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Article

Unnotched impact toughness of polybutylene terephthalate/polyamide 6/carbon black blends

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Abstract: The combination of polybutylene terephthalate (PBT) and polyamide 6 (PA6) plastic mixture was taken from waste from the table production process along with carbon black (CB) reinforcement with the desire to create a potential plastic mixture widely used in many fields. The PBT/PA6/CB mix is created by injection molding with a CB weight ratio of 0%, 4%, 8%, and 12%. This study has shown the change in plastic's mechanical properties when adding CB to the mixture by testing the unnotched impact toughness according to ASTM D256 standards. Research results show that the unnotched impact toughness was gradually reduced when increasing the CB content in the mixture from 0% to 12% CB. Specifically, at 0% CB, the resulting unnotched impact toughness was 12.85 kJ/m^2, reduced to 4.78 kJ/m^2.

Keywords: PBT; PA6; carbon black; PBT/PA6 blend; unnotched impact toughness

1. Introduction

Annual plastic waste from human activities is one of the causes of global warming and is seriously threatened [1]. This problem also gives scientific researchers a headache when studying how to handle that amount of plastic waste to prevent direct discharge into the environment and protect the human living environment. Currently, researchers around the world are working on doing that. The research team researched the recycling of PBT and PA6 materials for clean and green earth. The idea for this research originated from knowing that toothbrush bristles are usually made of two main types of plastic: PBT and PA. During production, a large amount of plastic waste is created from the cutting process for fur shaping. That plastic will no longer be used, causing a waste of resources and costs for waste treatment. The research team aims to use the discarded plastic waste after recycling it to be used in the electrical, automotive, and household appliances industries.

PBT is a thermoplastic that belongs to the polyester terephthalate family. PBT is also very popular due to its outstanding properties, such as good mechanical performance, electrical insulation, and water resistance [2,3]. From the above points, the research team sees this plastic material's high practicality and benefits. However, in addition to the advantages of PBT, there are still disadvantages, such as low heat distortion temperature and ease of flexural. It is warping due to mold shrinkage, low solvent absorption, and low unnotched impact toughness. Therefore, the application of PBT is limited by working conditions with solid impacts or some harsh conditions, such as high-temperature environments [4,5].

PA6 is a widely used semi-crystalline polymer due to its technical benefits, such as its high heat distortion temperature, good chemical resistance, high strength and hardness, and abrasion resistance. In contrast to PBT, PA6 has superior mechanical properties.

The research team used mixing two types of plastic, PBT and PA6, to improve their disadvantages while maintaining the good properties of each kind of plastic [6–9]. However, the compatibility between these two types of plastic, PBT and PA6, could be better, leading to the low durability of this mixture. Therefore, a study is needed to improve this plastic mixture to enhance its mechanical properties and meet the technical requirements of the product. In this study, the research team used CB as a filler. Reinforcement for the PBT/PA6 plastic mixture. CB is a relatively new filler in the plastics industry, so more detailed research is needed on this type of filler. This filler is also a big challenge for the research team. However, detailed information about this type of filler is essential for today's plastic recycling industry, where the source of recycled materials is highly abundant. Information about the influence of CB on the PBT/PA6 mixture helps plastic recycling businesses have a better basis to perfect their products and improve economic efficiency from recycled materials. This study will minimize the negative impact of plastic waste on the environment and contribute to sustainability in production.

In short, this research can solve the remaining PBT and PA6 wastes to create usable products. Furthermore, this study provides more detailed information about the PBT/PA6/CB mixture, a reference source that contributes to the basis for future research on polymer blends.

Revolving around the issue of improving the properties of polymer mixtures, many researchers have implemented a third method of adding fillers. Typically, in the study of Nga et al. [10], researchers have shown that glass fiber combined with the PBT/PA6 mixture gives this plastic mixture better tensile strength and more durability. Fire resistance is thanks to the properties of fiberglass. In the research paper by Nga [11], the author concluded that activated carbon makes the microstructure smaller and finer, enhances cohesion, and improves the mechanical properties of the PBT/PA6 mixture. This study shows that each type of filler will change the internal structure, leading to different physical and mechanical properties. Research by Li et al. [12] has investigated PBMMA particles as strength modifiers and compatibilizers used to harden the PA6/PBT mixture to increase the unnotched impact toughness of this mixture. Research continues to demonstrate fillers' role in improving the mechanical properties of PBT/PA6 composites. However, this study still needs some information about mechanical and flexural properties. In the paper of Jubinville et al. [13], researchers reported that the compatibility and tensile strength of the PBT/PA6 blend were improved by adding the renewable bio-derived PA11 compatibilizer. However, the research team found that the most significant barrier to this research is the high cost of PA11, leading to low production feasibility.

