Tensile and flexural investigation on polypropylene recycling

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Abstract. Plastic recycling can be an effective way of reducing large amount of plastic waste in plastic manufacturing industry. Polypropylene (PP) is a versatile material that is capable of numerous commercial applications. This study is about the effect of composition between virgin and recycled PP towards their mechanical properties. The effect of blending PP product was investigated whether it can improve the performance of the material without deteriorating its original mechanical properties. The tensile and flexural tests were conducted according to ASTM D638 and ASTM D790, respectively. The results from tensile and flexural tests revealed that the sample which consisted of 75wt% of virgin PP and 25wt% of recycled PP were the optimum composition. The blended PP had positive influence on tensile strength, percent of elongation at break and Young’s modulus. Opposite trends were obtained from flexural tests where both flexural strength and bending modulus performed slightly less compared to virgin PP. In fact, blending virgin and recycled PP together at any composition did not seriously deteriorate the mechanical properties. Therefore, recycled PP can be used in production without the need to sacrifice its mechanical properties. Besides, PP recycling can reduce material costing and help to save the environment by reducing PP waste.

1. Introduction

Plastics are widely used materials and can be found anywhere during our daily routines. Plastics are commonly a short-lived product for example food packaging and water bottle. They are usually non-renewable raw material such as petroleum. Once it is not needed anymore, it will be discarded and end up in landfilled or incinerated. Plastics are also associated with environmental issues which are a growing concern faced by the society [1]. Therefore, recycling method is an effective waste management technique to overcome the problem. Recycling not only can save a remarkable amount of non-renewable resources, less energy is required to recycle polymer rather than producing the same polymer material from virgin material [2].

Injection molding is a well-known manufacturing process to produce plastic parts. Thermoset and thermoplastic polymers can be utilized to produce parts. Injection molding is a highly desire manufacturing process despite having expensive tooling cost. It is beneficial especially in a mass production industry as it can produce complex shape parts at relatively high output but very low operational cost [3].
Mechanical properties are one of the crucial aspects for many materials and its application. Each materials response differently when subjected to forces or loads. Polymer blending will significantly alter the behavior and the characteristic of the material which may improve mechanical properties. Therefore, it is important to further understand on the subject if the blending polymer can provide better performance without sacrificing the mechanical properties of pure polymer itself [4].

Polypropylene (PP) is widely used around the world for its thousands of applications due to its special characteristic and one of this characteristic is being recyclable. Cost effective nature and continuous development of PP is also a reason for its numerous application in industries such as automotive, electrical, aerospace, furniture, domestic etc. [5]. Recycling is defined as a process of converting waste material into reusable object. In this case, defect or scrape PP can be recycled and reprocessed into recycled product using injection molding. Recycled PP can be beneficial towards both the consumers and the environment. PP product takes years and years to degrade before it is fully decomposed. Therefore, cost-effective measure such as recycling PP product is much needed as an eco-friendly way to overcome the problem. PP is also a petroleum-based product. Hence, oil and petroleum resources can be preserved through recycling method and at the same time it will reduce the amount of waste thrown to the landfills.

In this study, the effect of blending between different compositions of PP products towards mechanical properties was investigated. Different compositions of PP may affect the mechanical properties of the material. Deterioration of mechanical properties of virgin PP product may occur when it is blended with recycled PP. Therefore, the optimum composition of blending between virgin PP and recycled PP is crucial to minimize the deterioration as well as maintaining the performance of the PP product. The comparison of strength and flexural properties between the blended virgin-recycled PP and virgin PP was also discussed in this study.

2. Experimental work

2.1. Materials and sample preparation

Virgin and recycled PP materials were selected and used for the investigation. Recycled PP was prepared and fabricated using MA23 Injection Molding machine. The parameters of the injection molding machine were shown in table 1.

| Parameters                  | Setting |
|-----------------------------|---------|
| Melting Temperature (°C)    | 210     |
| Injection Pressure (bar)    | 70      |
| Injection Speed (rpm)       | 30      |
| Holding Pressure (bar)      | 50      |

