Effect of high shear rate on the mechanical properties of polyethylene, poly(ethylene terephthalate), polystyrene, and polypropylene waste blend

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Abstract: The effect of high shear rate on the mechanical properties of polyethylene (PE), poly(ethylene terephthalate) (PET), polystyrene (PS), and polypropylene (PP) waste blend was investigated. The process was carried out at a temperature of 120°C using a counter-rotating twin-screw extruder. A constant screw speed of 250 rpm and a constant weight ratio of the PE/PET/PS/PP components of 1:1:1:1 were used. The preliminary research showed that the high shear rate had no effect on the impact strength. However, the significant improvement in the flexural properties was observed as compared to those obtained at a lower screw speed of 80–120 rpm.

Keywords: recycling, shear rate, polymer blends, mechanical properties.

Wpływ dużej szybkości ścinania na właściwości mechaniczne mieszaniny odpadów polietylenu, poli(tereftalanu etylenu), polistyrenu i polipropylenu

Streszczenie: Zbadano wpływ szybkości ścinania na właściwości mechaniczne mieszaniny odpadów polietylenu (PE), poli(tereftalanu etylenu) (PET), polistyrenu (PS) i polipropylenu (PP). Proces prowadzono w temperaturze 120°C przy użyciu przeciwbieżnej wytłaczarki dwuślimakowej. Stosowano stałą szybkość obrotową ślimaka 250 min^{-1} i stały stosunek masowy składników PE/PET/PS/PP 1:1:1:1. Wstępne badania wykazały, że duża szybkość ścinania nie miała wpływu na udarność. Zaobserwowano jednak znaczną poprawę właściwości mechanicznych przy zginaniu w porównaniu z uzyskanymi przy mniejszej prędkości ślimaka 80–120 min^{-1}.

Słowa kluczowe: recykling, szybkość ścinania, mieszaniny polimerowe, właściwości mechaniczne.

Polymers usually have different type of functional groups, which make them incompatible to each other and immiscible, so the most common process of blending them must involve the compatibilizing agents [1]. Hence, the usage of compatibilizers is essential to obtain polymer blends with better properties [2]. The compatibilizers are effective only when there are 2 types of polymer involved. If there are more polymers involved, more types of compatibilizers are needed and the properties of product material would be inconsistent. Therefore, the polymers are usually segregated according to their types before processing. The segregation process could be the answer to the compatibility issue but unfortunately this method is inefficient and laborious. It could be also very expensive as the experts are needed to recognize the types of polymers. In today's world and the pandemic reality leading to the unstable security over the economic sectors, many industries must consider cutting all unnecessary costs [3]. Nowadays more and more developed and developing countries export their waste to the poorer countries to deal with them [4]. This global waste trade is getting out of hands causing the affected countries many problems as more and more landfills emerge [5]. The degradation of polymer waste requires heating so it can cause hazardous gases emission and the unwanted by-products of degradation process may contaminate air, soil, and water source leading to the future environmental problems [6]. The recycling process of plastics might need a new unconventional way to deal with these problems and to have a better outcome and reduce the risk of unwanted side effects.

One of the unconventional methods is the high shear mixing (HSM). This method is called a newplast-process. High shear mixing is a method adapting the homomicronization technique which is the process of mixing polymer under ultra-high shear at screw speed up to 1500–3000 rpm. During the process, materials are subjected to ultra-high shearing force and subsequently are melted and blended. This method is suitable for all sorts of polymers which are mixed in a special chamber consisting of an ultra-high shearing mixer. In this chamber plastics are melted and subjected to the high shearing force due to high screw speed and torque which enhance mixing and increase the heat [7]. The melting of polymers occurs due to the friction between blades and plastics and inside plastic material. The form of the resulting blend

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is a homogenous dough. Unfortunately, this method of polymer blending is being halted and there is a lack of new reports focused on it. In this method twin screw extruder is used which is one of the common machinery that can mimic high shear mixing and no additional compatibilizers are necessary. The counter rotating twin screw can generate enough shearing force inside the barrel to improve the blending. Thus the process of segregation and the use of chemicals as compatibilizers are unnecessary [7].

