Mechanical properties of PE-PET-PS-PP blends produced by high shear mixing

Mohd Adly Rahmat Saat1), **Rozaidi Rasid**1), *), **Maria Abu Bakar**2), **Azman Jalar**1), 2), **Emee Marina Salleh**1)

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Abstract: This work focused on mechanical behavior of polymer by implementing high speed mixing (HSM) method of polymer blending. In this study, polyethylene (PE), poly(ethylene terephthalate) (PET), polystyrene (PS), and polypropylene (PP) were used as they are the most abundant polymers used at the current time. The research was carried out using counter rotating twin screw extruder at constant speed of 249 rpm and at 120 °C with weight mixing ratio of the plastics are 1 : 1 : 1 : 1. According to tensile study, stress strain curve of the HSM sample exhibited an alloy-like characteristic. With references to other type of virgin polymers and some polymer blends the yield stress, Young's modulus and strain rate of high-speed mixing were quite comparable to the other samples.

Keywords: polymer recycling, high speed mixing, polymer blending, mechanical blending, mechanical properties.

Właściwości mechaniczne mieszanek PE-PET-PS-PP wytwarzanych w warunkach dużej szybkości ścinania

Streszczenie: Zbadano właściwości mechaniczne mieszaniny polimerów wytworzonej w wyniku mieszania składników w warunkach dużej szybkości ścinania (HSM). Składowymi przygotowywanej mieszaniny były poużytkowe odpady najbardziej rozpowszechnionych tworzyw: polietylenu (PE), poli(tereftalanu etylenu) (PET), polistyrenu (PS) i polipropylenu (PP). Badania prowadzono z wykorzystaniem przeciwbieżnej wytłaczarki dwuślimakowej przy stałej prędkości obrotów ślimaka 249 obr./min (rpm) w temp. 120 °C i stosunku masowym użytych tworzyw 1 : 1 : 1 : 1. Stwierdzono, że krzywa naprężenie-obciążenie próbki uzyskanej metodą HSM miała przebieg podobny do przebiegu krzywej charakterystycznej dla stopu polimerów. Wartości granicy plastyczności, modułu Younga i szybkości odkształcania próbek wytworzonych w warunkach mieszania z dużą szybkością ścinania były porównywalne z odpowiednimi wartościami uzyskanymi w wypadku innych rodzajów polimerów pierwotnych i niektórych mieszanin polimerowych.

Słowa kluczowe: recykling polimerów, mieszanie z dużą szybkością ścinania, mieszanie polimerów, mieszanie mechaniczne, właściwości mechaniczne.

Recently, the most common plastics that have been used are poly(ethylene terephthalate) (PET), polystyrene (PS), polypropylene (PP) and polyethylene (PE). According to United States Environmental Protection Agency (EPA), 4 million tons of PET plastic were discarded in U.S. with 26% to 41% water bottles [1]. National Association for PET Container Resources (NAPCOR) reported in 2011, there were 5 478 million pounds of PET jars and bottles available for recycling, but only 29 percent of the total amount was recycled [2]. Conventional process of recycling polymers often involves the usage of chemical substances as the compatibilizing agent since the polymers cannot be technically blended together [3]. Hence, compatibilizers are essential for the polymers blending and mixing processes as might provide their better properties [4]. Then, disposing and degradation are favored compared to recycle and reuse approaches. On top of that, recycle and reuse takes a long time since most of the polymers are incompatible with each other. On the other hand, segregation process is essential in the recycling process due to its compatibility issues. These processes are inefficient in today's world since the unstable economic growth makes the industries to cut all the costs rather than implementing the recycle and reuse policy. Unfortunately, if this is the case there will be a lot more landfill will emerge to dispose all those unwanted trashes especially plastics

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1) National University of Malaysia, School of Applied Physics, 43600 Bangi, Selangor.

