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Research paper

Tensile Property of Melt Mixing Co-Polypropylene with Waste Polymer at Different Composition Ratios

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Abstract

In order to implement economical way of managing unwanted substances, waste polymer (WP) can be recycled instead of throwing it away. It can be reused via "sink-float" technique and mixed with another binder like co-polypropylene (co-PP) to enhance the mechanical properties of the material. This is because co-PP is a bit softer but has better impact strength, much tougher and more durable than polypropylene (PP). Two materials underwent injection moulding with 170°C temperature to produce dog bone samples for tensile test. The test started with 10% up until 80% of WP content mixed with co-PP. Tensile test speed used for this experiment was 5mm/s. Stress vs. strain graph was obtained from the test and the modulus of elasticity was obtained by using the stress over strain formula. The stress versus strain result for the composite with WP is lower than that of co-PP, proving that WP is more brittle compared to the more elastic co-PP. Morphological analysis of surface structure based on Optical Microscope (OM) indicates that co-PP has smooth surface while WP has a rough surface.

Keywords: *Co-polymer; Waste polymer; Injection moulding; tensile test; Stress-strain.*

1. Introduction

Ever since the last decades, enormous population increase worldwide together with the human needs to adopt improved conditions of living led to a dramatically increase in polymers consumption which is mainly plastics [1]. There are three types of polymer that will be discussed. They are polypropylene, co-polymer and waste polymer. Each and every polymer has its very own characteristics and pros and cons. Polypropylene (PP) is a type of thermoplastic or usually known as “addition polymer”, where it is made from the combination of propylene monomers [2]. It underwent phenomenal growth in production and use throughout world during the latter half of 20th century and as per year the demand keeps getting higher, which requires the production to keep up with the growing demand [3].
On the other hand, it has gained a strong acclaim in a short period of time due to the fact that PP has the lowest density among other commodity plastics [4]. The main advantage is that it is linked to high temperature resistance that makes PP a material suitable specifically for items such as trays, funnels, pails, bottles, carboys and instrument jars that have to be sterilized (cleaned) frequently for clinical environment application [5]. It is an economical material that offers a combination of phenomenal physical, mechanical, thermal and electrical properties which cannot be found in any other thermoplastics. It is usually used in both household and industrial applications. Generally, most propylene monomer comes from the steam-cracking process using naphtha which is a precious fraction of crude oil [6]. There are four different routes to embellish the polymerization of any polymer which is suspension polymerization, bulk polymerization and gas-phase polymerization [7].

In copolymer polypropylene (co-PP) case, it is a bit softer but possesses better impact strength, tougher and is more durable than homopolymer polypropylene [8]. A polymer properties can be amplified by using filler which was has been receiving careful attention from researchers and industries for the past decades because there is progress in the increase of thermal expansion coefficient, mechanical properties, thermal stability and stiffness [9]. The distinguishing commercial application of polypropylene is through the coloration structure of distinction with macroscopic properties [10]. One of the aspects that are important in this toughened polypropylene PP is its properties, which is weak heat deflection compared to homopolymer PP [11]. Various propylene-copolymerized polyethylene (ethylene−propylene copolymers, EPC) and polypropylene (PP) chains have a variety of tacticities [12]. There are some differences in terms of composition and structure of chain sequence, which differentiates Co-PP from Homo-PP. Co-PP is the result of gradual changes in sequences of fractions and structures and composition [11].
Polymer recycling is one of the ways to reduce environmental problems caused by polymeric waste accumulation generated from day-to-day applications of polymer materials in packaging and construction [13]. The recycling of polymeric waste helps to conserve natural resources because most polymer materials are made from oil and gas. Treatments disposal and incineration of plastic waste are less desirable due to high cost, poor biodegradability and the possibility of hazardous emissions [14]. Recycling of the right ingredients (conversion of polymer scraps into new products) is a popular recovery method but recycled plastic products often cost more than those of virgin plastics [15]. There are several options for how this can be done which are reuse, mechanical recycling and chemical recycling [16].
However, up till now the reuse of polymeric wastes is of very limited potential because of the problems they entail [17]. Current-

ly, on average only 7% are recycled to produce low- grade plastic [18]. An alternative strategy which is chemical recycling has attracted much interest recently due to its aim of converting waste polymers into basic petrochemicals to be used as feedstock or fuel for a variety of downstream processes [19]. On the other hand, incineration and recycling are operational in a relatively short time for the improvement of the situation at present and in the near future.

2. Methodology

2.1. Raw Material

Table 1: Composition (weight percentage, %)

Sample	Co-PP	70% WPP + 30% RH
1	100%	0%
2	90%	10%
3	80%	20%
4	70%	30%
5	60%	40%
6	50%	50%
7	40%	60%
8	30%	70%
9	20%	80%
Co-PP – Copolymer Polypropylene WPP – Waste polypropylene RH – Rice Husk		

Table 1 shows the individual composition for each sample. Each composition consists of virgin copolymer polypropylene which is to be mixed blended with waste polypropylene and rice husk pellets of the stated ratio through injection moulding.