Meanwhile, the research paper of Li et al. [14] presented research results on a PBT/PA6 mixture combined with carbon black as a filler, helping to improve tensile strength when mixed with 6% CB. However, this study does not specifically state or provide more detailed information about the effects of CB on the entire plastic mixture; instead, it simply studies the electrical conductivity of the entire plastic mixture. In the article on the non-isovolumic viscoelastic properties of PBT/PA6 [15], researchers have shown that the Poisson's ratio when plastic deformation of PBT/PA6 is less than 0.5 and the plastic properties of PBT and PA6 are not isovolumic. The article by Yang et al. [16] has successfully researched the PA6/GF mixture that can increase fire resistance and is environmentally friendly with fireproof properties and a fireproof index reaching UL94-V0. From previous studies, the research team realized that studying the influence of CB on the PBT/PA6 mixture is necessary to have a more detailed view of this new material.

This research holds immense potential for the recycling of plastic waste from PBT and PA6 sources. By ensuring the production of high-quality products with excellent mechanical properties, we can significantly enhance the economic value of plastic recycling businesses. Moreover, our ultimate aim is to reduce costs associated with plastic waste treatment and make a substantial contribution to environmental protection, a cause we all deeply care about.

To achieve this purpose, the following objectives need to be achieved:

- To find the CB ratio in the PBT/PA6 mixture that provides the best mechanical properties, the research team will create durability test samples with CB ratios of 0, 4, 8, and 12% by injection molding.
- The research team tested and analyzed the results to determine the unnotched impact toughness of the entire PBT/PA6/CB mixtures.

2. Materials and methods

Research uses three types of materials: PBT, PA6, and carbon black. The materials used in the study are shown in **Figure 1**.

(a) **(b)** **(c)**

Figure 1. Materials used in research: **(a)** PBT; **(b)** PA6; **(c)** black.

Through research, choose the plan and mix it according to the ratio in **Table 1**.

Table 1. Mixing ratio of PBT/PA6/CB blend.

Samples	PBT (wt.%)	PA6 (wt.%)	Carbon black (wt.%)
0CB	75	25	0
4CB	72	24	4
8CB	69	23	8
12CB	66	22	12

The machine used to measure unnotched impact toughness is shown in **Figure 2**.

Before measuring, after performing injection molding, randomly select five samples for each ratio. Before performing the measurement, ensure that the measurement environment is at a temperature of 23 ± 2 °C and a relative humidity of

50% ± 5%. Laboratory samples should be stored for at least 40 h.

Figure 2. Tinius Olsen impact testing machine for measuring sample unnotched impact resistance.

Your role in this process is crucial. The first step is to enter measurement parameters into the machine at a 1.59 mm/min speed. To measure, you need to carefully place the part on the machine table and position it securely. Then, measure and record the final result. Take the part out of the machine. Repeat this for each case, ensuring accuracy and consistency in your measurements.

3. Results

The sample used to measure unnotched impact toughness is shown in **Figure 3**.

Figure 3. Sample used to measure unnotched impact toughness.

Table 2 shows the description of the unnotched impact toughness parameters of the sample.

Table 2. Unnotched impact toughness parameters of each sample 75PBT/25PA6/CB.

Sample	0% CB	4% CB	8% CB	12% CB
1	13.64	6.33	10.41	5.63
2	10.17	9.68	9.07	5.09
3	16.06	9.74	5.75	5.82

Table 2. (*Continued*).

Sample	0% CB	4% CB	8% CB	12% CB
4	14.00	9.09	7.06	6.09
5	15.33	12.35	6.80	7.17
6	11.37	8.10	7.26	4.15
7	17.03	9.52	7.23	2.54
8	13.28	9.10	7.29	3.98
9	9.87	12.62	8.88	2.540
10	7.70	10.31	7.91	4.75
Average	12.85	9.69	7.77	4.78
Standard deviation	3.00	1.84	1.34	1.51

The average display of unnotched impact toughness is depicted in **Figure 4**.

