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Research paper

Effect of Injection Molding Parameters on Mechanical Properties of Keychain Made of Recycled Polypropylene

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Abstract

Injection moulding is a common method of plastic processing in which thermoplastic materials can be moulded into arbitrary complex shapes. In order to save the environment, the plastic waste from the injection moulding process needs to be recycled to overcome the non-biodegradable issues. This study is focused on producing the UiTM keychain using injection molding process from the mixing of a specific amount of virgin Polypropylene (vPP) and recycled Polypropylene (rPP). The effect of different injection moulding parameters on mechanical properties of the UiTM keychain on different weight ratio between virgin and recycled Polypropylene was investigated. The effect of injection molding parameters namely holding time and cooling time to the shrinkage of the UiTM keychain was also studied. Mechanical properties were determined by the tensile and flexural tests. Based on the test results, the keychain that contained 80 wt% of virgin Polypropylene and 20 wt% recycled Polypropylene has the most optimum weight ratio. Holding time was the most effective factor to the shrinkage of product. Cooling time was not significant in affecting the shrinkage and tensile properties of PP products. The study helps to promote the usage of recycled PP in the manufacturing industries.

Keywords: *Flexural; injection molding; polypropylene; recycle; tensile*

1. Introduction

In recent years, plastics contribute to the increasing waste materials in the environment. Plastics cannot be decomposed naturally likes other biological materials such as wood, plant product, paper and so on [1]. Moreover, incinerating non-biodegradable plastics will create environmental issue because carbon dioxide will be released as well during the process. However, cheap and easy to shape are the common factors that are still attracting plastics to be used in manufacturing industries. Plastic waste comes from the scraps during the plastic mass production such as sprues, gates, runners and others. Reprocessing or recycling the plastic scrap is one of the solutions to fully utilize the usage of plastics as well as reducing the usage of new plastics.

The most well-known plastic processing is the injection moulding which is suitable to produce a high-volume production for many sectors such as automotive and medicine [2]. It can produce complex shape products and it is easy to handle. In this study, Polypropylene (PP) was used to investigate its capability to be recycled. It is irrational not to use PP as it has huge diversity in applications. PP can be recycled by mixing it with a virgin material. However, the materials properties value might be changed due to the various weight ratio of virgin PP and recycled PP [3]. Besides, the different parameters setting may also influence the mechanical properties of the final product [4].

In order to define the optimum weight ratio and parameters, tensile testing and flexural testing were conducted to determine its mechanical properties. The tests defined the values of ultimate tensile strength, tensile strength at break, Young modulus, flexural yield strength and bending modulus. On the other hand, physical appearance observation and microstructure analysis were conducted. Holding time and cooling time are the parameters that have been used in this study to investigate the sample performance as well as the effect of weight ratio.

Many studies investigated the effect of composition between virgin PP and recycled PP to its mechanical properties [5-6]. Previous study showed that 60 wt% of virgin PP gave the best performance for the tensile strength while 90 wt% of virgin PP had the highest flexural strength. The optimum weight ratio is considered based on the mechanical properties of the product [5]. Unfortunately, fabrication of recycled PP causes depletion in their mechanical and optical properties [6]. Recent findings [7-10] revealed that the melting temperature is the most significant parameter affecting the quality and properties of the plastic product especially shrinkage. However, the effect of other injection moulding parameters was fairly focused.

Thus, the aim of this study is to find the optimum composition and effect of injection molding parameter setting based on the mechanical performance and appearance of the final product. Holding time and cooling time are the parameters that were investigated in this study. The quality of the final product was checked based on its defect and shrinkage.

2. Materials and Keychain fabrication

2.1. Materials and keychain

The raw polypropylene is homo-polymer pellets purchased from Lotte Chemical Titan (M) Sdn. Bhd. The recycled pellets used in this study were limited to first recycling process. All the pellets were dried in an oven prior to injection moulding production. Fig.

1 shows the product size of the keychain. The keychain has a thickness of 3 mm.

