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Study on Tensile Strength of High-Density Polyethylene/ Polyethylene Terephthalate Blend

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Abstract. This paper studies and evaluates the mechanical properties of a blend of Polyethylene terephthalate (PET) and high-density polyethylene (HDPE). The HDPE/PET blends are prepared by injection molding PET into HDPE with a ratio of 0%, 10%, 20%, and 30%, respectively. After the injection molding, the samples are measured for tensile strength according to standard D638. As a result, the tensile values of HDPE/PET gradually decreased with the ratio of 0%, 10%, 20%, and 30% (PET) and 18.45, 17.31, 15.45, and 14.43 MPa, respectively. It was shown that the tensile strength of the HDPE/PET composite decreased gradually as the PET percentage increased because the penetration of PET in the HDPE structure increased the elastic modulus of the PET ratio, leading to a decrease in tensile strength. The packaging is known to be mostly blown from HDPE, which has many outstanding features. However, some disadvantages exist, such as low bending strength, low heat distortion temperature, low transparency, and, most importantly, packaging. The packaging blown from HDPE is unstable. This problem is a limited application of HDPE in the packaging industry. To improve the recycling of plastic packaging from HDPE, adding PET is the most effective way. PET plastic packaging is transparent, flexible, toxic, and difficult to recycle, so it can only be used once. Incorporating PET into HDPE will improve the transparency and mechanical properties of HDPE and reduce the cost of PET plastic, and reduce environmental pollution.

Keywords. High-Density polyethylene, polyethylene terephthalate, HDPE/PET blend, tensile strength, blend.

1. Introduction

The plastic industry is currently considered a growing industry in the world economy. The demand for plastic materials is increasing, replacing other materials in packaging, household appliances, and construction materials because of their low cost and ease of manufacture. Now, the packaging technology industry has a high demand. It is widely used, but the production of plastic packaging currently still has limitations, such as low

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transparency and difficulty in shaping when blowing packaging. Researching and developing plastic materials capable of bearing loads at high deformation to improve the limitations of packaging production is an essential and exciting goal [1,2].

High-Density Polyethylene (HDPE) is a widely used material in the plastic industry. HDPE has a high tensile strength at deformation, impact resistance, low friction, and chemical resistance coefficient, is lightweight and highly durable, and widely used in marine biology, packaging, industry, pipe systems, water, beverage, and consumer industry. Besides, HDPE also has characteristics affecting production quality that need to be limited, such as HDPE low heat resistance, flammability, and difficulty in bonding with other compounds. To improve the research disadvantages, this study was conducted by mixing with another substance to give the desired properties of HDPE. It was aimed at enhancing its ability to withstand tensile stress at high strain to meet production needs.

Polyethylene Terephthalate (PET) is widely used in canned goods and plastic bottles with advantages such as flexibility, high-temperature resistance, non-break, high abrasion hardness, and lightweight. It also saves costs when shipping products using PET packaging and is an ideal material for recycling [3]. Besides advantages, PET has disadvantages such as poor gas and oil repellency and easy oxidizing. Furthermore, PET plastic is more difficult to recycle than other plastics, and PET also causes pollution during production [4-6].

Besides the advantages and disadvantages of each type of plastic material applied in each field, meeting the demand for use will be limited by weaknesses. Therefore, some methods have been conducted to improve the advantages of fabrics and overcome the disadvantages to meet widely in many manufacturing industries, such as injection molding, extrusion, compound oxidation, and radiation [7]. The more commonly used and popular method is mixing blends of substances by injection molding, such as PE mixing with the HDPE by Mbarek et al. [8] or EMA mixing by Fasce et al. [9].Through many studies, PET has a better effect on HDPE than others, such as Mr. Antonio et al. showed that the addition of PET resins to HDPE reduces the effective stiffness of the blends and HDPE/PET recycling helps to minimize surface roughness but provides a higher bond condition between HDPE/PET and gives specific mechanical strength such as flexural strength, impact toughness of the composite that has been increased and highly effective [10]. Koleoso et al. [11] researched the solubility and waterproofing between HDPE and PET when added to the copolymer. In parallel with these studies, Guillermina et al. [12] showed that the compatibility of HDPE and PET significantly improved mechanical properties when oxidized. The compatibility between HDPE and PET was also enhanced in the study of Mariano [13].

