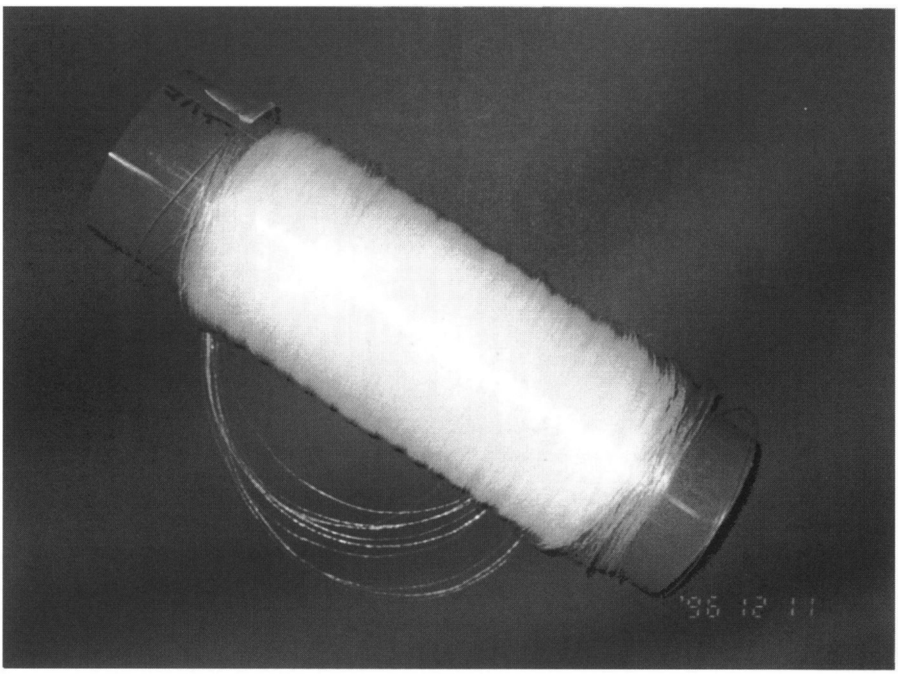


Figure 2. Spun maleic anhydride grafted PP (g-PP).

fiber waste as shown in Fig. 1c was also examined as an example of making a polymer alloy from a matrix.

For glass fibers, a glass roving (convergence number of 1600 filaments, 600 tex) was used which was surface-treated with amino silane often used for compositization with polyolefin resin during the regular molding process of composites.

As the fiber waste used in this research was not intended for recycling, PP (density of 0.91 g/cm^3, graft denaturation rate of 0.30 wt%) [1, 2] denaturated with anhydromaleic acid was used as adhesive resin with glass fibers or as phase solvent when different types of fiber waste were mixed and non-extended fibers were fabricated using a mono-filament solvent yarning device in order to facilitate supplying to the molding machine, as discussed later.

Figure 2 shows anhydromaleic acid denatured PP fibers (called g-PP hereafter) wound by a bobbin in a bundle of 10.

3. INJECTION MOLDING METHOD

For molding of fiber reinforced composite materials, the injection molding method that was devised by the authors [3] was used: this feeds synthetic fiber waste and reinforcing fibers directly into a molding machine without forming pellets. With this method, simultaneous supply of woven g-PP is possible. Although g-PP can be supplied in the pellet shape, the supply can be stabilized by yarning, as in this article.

Figure 3 shows an overview of the molding machine used. The main body of the molding machine is an injection molding machine (manufactured by Toyo

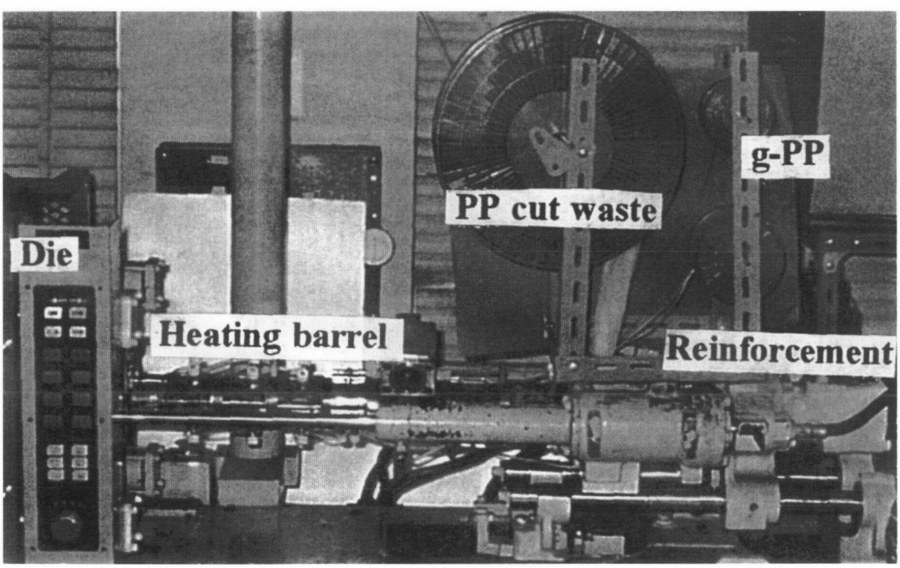


Figure 3. Aspect of injection molding system.