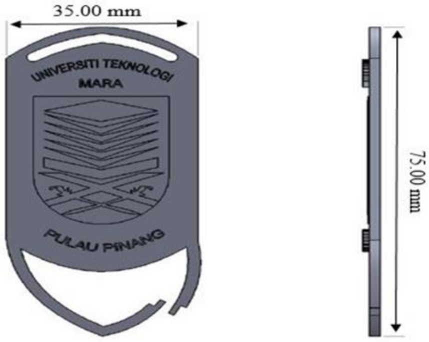

Fig. 1: Keychain product

2.2. Keychain and testing specimen fabrication

The keychain product consisted of blended virgin PP (vPP) and recycled PP (rPP) made at different weight ratios. The weight ratio was selected based on the previous finding [5] that at least 60 wt% virgin PP must be used to obtain good tensile properties. Hence, the weight ratio of vPP/rPP blends chosen to be investigated in this study were 60/40, 65/35, 70/30, 75/25 and 80/20, respectively. Both product and testing specimen were produced by injection moulding machine following the process parameters as shown in Table 1. The recycled pellets were produced using the MA23 injection moulding machine manufactured by Tat Ming Technology Co. Ltd, Hong Kong and a granulator, ML-SC5-150 model supplied by Ming Lee industrial Co. Ltd, Hong Kong.

Table 1: Setting of Injection Molding Parameters.

Injection moulding parameter	Values
Melting temperature (°C)	200
Injection pressure (bar)	90
Injection speed (rpm)	40
Cooling time (s)	5-7
Holding time (s)	5-7
Holding pressure (bar)	70

2.3. Mechanical testing

A Shimadzu AG-IS 50 kN universal testing machine was used in the mechanical testing. The tensile testing specimen was produced according to the size required in ASTM D638 standard. The specimen had dimensions of 100 mm x 13 mm x 3.4 mm. Tensile test was conducted using 5 mm/min of crosshead speed and 10 kN load. Each test was conducted until the specimen failed. As for flexural testing, the specimen was fabricated in accordance to ASTM D790 standard. The specimen had dimensions of 125 mm x 13.5 mm x 3.4 mm. Then, flexural test was conducted using the same universal testing machine with cross head motion speed of 1.28 mm/min and 50 kN load. Each specimen was bent until 5% of maximum deflection.

2.4 Shrinkage measurement

Controlling shrinkage of the final product is important in part dimension, mould designs, process control, particularly in applications requiring tight tolerances. Shrinkage that leads to sink marks or voids can be affected by injection pressure, holding time, cooling time, melt temperature, mould temperature and holding pressure [11]. The shrinkage of PP keychain, *S* was calculated by: [10]

$$\text{Shrinkage, } S = [(Vm - Vp)]/ Vm \times 100 \quad (1)$$

where *Vm* is the volume of mould and *Vp* is the volume of keychain product.

2.4 Surface morphology analysis

The keychain products were examined using naked eye to diagnose any defect such as warpage, bubble mark, over burn, sink mark and so on. The tensile specimen was cut to undergo fracture surface analysis. A Hitachi TM3030PLUS Scanning electron microscope (SEM) machine attached with Energy Dispersive analysis (EDX) was used to identify the fracture surface and elemental composition. The flexure specimen did not break thus no fracture surface was determined in this study.

3. Results and Discussion

3.1. Product appearance checking

The bubble mark in Fig. 2 was found almost on all of the samples at the keychain split ring part regardless of the effect of injection moulding parameters and composition. Bubble mark is air bubbles which are trapped under the sample surface due to many factors [12]. In fact, the excessive moisture in raw material is not possible because the raw pellets were oven dried before putting them into the injection moulding machine. One of the factors may be the temperature of the cylinder barrel is too high. It can cause the molten material to be too fluid. Anyway, the temperature must not be too low as unmelted particles may be trapped in the final product. The other factor may be the high injection pressure. The high pressure will cause the molten material to flow in turbulence form and lead to the existence of the bubble. Thus, injection pressure should be reconsidered in further study to eliminate the defect. According to A. Wavare and S. Ubale [10], the warpage problem may arise if the cooling time is not suitable. However, there is no warpage defect found in any keychain produced at various cooling times from 5 s to 7 s.