Although several studies have shown improved solubility and mechanical properties of HDPE, it needs to be clarified how much of an improvement in the tensile strength of the compound is. This research measures and explains the change in tensile strength when mixing PET into HDPE proportionally. Besides, it also serves as a reference for students and materials researchers.

2. Materials and Methods

The study used mainly two primary materials, HDPE and PET (figure 1). The purpose of incorporating PET into HDPE is to effectively improve the mechanical properties, namely the tensile strength of HDPE. HDPE plastic is made in Thailand by A Dong

ADG Joint Stock Company providing HDPE plastic code (2308J). PET plastic code (GO80A) provided by My Toan Trading and Production Co., Ltd.

The process also affects the mechanical properties of the composite, so differences in mechanical properties, precisely the tensile strength of the blends, must be considered during the prototyping process. Conduct injection molding, bring the product to mince and dry, then install molding again to reach the finished product and measure the tensile strength. Dry the chopped plastic after pressing at 120 °C for 4 hours for best results. Injection temperature also affects the finished product. It was conducted injection molding of dried plastic at a temperature of 270 °C. The proportions of the blends are shown in table 1.

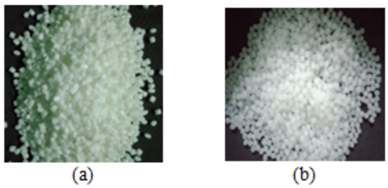


Figure 1. Two primary materials in the research (a) PET, (b) HDPE

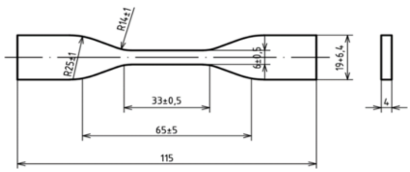


Figure 2. Sample size for tensile test according to ASTM D638 standard.

Table 1. The concentration of materials used in the experiment (wt.%)

Sample name	HDPE (wt.%)	PET (wt.%)
HDPE	100	0
PET10	90	10
PET20	80	20
PET30	70	30

After injection molding is completed, the tensile test process is according to ASTM D638-02 standard (figure 2) with a Shimadzu tensile tester. Randomly select five models for each measurement case and must ensure ambient temperature and humidity conditions. To measure, it is necessary to attach the part to the two clamps and tighten the two clamps to fix the part. Then measure and record the final result and take the part out of the machine.

3. Results and Discussion

3.1. Specimen Details

Figure 3 indicates the samples before and after the tensile test. Some models of PET20 and PET30 ratios have warping and concave surfaces in the first samples when injection molding. This phenomenon is because the lower melting temperature of PET leads to an increase in the cycle time. This problem can be handled by increasing the duration of each cycle or adjusting the cooling system. There are very few cases of mold jamming in the injection molding process. In summary, the cycle time increases when increasing the PET content in the HDPE/PET blend. To ensure the requirements in terms of size and time, it is required that the operator must have experience in the field of injection molding—specifically, the adjustment of the cooling system to optimize the time for each cycle.

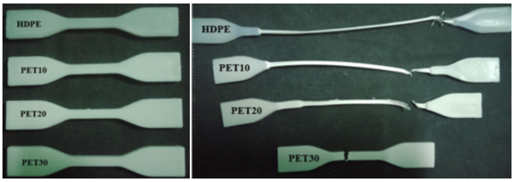
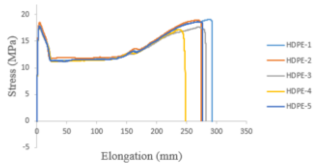


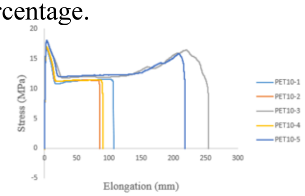
Figure 3. Sample (a) before and (b) after the tensile test.