Machinery & Metal Co. Ltd., Plaster Ti-30G) used for plastics with regular pellets as the molding raw material. Vent screws (with diameter of 24 mm and aspect ratio of 25) are used for easy degassing.

The diameter of the supply outlet is 30 mm. In the molding of composite materials by this method, synthetic fiber waste and g-PP, both of which are supplied simultaneously, are solvent-mixed inside a heated cylinder and the glass fibers are compositized while being cut. The volume fractions of the reinforcing fibers were varied by adjusting the supply amount (number of bundles) of the synthetic fiber waste and the reinforcing fibers. About 10 wt% of g-PP was mixed. The molding temperature was determined as the melting point obtained by a DSC test of the synthetic fiber waste as a reference. The molds were tensile testing specimens whose size followed the JIS K 7113 standard and tensile strength was obtained for each specimen. In addition, a scanning electron microscope (SEM) was used to observe the broken surface and the interface between the matrix and the fibers.

4. RESULTS AND DISCUSSION

4.1. Tensile characteristics

All the fiber waste used was bitten by the screws of the mold machine by being lightly pushed into the outlet of the mold machine at the start of molding and automatic continuous molding was possible thereafter. Figure 4 shows the tensile strength of the fiber reinforced composite molded by simultaneously supplying polypropylene non-woven fiber waste and glass fibers. The circles in the figure are the result without using g-PP. As is seen from the figure, the strength was improved along with the increase of the reinforcing fiber weight fractions, but the strength was significantly lower compared with those molded from commercial virgin pellets (shown by the diamond marks). However, as shown by the double circle marks in the figure, the strength of those where g-PP was simultaneously supplied showed a comparable strength to that of the virgin pellet material. It is believed that such strength improvement is due to the improvement of adhesivity between the matrix and glass fibers by g-PP as is seen from the fracture surface photo.

Figure 5 shows the strength of the composite (PE/G) of fiber waste of fishing nets made of high-density polyethylene (PE) and the composite (PP/PE/G) of non-woven fiber waste, which is a mixture of polypropylene and polyethylene (PP/PE) with glass fibers, by choosing the polyethylene weight fraction as the horizontal axis along with the result for the above mentioned polypropylene fiber waste. The glass fiber weight fraction in the composites was 10 wt% for each.

It is seen from the figure that no reinforcing effect by the glass fibers was observed unless g-PP was used when polyethylene fiber waste was used as the matrix, similar to the above mentioned polypropylene fiber waste (the diamond marks). However, by mixing g-PP simultaneously, a strength gain of about 1.7 times was obtained

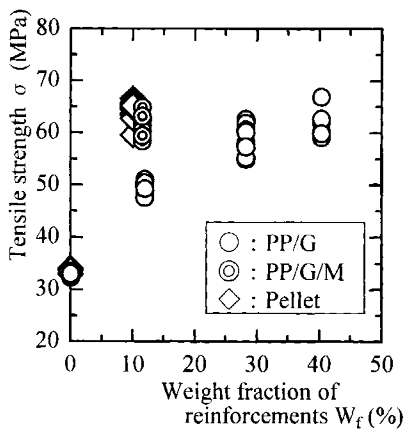


Figure 4. Tensile strength of composites (PP series).

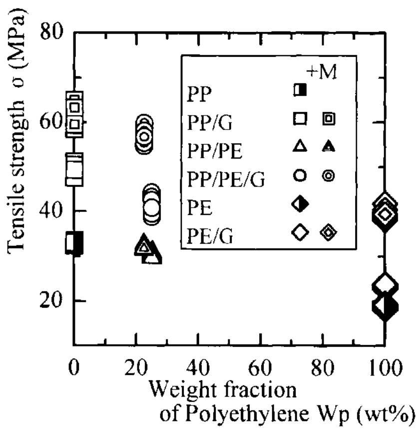


Figure 5. Tensile strength of composites (PE, PP/PE series).

(the +M and diamond marks in the figure). For the composite with PP/PE mixture fiber waste as the matrix, no significant strength improvement was obtained unless g-PP was used, as shown by the circle marks in the figure. However, by mixing g-PP simultaneously, a significant gain was obtained (shown by the double circle marks).