The experiment was only focused on the first cycle of recycled PP. A granulator machine was used to scrap the virgin PP product into small and fine pellets to form the recycled PP raw materials. The granulator machine used was ML-SC5-150. Five different compositions of virgin and recycled were prepared at different weight ratios as shown in table 2. Each composition of PP product was placed into a vacuum oven at a constant temperature of 50°C overnight to remove moisture from the PP product. Tensile and flexural specimens were fabricated according to their ASTM standard D638 and D790, respectively.

| Specimen Code | Virgin PP(wt%) | Recycled PP(wt%) |
|---------------|----------------|------------------|
| VP100         | 100            | 0                |
| VP75          | 75             | 25               |
2.2. Mechanical testing and fracture surface analysis

The tensile properties such as yield strength, tensile strength at break, percent of elongation and Young’s modulus were obtained according to ASTM D638 specification. A SHIMADZU AG-IS 50kN universal testing machine was used for the testing. The load cell was set to 10kN at a cross head speed of 5mm/min. The dimensions of specimens were 144mm x 19mm x 3.2mm and the gauge length was 114mm.

The flexural properties such as flexural strength and bending modulus were obtained according to ASTM D790. The same universal testing machine was used for the testing. The load cell was set to 50kN at a cross head motion of 1.28mm/min and load cell range of 5% deflection was set to 6.4mm. The dimensions of specimens were 125mm x 13mm x 3mm and the support span length was 48mm.

Both tensile and flexural fracture specimens were cut to undergo fracture surface analysis. Hitachi TM3030PLUS SEM machine was used to identify the cause of failure.

3. Results and discussions

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\begin{array}{ccc}
VP50 & 50 & 50 \\
VP25 & 25 & 75 \\
VP0 & 0 & 100 \\
\end{array}
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In figure 1, the blending with 50 wt% recycled PP have increased the yield strength up to 0.23% while using 100 wt% recycled PP have reduced the yield strength to 1.43% compared with virgin PP. As overall, there is no significant different on yield strength between the entire composition of PP product. The graph remains almost constant within the average range of 38MPa with less than 2% different compared to virgin PP. In fact, the effect of thermal degradation towards the mechanical properties of recycled PP was not that severe as the study was only focused on the first recycling. Mechanical recycling at low temperature did not involve the dimensional changes or segmental motion in the polymer during the process [6]. Hence, the differences between any composition of PP products were not that significant.

Based on the figure 2, the blending with 25 wt% of recycled PP has the highest tensile strength with an improvement of 4.51% while blending with 50 wt% of recycled PP have decreased the tensile strength about 2.73% if compared to virgin PP. Anyway, the tensile strength of PP products remains almost constant throughout different weight percentages of recycled PP with the average range of
It is observed that the yield strength is greater than the tensile strength. This shows that PP product are brittle rather than ductile. The reason that yield strength is greater than tensile strength is due to short necking of PP product. The instability of PP was caused by the reduction in cross section which competed with strain hardening, thus led to catastrophic failure. It can be further confirmed when the fracture surface is flat type mode.

![Figure 2. Tensile strength at break at different weight percentages of recycled PP.](image)

It can be observed in figure 3 that there is an improvement in percent of elongation at break with addition of recycled PP compared to virgin PP. The PP product with 25 wt% of recycled PP shows an increase about 19.82% compared to virgin PP. Besides, the elongation at break of this PP product is the highest among the entire compositions. Elongation at break depends highly on both the degree of crystallinity and molecular weight of a material [7]. According to L. Incarnato [8], elongation at break is the most affected mechanical properties by degradation occurred during recycling. Their results also showed that percent of elongation at break for low molecular weight of PP was 28%. Therefore, it can be said that the current study is focused on a low molecular weight PP whereby the result for elongation at break is
ranged from 17% to 21%. Thermal degradation from the reprocessing PP material can cause the breakage of polymer chain and the phenomenon is known as chain scission. This phenomenon has shorten the chain within the polymer and resulted in a reduction of molecular weight [9]. As molecular weight decreases, chain mobility increases, and crystallinity occurs in a more and more ordered way. Thus, the amount of developed crystallinity tends to increase [10]. The degree of crystallinity is significantly higher compared to virgin PP and results in higher friction between particles. Thus, the increase in number of recycled PP in blended PP product will result in the increase of elongation at break.