2) National University of Malaysia, Institute of Microengineering and Nanoelectronics (IMEN), 43600 Bangi, Selangor.

*) Author for correspondence; e-mail: rozaidi@ukm.edu.my

which are the most abundant waste disposal. This will give out instability in the ecosystem since the landfills are filled with non-biodegradable substances [5]. Heat are needed to degrade those plastics, unfortunately this heat process can affect the environment. All of these polymers recycling might need a new or revised process to better the outcome and reduce the other form of unwanted side effects [6].

One of the methods that can yet to be fully explored is the high shear mixing (HSM). HSM is conducted by applying high speed and torque to enhance the mixing and increase the heat generation of the processing without using compatibilizer. Twin screw counter rotating will produce high shearing force inside the barrel to improve the blending. Thus, any kind of plastics probably can be processed directly without any costly segregation process with less chemical usage during the recycling process [7].

Shearing process is known to generate heat by adapting the homomicronization technique to mix the polymers using ultra-high shearing up to 1500–3000 rotational per minute (rpm). Due to the process, the polymers are melted by the friction involved between the screws and the materials and also between the materials itself. Adaption of this technique, using the counter rotating twin screw extruder is the first look into the fundamental of the homomicronization in terms of the mechanical characteristic of the blends. However, homomicronization process occurs in a chamber of machinery, in a specific time period and it is not a continuous process. On the other hand, the mechanism process of extruder is continuous and residence time of the polymer cannot be set and totally dependent on the screw speed. The higher the rotation of the screws the lesser the residence time. This matter can be overcome by using a narrower slit die of the extruder, hence the residence time will be increased. A particular residence time is needed for the polymer to be processed from the hopper until exiting the die and the higher the residence time the higher the shearing [8].

It is well established that the mechanical properties of secondary plastic materials obtained by recycling of plastic containers are poor due to the incompatibility between primary polymers and degradation of components during the heterogeneous reprocessing [9]. Therefore, it is common to have secondary recycled product with low mechanical properties. Then the usage of the secondary polymer product (recycled product) must comply with the certain level of mechanical properties. It is expected, HSM, without compatibilizers might produce lower mechanical properties as compared to the primary polymer. Obviously, this scenario is in line with the recycled product without using any compatibilizer, which can be considered as the great advantage of HSM. Therefore, this current work reported preliminary results of the mechanical behavior of several polymers experienced HSM processing to produce secondary recycled polymer blend [8].

EXPERIMENTAL PART

Materials

The polymers used in this research were polypropylene (PP), polyethylene (PE), poly(ethylene terephthalate) (PET), and polystyrene (PS) which all are commercially available in various forms and shapes. The polymers were obtained from plastic container shop at Selangor wholesale market.

Preparation of samples for tests

The plastics were divided according to their types and then were cleaned to remove unwanted substances and dried. Subsequently, the plastics were crushed by Ming Lee Strong Crusher type ML-SC 1.5 KW crusher machine into smaller size of plastic flakes. Then the flakes were stored in zip lock bag according to their type.

The second step was high shear mixing process, this process was carried out using twin screw counter rotating extruder – Thermo Scientific™ HAAKE™ Rheomex CTW 100 OS Twin-Screw Extruder [10]. The extruder's temperature was set at 120 °C and the rotation speed was set to the maximum capability of the extruder at 249 rpm to induce the shearing of mixing. The die of the extruder die was slit type with dimension of 1 mm thickness and 50 mm wide. The mixture of materials were prepared with weight ratio 1 : 1 : 1 : 1 and then manually mixed to gain a homogeneous mixture of the flakes in a container. The materials were poured into the feeder of the twin screw counter rotating extruder. The materials were extruded into sheets with dimension according to the dimension of the die's slit. The materials were cooled down to room temperature and crushed using the crusher to produce smaller flakes. The raw materials of HSM were stored at 65 °C for 24 hours [11].