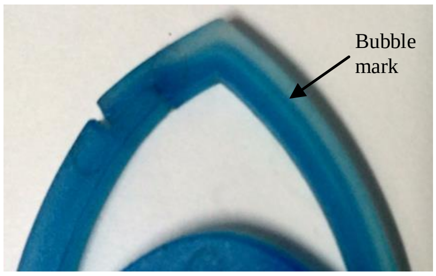

Fig. 2: Bubble mark

3.2. Shrinkage

Table 2: Shrinkage of keychain produced at constant holding time of 5s

	Shrinkage, S (%)		
	Cooling time (s)		
Composition (vPP/rPP)	5	6	7
60/40	11.55	11.38	11.38
80/20	11.38	11.38	11.38

Crystalline and semi-crystalline plastics are prone to thermal shrinkage especially when the plastics experienced re-heating in the recycling process. Anyway, there is no significant difference on the shrinkage of the keychain at different weight ratio and cooling time as shown in table 2. The results are similar and approximately about 12% of shrinkage by volume. Cooling time is important in a moulding cycle. When the molten plastic has been injected into the mould cavity, it takes time before the moulding has cooled and become sufficiently rigid to allow it to be demolded. For instance, if the cooling time is too short, the product may have warpage problem. Cooling time of 5 s used in this study is considered sufficiently long enough to avoid the development of residual stresses being locked into the product.

Table 3 tabulates the shrinkage effect due to different holding times for the keychains prepared at different weight ratios and constant cooling time at 5 s. The keychain produced at 5 seconds of holding time was shrinking about 11.21% to 11.90% from the original volume. The shrinkage of the keychain fabricated at 6 seconds of holding time was in the range of 10.40% to 10.69%. On the other hand, the keychain produced at 7 seconds holding time has the least shrinkage of about 9.31% to 9.83%. Therefore, holding time has more effect on the shrinkage of product. This is because the molten plastics have enough time to fully inject the raw material in to the mould at 7 s. The holding time is prolonged to allow for more adequate cooling and curing. The longer holding time can avoid the product from experiencing sudden "shock" before the next cooling step and avoid defects such as sink marks and voids. In contrast, if the holding time is too high, it will cause the increase of the product stress. Hence, longer holding time is not favourable as it will increase the cycle time of the mass production and reduce the production rate.

Table 3: Shrinkage of keychain fabricated at constant cooling time of 5s

	Shrinkage, S (%)		
	Holding time (s)		
Composition (vPP/rPP)	5	6	7
60/40	11.55	10.69	9.31
65/35	11.90	10.52	9.83
70/30	11.38	10.40	9.65
75/25	11.21	10.52	9.83
80/20	11.38	10.52	9.31

3.3. Tensile Performance

All tensile specimens show similar fracture manner as shown in Fig. 3. The tensile specimen experienced failure in the flat surface. Besides, there is no necking found at the fracture specimen. It shows that all PP specimens are brittle and break easily. Crack propagated fast to the entire surface and the crack distribution was perpendicular to the loading applied.

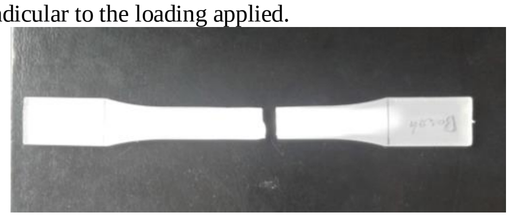

Fig. 3: Tensile test specimen after failure

It is clearly seen in Table 4 that cooling time has not much effect on the tensile properties of PP specimens. The ultimate tensile strength of homopolymer PP is reported as 30 MPa [5]. The cooling time ranged from 5 s to 7 s maintains the tensile quality of PP product. M. M. Raj et al. [5] noticed that there was not much deterioration in the strength of the recycled polypropylene from the first time until the third time of recycling. Hence, the mixture between virgin and first time recycled PP used in this investigation still achieved at least 29 MPa of tensile strength.