![Figure 4](image)

**Figure 4.** Young’s modulus at different weight percentages of recycled PP.

The blended recycled PP with virgin PP has no significant effect towards the Young’s modulus of PP product. Adding 25 wt% of recycled PP has increased the Young’s modulus of PP product up to 1.52%. As the number recycled PP is increased over 75 wt%, the Young’s modulus of PP product has decreased about 3% to 4%. As overall, the Young’s modulus between the entire compositions compared to virgin PP is not much differ as presented in figure 4. The low molecular weight species in the partially degraded material changed the rheologic and mechanical properties of a polymer after recycling [11]. The polymer degradation occurred when the macromolecule of PP was submitted to thermal and mechanical stresses which promoted chemical reaction. Hence, the polymer degradation can deteriorate the physical properties of the polymer.

| Specimen code | Flexural Strength(MPa) | Bending Modulus(MPa) |
|---------------|------------------------|----------------------|
| VP100         | 54.67                  | 1076.88              |
| VP75          | 53.25                  | 1045.04              |
| VP50          | 48.37                  | 1030.02              |
| VP25          | 50.41                  | 1024.70              |
| VP0           | 51.42                  | 982.12               |

From table 3, as the number of recycled PP is increased, the flexural yield strength is decreased. The presence of 50wt% of recycled PP in specimen code VP50 shows a decrease in the flexural yield strength.
over 11.52% compared to virgin PP which is the lowest among all the compositions of PP product.

The finding has similar trend compared to some previous studies [12]. This behaviour was due to a decrease in molecular weight during re-processing of material because of the chain deterioration. Thus, the material became more brittle and less yielding.

The bending modulus as shown in table 3 is decreased when the content of recycled PP is is increased. At 100wt% of recycled PP, Young’s modulus is decreased about 3.53% while bending modulus is dropped to 8.79% compared to virgin PP. This shows that addition of recycled PP has more positive impact toward tensile stiffness rather than flexural stiffness.

From the experiment, it can be observed that the flexural specimens did not break even beyond 5% deflection. It is suspected that the load applied were not sufficient. Only permanent deformation occurred toward the samples and not fractures as the universal testing machine only capable of maximum load of 50kN. Most thermoplastics do not break even after greatly deflected resulting to flexural strength cannot be determined. Instead, stress at 5% strain was calculated which is the loading necessary to stretch the outer surface at 5% [4]. The reason behind this is greatly related to semi-crystalline effect. PP is a semi-crystalline polymer. Semi-crystalline consists of the combination of amorphous and crystalline region. This combination is the explanation behind good strength and flexibility of PP. Amorphous region is responsible for the material flexibility while crystalline region is responsible for the material strength [13]. Due to the combination, semi crystalline polymers are tough and can bend without breaking.

Figure 7 shows the microstructure of PP product after testing. Figure 5(a) shows that there is a clear deformation on the microstructure whereby the structure elongates toward the direction of tensile force as a result of tensile effect. It can be observed that there is a huge difference toward the tensile microstructure compared to the initial microstructure. Figure 5(b) shows that the orientation of the microstructure is changed. The changes are due to compressive load applied not only affects the surface of the sample but also the midsection although samples did not break. Most of the microstructure orientation of the flexural specimen is shifted downward along the direction of compressive load.

![Figure 5](image_url)

Figure 5. (a) Tensile fracture surface (b) flexural fracture surface.

4. Conclusions
In this study, blending between virgin and recycled PP have maintained and preserved the tensile properties while flexural properties show a decrease trend compared to virgin PP. It has been found that the optimum composition between virgin and recycled PP are specimen code VP75 where it consists of 75wt% of virgin and 25% of recycled PP. As overall, blending both virgin and recycled PP has no significant effect towards the mechanical properties of PP especially on the first recycling. Based on the finding, blending with any composition of virgin and recycled PP is acceptable and will not seriously deteriorate its mechanical properties at first recycling process. Waste produce during injection molding
such as runner, gates and sprue also can be reused, recycled and fabricated into PP product. This finding could be beneficial to the environment and the manufacturing industries. Recycling PP material could be a good practice to reduce number of waste thrown as well as a cost saving method for the manufacturing industries. This finding can increase manufacturing industries profit by reducing cost for purchasing raw material as well as maintaining the performance without sacrificing the mechanical properties of PP.

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