2.1. Polypropylene

Polypropylene is a linear hydrocarbon polymer, expressed as CnH2n. Polypropylene is in the same category as polyethylene and polybutene, which is a polyolefin or saturated polymer. Polypropylene is one of the most versatile polymers available for applications, both as a plastic and as a fiber in virtually all of the plastics markets. It is a synthetic resin built up by the polymerization of propylene. Polypropylene is one of the thermoplastic materials, which is compatible with many processing techniques and used in many commercial applications.

2.2. Copolymer Polypropylene

Similar to polyethylene and polypropylene, polypropylene copolymer is classified as a polyolefin and is a high-molecular weight hydrocarbon. Copolymer PP (Co-PP) is essentially a linear copolymer with repeated sequences of ethylene and propylene, which consists of some advantages from both polymers. Copolymer PP is autoclavable, offers much of the high-temperature performance of polypropylene and provides some of the low-temperature strength and flexibility of polyethylene. Like all polyolefin, CO-PP is non-toxic, non- contaminating and lighter than water. Co-PP is milky-white translucent in appearance. Co-PP can easily withstand exposure to nearly all chemicals at room temperature up to 24 hours. Strong oxidizing agents can eventually cause embrittlement. Co-PP can be damaged by long exposure to UV light. As a summary, Co-PP is softer but possesses higher impact strength, improved heat sealability, lower melting point, resistance to environmental stress cracking and improved clarity. Application of copolymer polypropylene includes automotive bumpers, boxes and instrument pillar. Figure 1 shows the morphological view of copolymer polypropylene.

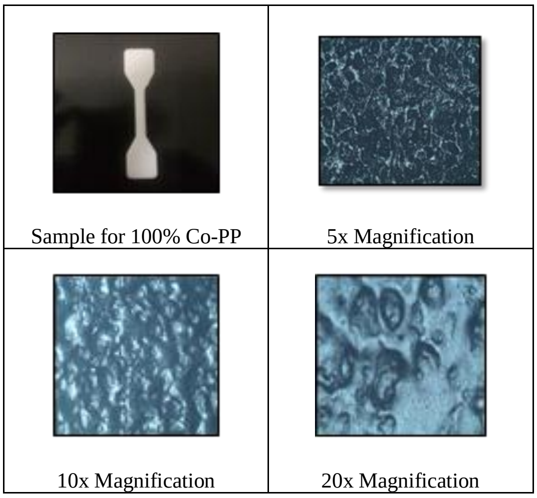

Fig. 1: Morphological view of 100% CO-PP from optical microscope

2.3. Waste Polypropylene

Waste polypropylene (WPP) used in this study is combined with rice husk. Figure 2 shows the material yield results of cross-linked and linear on the molecular chain configuration. Besides that, the composition also looks like an amorphous (random entanglement). It may have anisotropic props depending on the condition during solidification. From the observation in this study, the surface structure seems fibrous which means it consists of or characterized by fibre.

Fig. 2: Surface structure of WPP on optical microscope

2.4. Injection Moulding

Specimens for tensile testing were prepared by means of injection moulding according to ISO 527(5A) standard. The injection moulding was done using the Nissei NP7 Real Mini machine which was equipped with horizontal type screw. Temperature of injection molding was set to 170˚C in the injection mold machine. The temperature setup will stabilize for 30 minutes. Polymer-fiber mixture in form of pellets is fed into an injection Molding machine through a hopper. Heating elements are placed over the barrel to soften and melt the polymer-fiber. The molten polymer-fiber is then conveyed forward by a feeding screw and forced into a split mold, filling its cavity through a feeding system with sprue gate and runners. The mold is equipped with a cooling system providing controlled cooling and solidification of the material. The polymer is held in the mold until solidification and then the mold opens and the part is removed from the mold by ejector pins. Table 2 shows the temperature parameter used during injection moulding process.

Table 2: General setup for injection moulding

	Temperature, ˚C					
Zone	Feed	Rear 2	Rear 1	Middle	Front	Nozzle
Set	50.0	155.0	165.0	175.0	165.0	170.0
Real	46.2	155.9	170.3	175.1	165	174.8

2.5. Tensile Test

WPC samples underwent tensile test in accordance with ISO 527 (5A). The parameters of the tensile test were load frame with 5kN load cell and a crosshead speed of 5mm/min. The strain was measure over a 50 mm gage length by means of an extensometer. A minimum of five samples for each composition were analysed to obtain an average result

3. Results and Discussion

All The study of stress-strain performance of typical materials in terms of the engineering stress and strain is observed and calculated based on the original dimensions of the specimen.