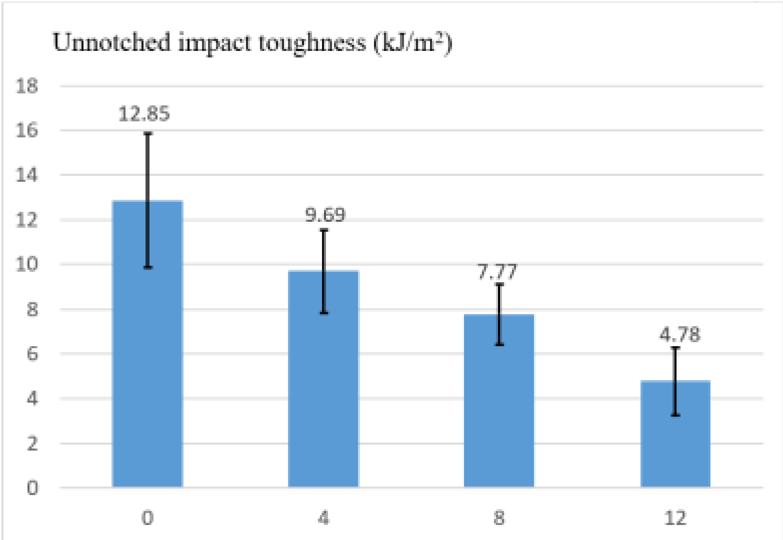

Figure 4. Average unnotched impact toughness of the sample.

Table 2 and **Figure 4** show that the unnotched impact toughness is clearly reduced when carbon black is involved. Initially, the unnotched impact toughness of PBT/PA6 is 12.85 kJ/m^2, and when CB is reinforced at a rate of 4%, 8%, and 12%, the unnotched impact toughness of the sample decreases by 9.69 kJ/m^2, 7.77 kJ/m^2, and 4.47 kJ/m^2, respectively. It can be said that CB can induce variation in the mechanical properties of plastics, but the reinforcement may not be flexible and effective. This result can reduce impact toughness, especially as CB content increases.

Adding the CB measurement function causes the unnotched impact toughness to decrease, as shown in **Figure 4**. It can be said that CB can create a change in the mechanical properties of the plastic, but the reinforcement may not be flexible and effective. This result can reduce impact toughness, especially as CB content increases. Similar research [17] shows that when the PB content increases from 10 to 70% by weight, the unnotched impact toughness of the composite decreases by 72%. When the PB concentration increases, the toughness of the composite material decreases. Incorporating PB particles into HDPE created stress concentration zones requiring less energy to create cracks in the composite, thus reducing unnotched impact toughness.

This effect may indicate reaching the limit when the CB content is excessive. The change of CB into the mixture is similar to the research results [18], showing that the PB content increases by 10%–30%–50% by weight, the flexural strength of the composite increases, and the flexural strength of the material increases. PB/HDPE composite was reduced to 70 wt% PB content, demonstrating that 70 wt% PB content is unsuitable for molding PB/HDPE composites. Thus, we see that the higher the % CB, the more it affects the tensile strength of the material and the flexural strength.

The research results are explained by the factors affecting the mechanical properties of materials when mixed with PBT/PA6/CB. The interaction between CB and polymer affects the flexural strength of the mixture. The limitations of this research are that more than the research time is needed to monitor material changes over a long period, and secondly, due to limited research environmental conditions and costs. To solve the above problems, we need time to monitor the process of changing materials and find the best funding source and research location so that the research process can happen in the best way.

This research and development direction is to expand its scope into the fields of research and production to serve the daily needs of people and today's industries. The difficulties encountered when doing extensive research are difficulties in finding documents, foreign languages, and data processing, in addition to difficulties in finance, equipment, and human resources in expanding research.

4. Conclusion

Overall reliability is improved when adding CB to PBT/PA6, following an increasing and then decreasing trend as CB becomes higher. Therefore, if we want to improve the material, we can add a reasonable CB content with the condition that CB must be less than 12%.

The consistent decrease in unnotched impact toughness with increasing CB content is a crucial finding. It indicates a potential for enhanced durability. Therefore, if the aim is to improve durability and impact, it's advisable to avoid adding CB. This direct influence of CB content on the material's unnotched impact toughness is a key factor to consider, offering a pathway to achieve optimal performance. Furthermore, this research paves the way for exciting future developments in the application of PBT/PA6 materials containing CB in various industries.

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