The next step was carried out to investigate the mechanical properties of the HSM. The raw materials obtained from extruder was subjected to thermal compression process to prepare the dogbone sample [12]. The raw materials were poured into 3 mm thick dogbone mold and compressed by the hot press machine (LABTECH Engineering Company LTD). The pressure was set at 6.9 MPa, the processing temperature were 180 °C, the preheating time was 2 minutes, the venting time was 6 minutes, the pressing time was 6 minutes, and the cooling time was 5 minutes [13].

Methods of testing

The samples were tested using universal tensile test machine (Testometric M500-50CT) in order to evaluate the mechanical properties. The test was performed at a constant strain rate of 150 mm/minute.

RESULTS AND DISCUSSION

Figure 1 shows that the curve was different from the other polymer common type curves as there was a plateau region observed from the curve. The plateau region was observed at 2.6 MPa until the strain was about 0.37%. After the constant stress, there was a significant increase in stress which might be attributed the strain hardening. This mechanism occurred until the strain was about 1.37% at the peak stress of 7.5 MPa. According to this curve, this polymer possesses an alloy-like curve. The HSM sample provided very low elongation which might be resulted by incompatible blend of the HSM sample. Most polymers tend to strain much more than 100%. According to this result, it showed that the strain of this material was quite low comparing to the other polymers and can be considered as brittle material [14].

Apparently, a significant increase in force during the strain hardening showed that the structure might possess a large amount of crystalline or aligned structure at this area of the curve as three of the polymers used are semi-crystalline polymer. As can be seen at the constant stress area might be resulted by a rearrangement of molecular or chain structure from agglomerate to linear [15].

Figure 2 displays HSM stress at peak was different from the virgin polymers. The HSM sample possessed around 44% of the strength virgin PP, 14% of PET strength. These differences were not common as the recycled material underwent more than one heat process. Comparing to the PP/PE blend, 50 wt % PE and 75 wt % PE results of the HSM sample was not deviated much from these two samples. Comparing HSM to the PP/PE (50 wt % PE) blend, the difference was less than 1% and between HSM sample and the PP/PE (75 wt % PE) blend sample the difference was about 7% lower than the HSM sample.

On the other hand, when comparing to some of the composites, HSM and the PP/PET/PP blend, the HSM results were 60% higher than the PP/PET/PP blend, these differences were considerably significant comparing both blends does not use any compatibilizers the only difference is that the HSM use higher rotational speed during the extrusion process.

Figure 3 shows the HSM sample exhibited maximum elongation of 1.48%. This elongation was comparable to virgin PS and virgin PP sample in which HSM offered 59.2% higher elongation than virgin PS. This finding was expected because PS is known for its brittleness and tends to have very low strain rate. But when comparing to HIPS (high impact polystyrene), the elongation of HSM sample was only 2.9% of the elongation of HIPS. On the other hand, HSM result was not varied too much from virgin PP samples with 22% difference from PP strain. For virgin PE, the results were also comparable as HSM results were 23% of the PE strain. For other composite like PP/PS/PET and PP/PE (75 wt % PE) the HSM result deviated more than 80% of the PP/PS/PET.

Figure 4 shows that Young's modulus of HSM was higher than HIPS, PP/PE (50 wt %) 200 °C, PP/PE

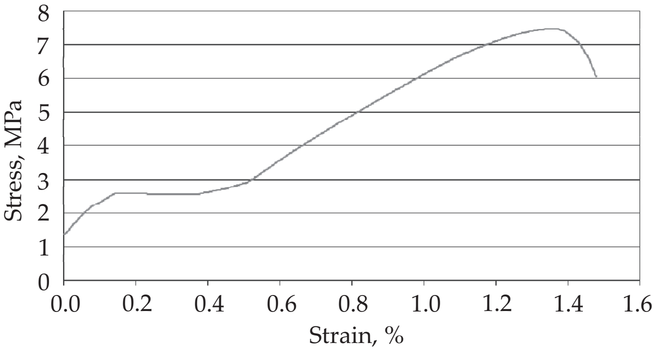

Fig. 1. Stress versus strain curve for blended material mixed at 120 °C and at 249 rpm