Adaption of the counter rotating twin screw extruder technique is the first look into the fundamental of the homomicronization in terms of the usefulness in characterization of mechanical properties of the blends. The homomicronization process in a chamber is not a continuous process and takes place in a certain period of time, however, the process of mixing using twin screw extruder is continuous and the residence time is dependent on the speed of screws [8]. In order to increase the residence time and prolong the period of mixing, a thin slit at the die of the extruder may be used. This would help the materials to blend longer under the high shearing force [8].

Commonly 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]. That's why to be useful the secondary plastics must meet at least certain minimum mechanical properties which are required for usage as daily life essentials. It is expected, that HSM would provide lower mechanical properties compared to the virgin materials because there are no compatibilizers involved in the mixing process. Because of that advantage of HSM, it can enhance the mixing of the incompatible polymers by exerting the materials with extra shearing and the result can be compared to the conventional methods of polymer blending. The current work reports the preliminary results of the research on the mechanical properties of polymers.

EXPERIMENTAL PART

Materials

The recycled polymers used in this research were commercially available in various forms and shapes polypropylene (PP), polyethylene (PE), poly(ethylene terephtalate) (PET), and polystyrene (PS). The sources of the recycled polymers were: water bottles in case of PET, bottle caps in case of PE, old compact disk casing in case of PS, and used plastic chairs in case of PP.

Methods

Polymers were divided according to their types, cleaned to remove unwanted substances and air dried. Subsequently, plastics were crushed using Ming Lee Strong Crusher type ML-SC 1.5 KW crusher machine into smaller size plastic flakes. Then the flakes were dried in an oven at 80°C for 12 hours and stored in zip lock bag according to their type [10].

The second step was high shear mixing process, carried out using counter rotating twin screw extruder (Thermo Scientific™ HAAKE™ Rheomex CTW 100 OS Twin-Screw Extruder). The extrusion temperature was 120°C and the screw rotation speed was 250 rpm to induce the shear mixing. The maximum rotation speed of the machine was 250 rpm and the commonly used mixing speed was about 80–120 rpm. The die of the extruder was slit type with dimensions of 1 mm thickness and 50 mm width. The plastic materials were weighed in ratio 1:1:1:1 and then manually mixed and stirred by hand to obtain a homogenous mixture of flakes in a container. Then it was poured into the feeder of counter rotating twin screw extruder. The plastics were extruded into sheets with dimensions depending on the dimension of the die slit [10], cooled down to the room temperature, and crushed to smaller flakes using the crusher. The raw products of HSM were dried in an oven at 65°C for 24 hours [11].

In the next step the mechanical properties of HSM product were investigated. The raw materials obtained from extruder were formed into the stick samples during the thermal compression process [12]. In this process they were poured into 3 mm thick popsicle stick mold and compressed using the hot press machine (LABTECH Engineering Company LTD). The conditions of the process were as follows: pressure 6.9 MPa, processing temperature 180°C, preheating time 2 minutes, venting time 6 minutes, pressing time 6 minutes, and cooling time 5 minutes [13].

The samples for Izod impact tests were notched at 45° using Izod impact test machine. The speed of pendulum was 3.49 m/s with a weight of 0.61 kg. For flexural properties measurements the samples were tested using universal tensile test machine (Testo metric M500-50CT). The test was performed at a constant strain rate of 150 mm/min.

RESULTS AND DISCUSSION

Figure 1 shows the comparison of impact properties of various polymer blends and HSM blend. The impact

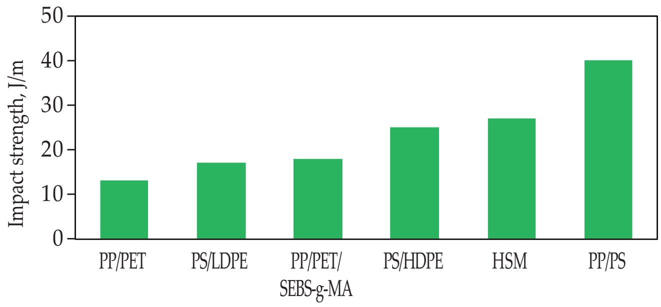

Fig. 1. Comparison of various polymer blends impact strength

strength of HSM blend was 27 J/m, which is quite good in comparison with the others. The lowest one was for PP/PET mixture [14], which had only 48% of the impact strength of HSM blend. PP/PS blend [15] had the highest impact strength in comparison with the others; it was the effect of very high impact resistance of PP, which improved the impact strength of PP/PS blend. The blend had 40% more of impact strength when compared to HSM. On the other hand, the PS/HDPE blend [15] had almost the same impact strength as the HSM blend – the difference was only 9%. In comparison with blend of PS/LDPE [16], the HSM blend had 58% higher impact resistance. The impact strength of HSM blend was almost double of the PP/PET value. HSM, as the mixing method which didn't use any compatibilizer, made blend with the 33% increase in impact strength in comparison with PP/PET/SEBS-g-MA [14], obtained with the use of compatibilizer.