Table 4: Tensile strength of specimens produced at constant holding time of 5 s

Composition (vPP/rPP)	Ultimate Tensile strength (MPa)		
	Cooling time (s)		
	5	6	7
60/40	29.80	29.87	29.95
70/30	30.29	30.68	30.37

Fig. 4 and Fig. 5 relate the effect of composition and the holding time on the tensile properties of specimens at constant cooling time (5 s). The specimens produced in 7 s of holding time exhibits higher tensile strength and Young modulus. According to the investigation found by A. Kiaeifar et al. [13], tensile strength should increase as the percentage of the recycled material decreases because the recycled materials have lower molecular weight that reduced the tensile strength.

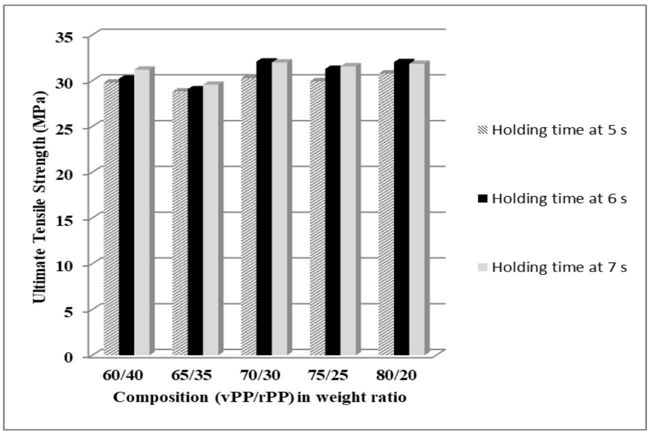

Fig. 4: Effect of composition and holding time to the ultimate tensile strength of specimens

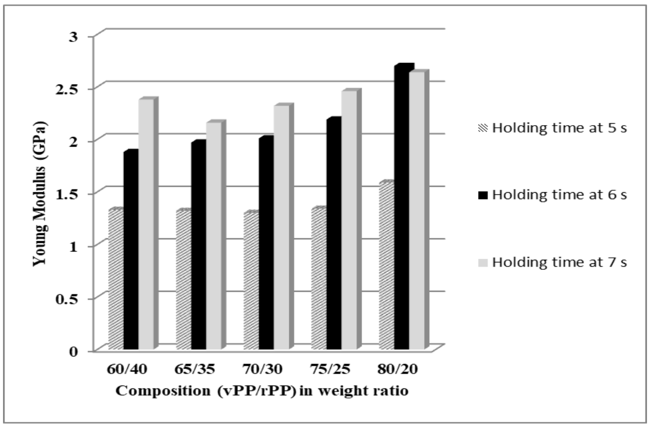

Fig. 5: Effect of composition and holding time to the Young Modulus of specimens

The vPP/rPP specimen produced in weight ratio of 80/20 shows the highest ultimate tensile strength because the amount of the recycled PP is only 20 wt%. In fact, this study shows that the tensile performance can be sustained when there is not more than 30 wt% of recycled PP utilized in the product. The results are similar to the previous finding [15] where the strength of the PP dropped if more than 25 wt% was included in the mixture of vPP/rPP blends. R. Prabhu et al. [14] stated that recycling polymer will degrade the chain of molecule to make the polymer become less deformable as well as brittle. This is because of the degradation by chain scission undergone during successive extrusions, decreasing the molecular weight and the quantity of entanglements which give strength and elasticity to the bulk [15]. The specimen fabricated at a holding time of 6 s is sufficient to maintain the Young Modulus values closed to the Young Modulus of the original PP, which is 1.7 MPa [5].

Fig. 6 presents the SEM images for tensile specimens before and after the tensile failure. In Fig. 6 (a), it shows that the virgin Polypropylene and recycled Polypropylene are well mixed together and the microstructure has no defect. The PP blends are homogenous and well distributed. Fig. 6 (b) shows the microstructure after the sample experienced failure. It shows that the microstructure is stretching out from the surface. There is a stretch line outside the bright area. The tensile specimen is brittle. When the load was applied, the load was distributed to the entire surface. However, the side of the surface started to stretch first in order to maintain its structure but when the structure chain was weakening, the load was focused at the middle of the surface. Unfortunately, the middle section has lowest strength and it immediately achieves the failure without necking.