Figure 6 shows the strength of the mold of polymer alloy (PP/NY6) by supplying polypropylene fiber waste and nylon-6 fiber waste simultaneously and the composite (PP/NY6/G) by adding glass fibers with about 10 wt% by choosing the weight fraction of nylon-6 as the horizontal axis. Also shown in the figure are the results when the above mentioned polypropylene was used as a matrix and the case where only nylon-6 was used as a matrix.

As is seen from the figure, the strength of the matrix (PP/NY6) shown by the circles is almost identical to that of PP (squares) even though NY6 with the high strength is mixed compared with PP without using g-PP. This is believed to be due

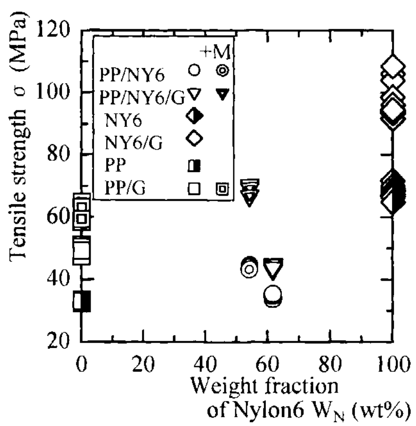


Figure 6. Tensile strength of composites (PP/NY6 series).

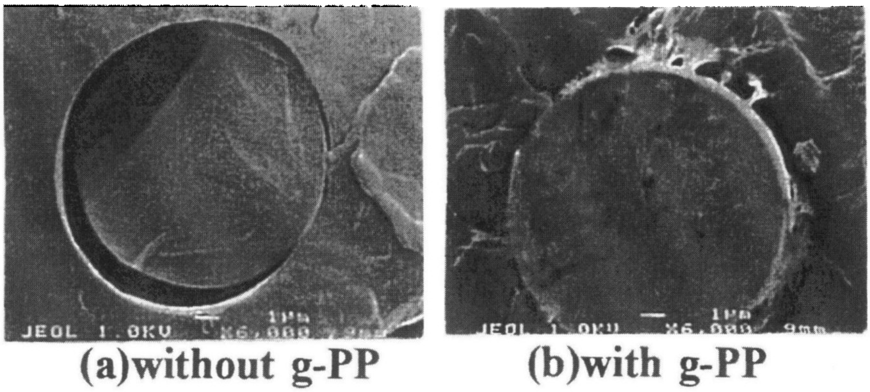


Figure 7. SEM micrographs of PP/glass interface (× 6000).

to the affinity between PP and NY6 when supplied simultaneously. However, it is seen that the strength gain was obtained when g-PP was simultaneously supplied using the method in this article (the double circle mark). The strength improvement for the glass fiber reinforcement was small unless g-PP was used but a significant increase in strength was obtained by adding g-PP (reverse triangles).

4.2. Observation of fracture surface

Figure 7 shows the interface between the glass fiber and the matrix with g-PP and without g-PP for polypropylene fiber waste as an example. Figure 8 shows the difference of the fracture surfaces of the mixture of polypropylene and nylon-6 with g-PP and without g-PP.

As is obvious from both figures, using g-PP greatly influences the effect of interface adhesion and the affinity effect of different resins and it is believed that this is why there exits such a significant difference in strength whether g-PP was used or not.

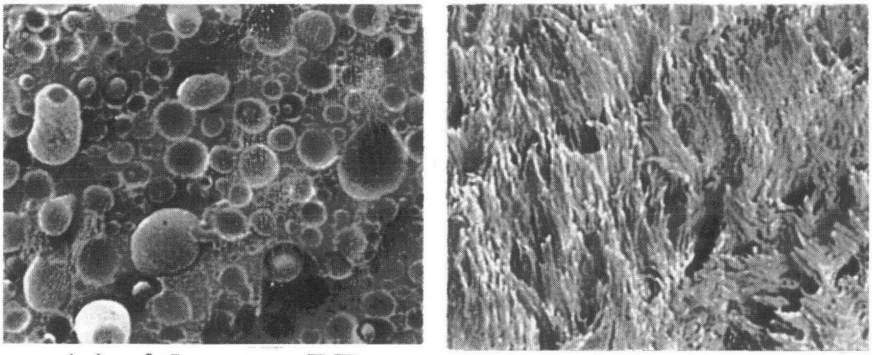


Figure 8. SEM micrographs of PP/NY6 polymer alloy (× 250).

5. CONCLUSIONS

It was shown that fiber waste made of polyolefin resin can be reused as a matrix material of composites by yarning adhesive or compatible resin and supplying it to a molding machine simultaneously, as shown in this article, and a significant reinforcing effect was achieved as the volume fraction of the reinforcing fibers increased. Although only fiber waste was examined in this article, it is believed that the knowledge gained can be applied toward establishing a molding method when polyolefin plastic industry waste powders other than fiber waste are to be resued as a mold material.

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