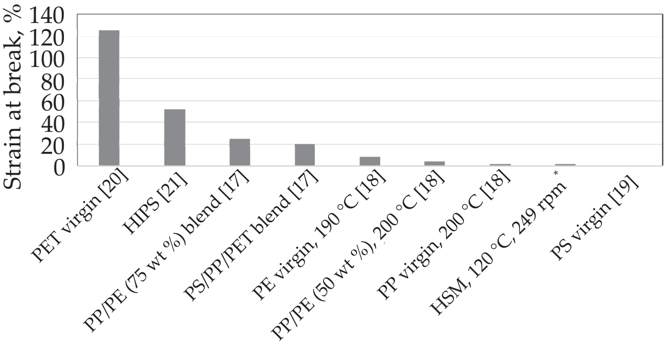

Fig. 3. Comparison of strain at break for different type of polymers

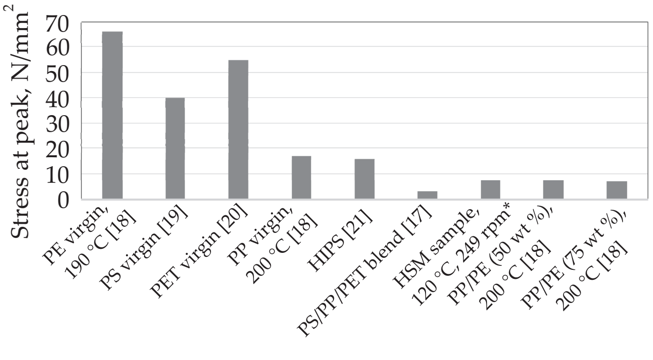

Fig. 2. Comparison of stress at peak for different type of polymers
*** this research**

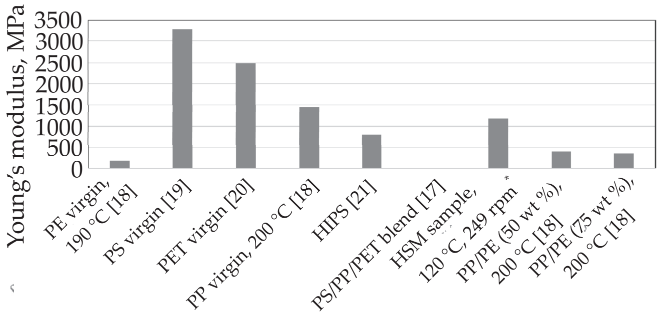

Fig. 4. Comparison of Young's modulus for different type of polymers
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(70 wt % PE) 200 °C. In comparison with the HIPS, the Young's modulus of HSM was 47.5% higher. The other composites' Young's modulus were higher than HSM by more than 50%. On the other hand, most of the virgin material provided a higher modulus compared to HSM. However, the HSM result was comparable as its modulus was only 255.6 MPa less than PP. For PS and PET, both of have higher Young's modulus compared to HSM but the differences are not more than 70%.

CONCLUSIONS

A type of polymer blend was produced by direct mechanical mixing without the presence of additives or compatibilizers by using high shear mixing (HSM) method. According to evaluation of mechanical properties, it was observed that the stress strain curve of HSM polymer blend possessed a constant area with increasing strain of the curve. The constant stress was observed at 2.6 MPa until the strain was about 0.37%. The Young's modulus of HSM polymer blend possessed comparable result to virgin PP, PS, and PET except PE in which HSM polymer blend Young's modulus was the highest. On the other hand, Young's modulus of HIPS, PP/PE (50 wt %) 200 °C, PP/PE (70 wt % PE) 200 °C and PP/PE/PET were lower than HSM polymer blend.

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