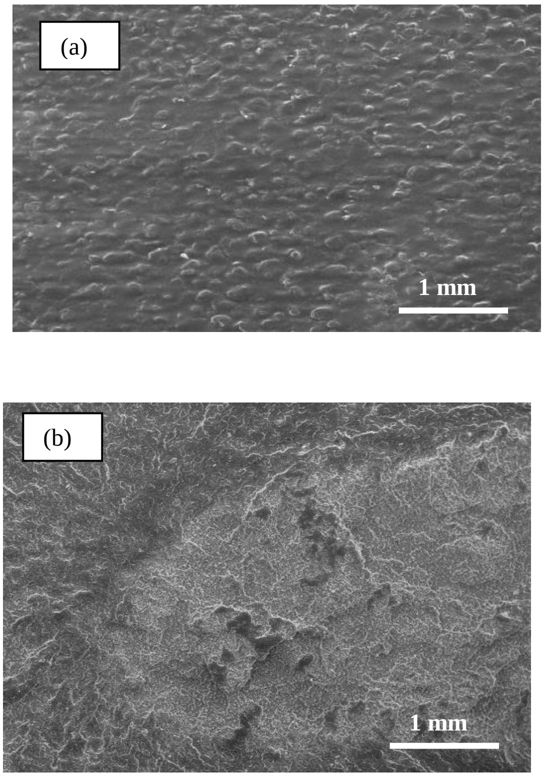

Fig. 6: Tensile specimen 60/40 prepared at constant 5 s of cooling time and 7s of holding time (a) before testing (b) after testing

3.4. Flexural performance

In the flexural test, all specimens did not break when bent to 5% maximum deflection as shown in Fig. 7. Flexural strength depends on the surface energy and molecular bond that can resist the bending forces [16]. Most of the thermoplastics do not break even after greatly deflected. Consequently, their flexural strength cannot be determined. Instead, flexural yield strength is determined, which is the loading necessary to stretch the outer surface at 5% [17].

Fig. 7: Flexural testing specimen after 5% max deflection

A pure PP homo-polymer has a flexural yield strength of 41 MPa [5]. All the specimens produced using 70 wt% of virgin PP in the vPP/rPP blends perform better flexural yield strength than the virgin PP. Previous finding reported by M. M. Raj et. al [5] shows the same trend with the current study. Brittle material is usually stronger in compression rather than in tension [17]. This is because the transverse crack will tend to close up and so could not propagate.

Table 5: Flexural yield strength of PP specimens at constant holding time of 5s

Composition (vPP/rPP)	Flexural yield strength (MPa)		
	Cooling time (s)		
	5	6	7
70/30	55.30	52.43	54.58
80/20	53.87	51.71	53.15

In Table 5, the cooling time slightly affects the flexural properties. It is found that the specimen produced in 5 s of cooling time reveals better flexural yield strength. PP transformed from molten resin into solid end PP product during cooling phase. More solidification transformation happens at longer cooling time and resulted in higher crystallinity and brittleness. Hence, the following investigation about the effect of composition and holding time on the flexural properties of PP specimens was focused at 5 s of cooling time. Fig. 8 and Fig. 9 show the flexural properties of PP specimens produced at different compositions and holding times.

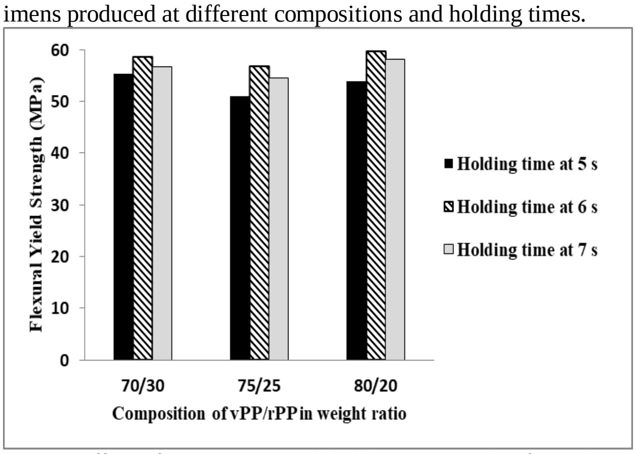

Fig. 8: Effect of composition and holding time to the flexural yield strength of specimens

Longer holding time is not favourable for better flexural properties. The highest bending modulus and flexural yield strength was achieved by the specimen fabricated at 5 s of holding time. Table 6 shows the EDX results for specimens produced at different holding time. It is noticed that more oxygen was produced at 7s of holding time. Longer holding time will have more broken chains. Chain-scissions will form and thus a reduction of the structure's molecular weight.