Based on the results given above it may be stated that the use of PET and PP in HSM method might compensate the low impact strength of PE and the high shearing inside the barrel of twin screw extruder might also affect the quality of all four polymers' blend. Due to the low temperature of the HSM process, the higher melting point polymers such as PET might not have been melted completely and therefore might have been dispersed in the PP, PE, and PS matrix acting as fillers strengthening the blend.

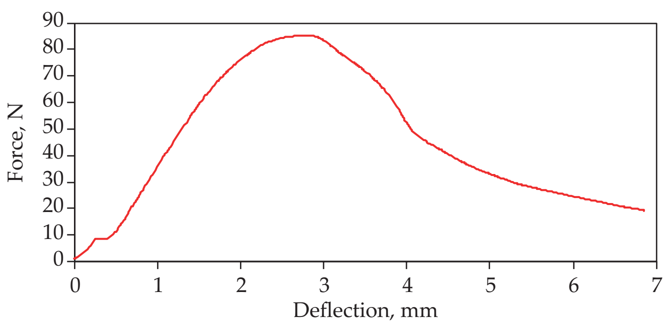

Fig. 2. Flexural stress-strain curve of HSM blend

In Fig. 2 it is shown that HSM blend doesn't exhibit a typical flexural behavior. The most noticeable difference is a slight scission at the beginning. This phenomenon could be related to the rearrangement process of the polymer chain under stress. During this process, the agglomerated polymer chains would tend to align under the applied force resulting in stronger polymer chain structure, so after the end of the process greater force would be required to bend the polymer. That resulted in the sharp increase in force after the slight flattening of the curve [10].

Based on Fig. 3 it may be stated that the flexural properties of HSM blend were better in comparison with the other composites. The HSM blend peak strength was 70.3 MPa, which was 66.6% higher than the value of PE/PVC(15wt%) [17] and 51.7% higher than the value of PE/PP(15wt%) [17]; both samples were blended in a friction stir process. In comparison with a virgin PP [18] flexural strength of HSM blend was about 10.5% higher. Comparing to the other polymer blends, HSM possessed 7% higher strength than PS/PMMA (20wt%) [19], 14.7% higher than PP/HDPE (20wt%) [18], and 46% higher than PS/PP (20wt%) [19]; all of these blends were produced using conventional low speed high temperature mixing.

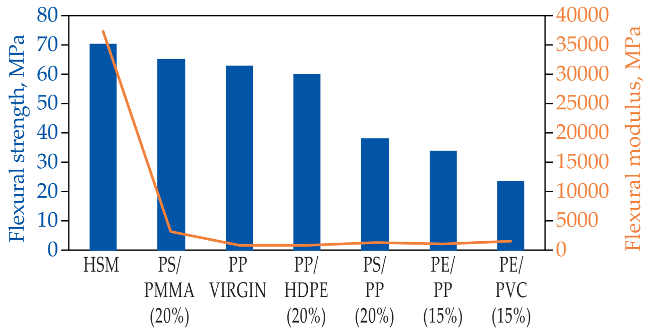

Fig. 3. Comparison of flexural strength and modulus of various polymer blends

Flexural modulus describes how much a material can withstand bending under load. Its value for HSM blend was 37 116 MPa, which was 91% more than the closest comparable value obtained for PS/PMMA(20wt%). On the other hand, for the other blends flexural modulus was less than 5% compared to HSM blend.

CONCLUSION

The properties of the blend obtained by HSM method without using compatibilizers are comparable to the other types of polymer blends, even exceeding some blends made by using the conventional slow mixing method. In comparison with other types of polymer blends obtained using other methods, HSM blend exhibited better flexural strength and very high flexural modulus.

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