3.1. Injection Moulding

The injection machine melt plasticize the molding material inside the heating cylinder and inject it into the mold tool to create the molded product by solidifying it inside. The injection machine is constructed of a mold clamping device that opens and closes the mold tool and a device that plasticizes and injects the molding material [20]. Injection moulding can be performed with a host of glasses, elastomers, confections and common thermoplastic and thermosetting polymers. Material for the intended product is fed into a heated barrel, mixed and injected into a mould cavity where it cools and hardens to the configuration of the cavity.
Generally, the research activity on injection molded polymers characterization by process parameters has been developed by several groups and different approaches have been carried out. Injection speed, melt temperature, mold temperature, packing time, packing pressure, cooling time are the parameter to be focused on. PP properties initially are studied in terms of its holding pressure, cooling time, melt temperature and injection speed on different molded parts (via conventional or SCORIM process) [21].
They reported the substantial increase in Young's modulus of molded produced by SCORIM and the mechanical behaviour about stiffness and impact resistance. Then, recent works concerning PP filled with calcium carbonate have been made [22]. Their aim has been the optimization of six molding conditions (melt temperature, packing time, cooling time, injection speed and pressures) to reduce the shrinkage and warpage of a standardized test specimen, through the statistical Taguchi method. Meanwhile, some researchers reported the influence of processing conditions for polymers other than PP. For example, a study about the behaviour of polycarbonate linked with injection velocity, packing pressure, cooling time, mold temperature and melt temperature [23]. They showed that the tensile stress increases with melt temperature and mold temperature, which helps the polymer to set a higher molecular orientation and have lower residual stresses.
High temperature of mold will result in lower the cooling rate. This condition increases part performances. Packing pressure and injection speed are not much significant to the polymer strength. For this study, the general setup consists of setting and real condition of the temperatures which monitors the real temperature of the machine. Five samples were produced for each PP and WPP. Changes in temperature were neglected because the temperature did not require any alterations considering that the basic material used has the same melting temperature.

3.2. Copolymer Polypropylene

An average of five samples of CO-PP was used to undergo tensile test. Load was exerted on the sample causing it to elongate until it reaches its ultimate strength and fracture. Figure 3 illustrates graph of stress versus strain for Copolymer Polypropylene (CO-PP). From the graph, it can be observed that PP3 has the highest yield stress resistance among other samples whilst PP2 has the lowest yield stress resistance to stress. On the other hand, PP1 has the most significant change compared to other samples since fracture occurred the earliest. All samples have the same pattern, which means that CO-PP shows plastic behaviour of polymer. In addition, the strain rate significantly influences the modulus of elasticity, tensile strength and ductility [24].

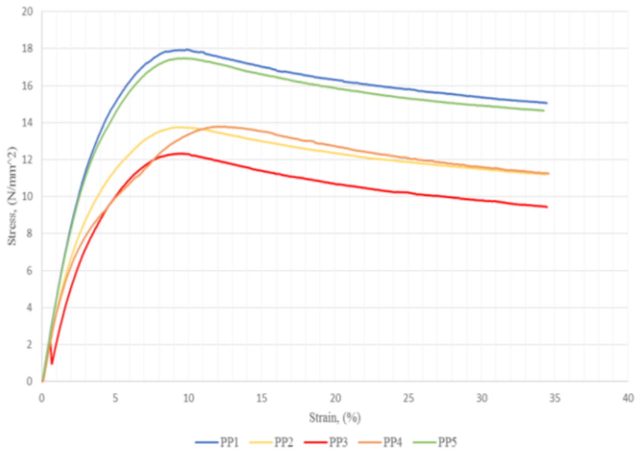

Fig. 3: Graph of stress versus strain for CO-PP

Table 3: Stress and strain values for CO-PP

Sample	Max Stress (N/mm^2)	Max Strain %
PP1	13.75	9.095
PP2	17.478125	9.74917
PP3	12.378125	9.48333
PP4	13.7875	12.4933
PP5	16.334375	9.035
Average	14.745625	9.97116

Table 3 shows the value for stress and strain of CO-PP. From the result, it can be seen that the plastic shows mechanical properties (brittle plastic) (Polymer Properties Database, 2017). In compression, the filled polymer behaves as a ductile material with a yield point and higher elongation to break. This can be treated as a relaxation phenomenon [25]. Based on the result, the initial reading the efficiency of the data is close to each other and the initial yielding of the material depends on pressure, strain rate and temperature [26].