The average molecular weight of virgin PP was 489,560 and the average molecular weight of recycled material was 77,526 [18]. Therefore, a higher melt flow index (MFI) would be expected for recycled material. Chain-scissions that reduced molecular weight could have a significant impact on the process ability and performance of products, especially their mechanical properties.

Another reason behind this is greatly related to semi-crystalline behaviour of PP. PP has amorphous and crystalline regions. This combination is the reason for good strength and flexibility of PP. Due to the combination of amorphous and crystalline phases, semi crystalline polymers are tough but flexible with the ability to bend without breaking [17].

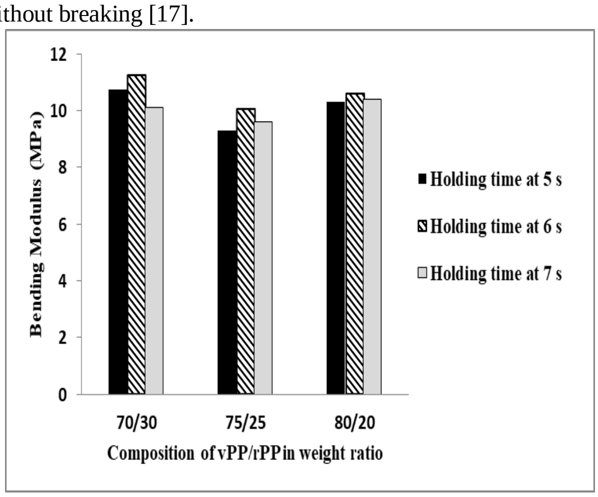

Fig. 9: Effect of composition and holding time to the bending modulus of specimens

Table 6: Energy Dispersive Analysis (EDX) of specimens 70/30 prepared at constant 5 s of cooling time

Element	Weight %	
	Holding time (s)	
	5	7
Carbon	96.256	95.932
Oxygen	3.744	4.068

4. Conclusion

In this study, PP keychains were successfully produced by adding specific amount of recycled PP. However, a defect appeared on the product which was bubble mark. Further study is needed to focus on the process setting such as injection pressure to mitigate the defect.

Despite composition and cooling time, holding time is the most influencing parameter in shrinkage and mechanical properties of the product. The range of shrinkage percentage to its original volume is mostly affected by length of the holding time. Longer holding time at 7 s managed to reduce the shrinkage to 9.31 %.

It has been found that the optimum composition between virgin and recycled PP was the specimen consisting of 80wt% of virgin and 20% of recycled PP. Blending between virgin and first recycled PP had no significant deterioration towards the mechanical properties. The vPP/rPP blends still maintained their initial mechanical properties if compared to the original performance of virgin PP. It is suggested that the recycled PP with no more than 30 wt% will be utilized in the mixture to avoid serious deterioration of the mechanical performance. In summary, blending with any composition of virgin and recycled PP is acceptable and preserved the mechanical properties as long as the recycled PP was from the first cycle.

This study helps to promote the usage of recycled Polypropylene in the plastic industries. Recycling PP material could be a good practice in order to reduce the amount of waste thrown. Besides, the optimum composition of parameter setting and weight ratio can be used as the guideline for the industries to recycle the Polypropylene. This finding could help to utilize the Polypropylene waste from injection moulding process such as sprue, runner and gate to be reground and mixed with the virgin Polypropylene.

The current research only emphasized on the first cycle of recycling. It is recommended that further research could be conducted on multiple cycles of recycling and determined at which cycle that deterioration of mechanical properties performed the worst.

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