3.2. Tensile Strength

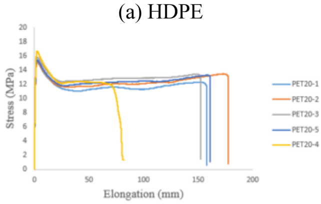
The stress-strain of tensile strength of samples HDPE/PET was demonstrated in figure 4. It can be seen that the PET30 curve differs from the rest. Precisely, the curve of PET30, when reaching the peak, only stretched a small part and then returned to 0; for HDPE, PET10, and PET20 samples, the curve after peaking decreased gradually to about 10-12 MPa. However, since at the value of 30% elongation, the stress value increases proportionally to the strain. Since HDPE has a fiber bond form when stretched to a certain length, the links will be arranged orderly, increasing the tensile stress. Figure 5 illustrates the average stress-strain curves of HDPE/PET samples. When the PET percentage is 10%, the maximum elongation is only 220%; when the PET percentage is increased to 20%, the entire extension is 180%. The study by Y. Pietrasanta et al. [14] stated that when increasing the PET content, the long-lasting expansion of the HDPE/PET mixture will decrease because HDPE and PET are two incompatible polymers; their mixing creates a brittle material. So, the tensile strength of HDPE will decrease with the addition of PET percentage.



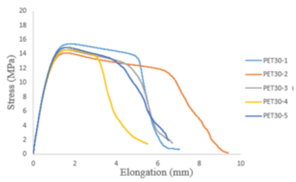
(a) HDPE



(b) PET10



(c) PET20



(d) PET30

Figure 4. Stress-strain curves of tensile strength of HDPE/PET samples.

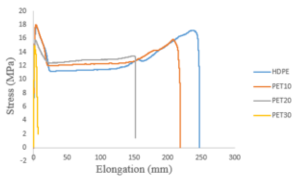


Figure 5. Average stress-strain curves of HDPE/PET samples.

Figure 6 shows the average tensile strength of the PET/HDPE sample. The tensile strength decreased when increasing the PET percentage in the HDPE/PET blend. Specifically, the tensile strength of the largest HDPE of 19.06 MPa decreased to 14.15 MPa for the sample HDPE/30% PET blend, indicating a reduction of 4.91 MPa compared to neat HDPE. The study by Guillermina Burillo et al. explained the change in characteristics compared to HDPE because the penetration of PET in HDPE is not strong enough to increase the tensile strength of the mixture. Besides, the deformation of the models also decreased but not evenly between the ratios when the PET percentage in the blends increased. The figure also presents a gradual decrease in tensile strength from 17.31 MPa to 14.73 MPa with the addition of PET percentage, a 14% decrease compared to neat HDPE. Guillermina Burillo et al. state that the reduction of tensile strength with increasing PET percentage can be explained by the fact that both HDPE and PET are incompatible polymers [15]. In the study by Mr. Karoly Dobrovszky et al. [16], this phenomenon can be explained by viscosity properties since HDPE used can be characterized by low flowability and thermal stability at 275 °C. At the same time, PET has a smaller size and density at the same temperature. Therefore, it is challenging to create a continuous matrix structure. Still, only a dispersed network in the blends, leading to an uneven reduction when increasing the PET percentage in the blends.

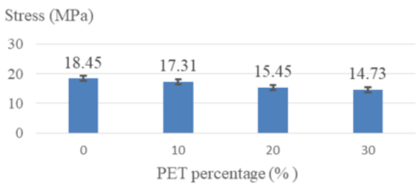


Figure 6. Average tensile strength of PET/HDPE sample.

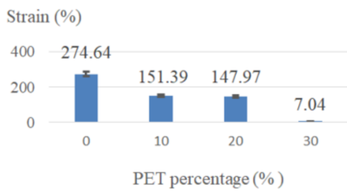


Figure 7. Average tensile modulus of PET/HDPE sample.

The average deformation of the ratios by PET percentage is described in figure 7. Just as the tensile strength gradually decreases stress with increasing PET percentage in the HDPE/PET blend, the strain decreases, as does the tensile strength, but the difference is much more significant here. When increasing the PET percentage, the most considerable deformation is in the 10% PET sample, 151.39%, and the smallest is in the sample with 30% PET, 7.04%. This result shows a 47.44% reduction in strain compared to neat HDPE.