3.3. Waste Polymer

Based on Figure 5, graph of stress over waste composition ratio generally has a descending trend. When waste composition ratio is at 10%, the value of stress is 13.3306 N/mm^2. When the waste composition ratio is increased to 20%, the value decreased to 11.9156 N/mm^2. For 30% waste composition ratio, stress value was further reduced to 9.4374 N/mm^2. At 40% ratio, the stress value becomes 7.6312 N/mm^2 whereas 50% ratio caused the stress value to dropped down to 6.8406 N/mm^2. The stress value for waste composition ratio 60%, 70% and 80% went through insignificant drop where the values are 6.7631 N/mm^2, 6.6456 N/mm^2 and 5.9531 N/mm^2 respectively. The value of stress, strain and percentage between composition ratios can be seen in Table 4. The nominal tensile strength is almost independent of the composition, while the other mechanical properties are similar to those of the degraded material up until the virgin PP content is at 75% where they approach the values embodied by virgin polypropylene [27].

Table 4: Composition ratio of stress and strain

Sample	Stress (N/mm^2)	Strain (%)
1	14.7456	9.9711
2	13.3306	9.6488
3	11.9156	8.9833
4	9.4374	8.7625
5	7.6312	8.0058
6	6.8406	7.5491
7	6.7631	7.1855
8	6.6456	6.8058
9	5.9531	6.0577

Figure 4 shows the graph of strain versus wood polymer composition ratio, where the overall trend is decreasing. When waste composition ratio is at 10%, the stress result shows the highest value of stress. When the waste composition ratio is increased to 20%, the value significantly drops. One of the ways to optimize the properties of WPC samples is by enhancing the ductility of the matrix itself [28]. Sample with highest content of virgin co-polymer polypropylene clearly exhibits better strength. As percentage of virgin co-pp gradually decreased, so did the strength of the sample. It is reported that cellulose and stress transfer efficiency are co-dependent where the addition of cellulose will increase crystallinity hence creating a rigid composites [29]. The addition of virgin co-pp enhanced the crystallinity of the sample, which explains why sample with highest content of virgin co-pp exhibits better strength. Moreover, the heating temperature at injection mold machine effect the quality of every specimen. Besides, the content of every waste plastic are not consistent.

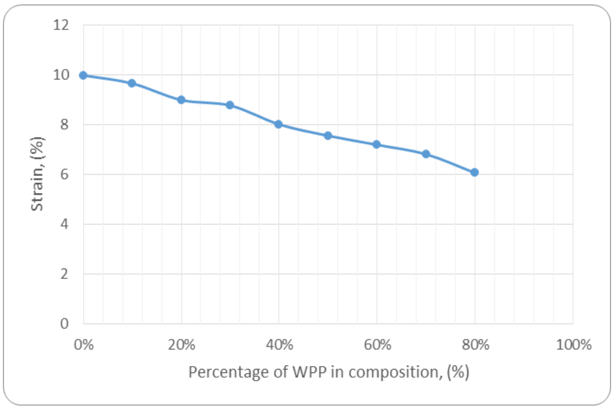

Fig. 4: Graph of strain versus WPC composition

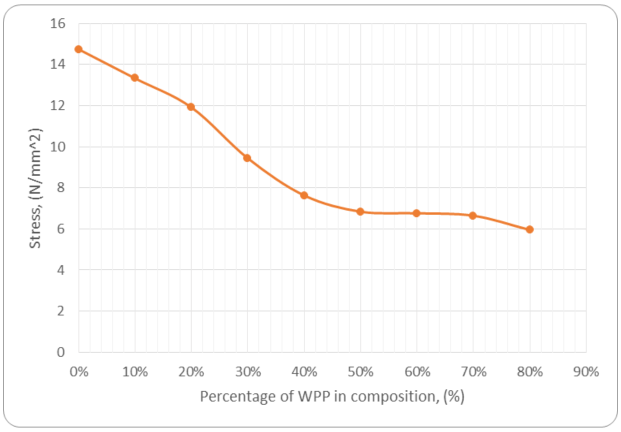

Fig. 5: Graph of stress versus WPC composition

4. Conclusion

In the study of stress-strain performance of typical materials in terms of the engineering stress and strain is observed and calculated based on the original dimensions of the specimen. These samples undergo tensile test which values of ultimate tensile strength, maximum elongation and yield strength are directly measured from this test. It is discovered that from the result of 100% co-polypropylene (co-PP), there is no significant change in terms of stress and strain value among 5 samples. It can be concluded that that the material has a ductile behaviour in the quasi-static state. Each WP sample has different composition. Hence, they all exhibit different result for stress-strain performance. It can be seen on each of WP's stress-strain graph. After analysing the graph, it is learnt that the PP specimen experienced more plastic deformation compared to the WP specimen and this is reflected by WP sample with the higher percentage of Co-PP. Thus, WP composition materials are quite fragile and can easily break or damage when pressure is applied. In conclusion, although the material is not quite efficient when compared to another polymer material, it is still useable for other purposes.

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