4. Conclusions

The effect of PET percentage in HDPE/PET blends on tensile strength has been studied, and conclusions have been drawn. The tensile strength and deformation decreased when the amount of PET in the blends increased. It shows that the PET percentage in the HDPE/PET composite is not proportional to the tensile strength and strain. When the PET percentage increased from 10% to 30%, the tensile strength decreased from 17.31 MPa to 14.73 MPa. HDPE has a high strain resistance at high strain. This property is rarely found in other plastics, so HDPE is a suitable material to replace materials subject to high deformation and needs further research.

Acknowledgments

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References

[1] Loultcheva MK, Proietto M, Jilov N, La Mantia FP. Recycling of high density polyethylene containers. Polymer Degradation and Stability. 1997; 57(1): 77-81.
[2] Hong-Nga TP., Van-Thuc N. Effect of calcium carbonate on the mechanical properties of polyethylene terephthalate/polypropylene blends with styrene-ethylene/butylene-styrene. Journal of Mechanical Science and Technology. 2020; 34(10): 3925-3930.
[3] Tamburini E, et al. Plastic (PET) vs bioplastic (PLA) or refillable aluminum bottles – What is the most sustainable choice for drinking water. A life-cycle (LCA) analysis. Environment Research. 2021; 196.
[4] Nga THP, Van-Thuc N. A study of morphological and mechanical properties of poly (butylene terephthalate)/High-density polyethylene blends. Advances in Materials Science and Engineering. 2020.
[5] Marin-Genesca M, et al. Application properties analysis as a dielectric capacitor of end-of-life tire-reinforced HDPE. Polymers. 2020; 12(11): 2675.
[6] Nguyen LK, et al. Uncertainty in the life cycle greenhouse gas emissions and costs of HDPE pipe alternatives. Resources, Conservation and Recycling. 2020; 154: 104602.
[7] Herrera-Franco PJ, et al. Dynamic mechanical properties of compatibilized PET with radiation oxidized HDPE. Polymer Bulletin. 2006; 56: 47-52.
[8] Mbarek S, Jaziri M, Chalamet Y, Elleuch B. Dispersed phase morphology and fractionated crystallization of high-density polyethylene in PET/HDPE blends. International Journal of Material Forming. 2009; 2(1): 15-24.
[9] Seltzer Rocio, Frontin P, et al. Mechanical and fracture characterization of 50:50 HDPE/PET blends presenting different phase morphologies. Polymer Engineering and Science. 2005; 45(3): 354-363.
[10] A´vila AF, et al. A mechanical analysis on recycled PET/HDPE composites. Polymer Degradation and Stability. 2003; 80(2): 373-382.
[11] Omeje HO. Production of ceiling tile with high density polyethylene (HDPE) and polyethylene terephthalate (PET) plastic wastes as main ingredients. Journal of Engineering and Applied Sciences. 2019; 15(1):114-127.
[12] Burillo G, Herrera-Franco P, Vazquez M, Adem E. Compatibilization of recycled and virgin PET with radiation-oxidized HDPE. Radiation Physics and Chemistry. 2002; 63(3-6): 241-244.
[13] Pracella M, Rolla L, Chionna D, Galeski A. Compatibilization and properties of poly(ethylene terephthalate)/polyethylene blends based on recycled materials. Macro Molecular Chemistry and Physics. 2002; 203(10-11): 1473-1485.
[14] Pietrasanta Y, et al. Reactive compatibilization of HDPE/PET blends by glycidyl methacrylate functionalized polyolefins. Macromolecular Chemistry and Physic. 1999; 200(1): 142-149.
[15] Burilloa G, et al. Compatibilization of recycled and virgin PET with radiation-oxidized HDPE. Radiation Physics and Chemistry. 2002; 63(3-6): 241-244.
[16] Dobrovszky K, Ronkay F. Effects of SEBS-g-MA on rheology, morphology and mechanical properties of PET/HDPE blends. Polymer Processing Society. 2015; 30(1): 91-99.