

Tensile Strengths of Polybutylene Terephthalate/Polyamide 6/Activated Carbon Blend Samples

Pham Thi Hong Nga*

Faculty of Mechanical Engineering, Ho Chi Minh City University of Technology and Education,
No. 1 Vo Van Ngan Street, Linh Chieu, Thu Duc, Ho Chi Minh City 71307, Vietnam

(Received May 29, 2023; accepted January 15, 2024)

Keywords: activated carbon, polyamide 6, PBT, tensile strength, blend

Activated carbon (AC) can be added to a polymer matrix to achieve electrical conductivity, leading to a potential sensor application. In this study, we evaluated the tensile strength of AC when mixed with a polybutylene terephthalate (PBT)/polyamide 6 (PA6) blend. The PBT/PA6/AC composite was prepared by injection molding with 0, 2, 4, 6, 8, and 10% AC. The samples were subjected to a tensile test following the International Organization for Standardization 527 standard. The tensile strengths of the PBT/PA6/2% AC, PBT/PA6/4% AC, PBT/PA6/6% AC, and PBT/PA6/8% AC samples were found to be 45.13, 44.60, 42.48, and 41.82 MPa, respectively. These values are higher than that (40.93 MPa) of the PBT/PA6 blend, which has no AC. Incorporating AC into the PBT/PA6 blend increases the tensile strength. The PBT/PA6/2% AC sample has the highest tensile strength, whereas the PBT/PA6/10% AC sample has a lower tensile strength of 39.79 MPa than the PBT/PA6 blend. All the PBT/PA6/AC samples have tensile moduli higher than that of the PBT/PA6 blend. When adding AC to the PBT/PA6 blend, the microstructure becomes smaller and finer, enhancing cohesion and improving the mechanical properties. A conceivable application area of the approaches analyzed in this work is that the PBT/PA6 blend can be recycled into conductive polymer composites with a small amount of AC.

1. Introduction

Some products such as antistatic plastic tweezers and trays need a high antistatic ability. There have been some studies on antistatic problems by adding antistatic agents such as activated carbon (AC). However, these studies only focused on evaluating the antistatic ability without investigating the product's mechanical properties. Toothbrush filaments are usually made from polyamide (PA) and polybutylene terephthalate (PBT) filaments. A mixed powder of PA and PBT is usually obtained when cutting with a toothbrush surface. The waste from toothbrush filaments currently requires more research. PBT has outstanding mechanical characteristics, such as high strength, hardness, and chemical resistance to a wide variety of solvents, oils, and greases.^(1,2) Francisco *et al.* stated that PBT has a suitable dimensional stability, a low hygroscopicity, and a high insulation resistance.⁽³⁾ In terms of processing, clear

*Corresponding author: e-mail: hongnga@hcmute.edu.vn
<https://doi.org/10.18494/SAM4533>

PBT can be processed in a temperature range from 230 to 270 °C. Although it is a special polymer for injection molding, it has some weaknesses and sensitivities, such as moisture, strong bases, and oxidizing acids. Polyamide 6 (PA6) is a semi-crystalline material. The crystallization fraction results from the amide groups.^(4–6) The high degree of hydrogen bonding between chains in the crystallization region results in PA6 with a high melting point. According to Randhawa's report, PA6 is hygroscopic, which means that it readily absorbs water from its surroundings.⁽⁷⁾ Hygroscopicity harms PA6 by affecting properties and acting as a plasticizer, increasing flexibility.

Reinforced materials are used in thermoset and thermoplastic applications to provide greater stiffness and reduce cost. Strengthening increases the stiffness and strength achieved through the dispersion of inorganic and organic fibers or granular fillers in a polymer matrix. Inorganic fillers are intrinsically stiffer than polymers and have superior properties, including high electrical conductivity, toughness, and thermal deflection.^(8,9) They also increase the strength of the material. Combining the excellent mechanical strength of PA6 with the low water absorption of PBT is a possible way to prepare the material with high comprehensive performance. However, the poor compatibility between PA6 and PBT leads to the low impact strength of the PBT/PA6 composite. According to Li *et al.*, PBT/PA6 is often combined with ethylene vinyl acetate-g-maleic anhydride to overcome this shortcoming.⁽¹⁰⁾ Furthermore, according to Sapsrithong *et al.*, the reaction between PA and PBT with epoxy can improve the mechanical properties of the PA/PBT mixture because this reaction provides an effective compatibilizer to reduce the size of the dispersed phase.⁽¹¹⁾ According to Luyt's report, the ethylene-glycidyl methacrylate copolymer affects the crystallization behavior and crystallinity of the PBT-PA blend.⁽¹²⁾ AC shows high porosity, many cracks, and tiny pores up to the molecular size. Such a particular structure makes the surface area of AC large, from which it is easy to absorb and react with many different substances. AC is created from burning carbon-rich fuels such as wood, coal, coconut shells, and bamboo at high temperatures from 600 to 900 °C under anaerobic conditions. Owing to small cracks and holes, AC quickly physically absorbs impurities, dirt, and pollutants such as chlorine and benzene in water and SO₂, CO₂, and H₂S gas in air, making these substances adhere to the surface of the carbon. The larger the AC surface area, the stronger the attraction. According to Aziz *et al.*, AC has recently been widely studied in wood technology. By both simulation and experimental methods, their study showed that medium-density fiberboard composite samples have a higher strength than plywood composite samples owing to the increased thickness of the AC filler.⁽¹³⁾ Interestingly, AC can be mixed into the polymer matrix to achieve electrical conductivity, leading to a potential sensor application. Sun *et al.* indicated that adding AC to a molecularly imprinted polymer might achieve electrochemical sensing.⁽¹⁴⁾ Xu *et al.* reported a polymer humidity sensor made of chitosan and AC, which was coated on a polyethylene terephthalate substrate.⁽¹⁵⁾ Remarkably, Radhi *et al.* used gamma irradiation to graft acrylonitrile on polystyrene modified with AC, creating a gas sensor.⁽¹⁶⁾

Our research aims to create a specific application for materials from the waste of toothbrush filaments. The usefulness of AC has long been recognized. Combining the excellent mechanical strength of PA6 with the low water absorption of PBT is a possible way to prepare materials with

high comprehensive performance. In this study, AC was combined with a PBT/PA6 mixture to improve the mechanical strength of the PBT/PA6 blend and create a material that inherits the excellent properties of AC.

2. Materials and Methods

In this study, we used three types of plastic material: PBT, PA6, and AC. The PBT plastic (Catalog no. PBT-POCAN B4225), which was obtained from India/China by Lanxess Plastic Company (Germany), was purchased from TA.COMA Co., Ltd. The PA6 plastic (Catalog no. PA6 B33 L09), which was sourced from China by BASF (Germany), was obtained from Phu Hung Plastic Co., Ltd. AC, which was imported from Europe, was supplied by Global Activated Carbon Joint Stock Company. PBT was mixed with PA6 at a ratio of 1:1, then AC was added at concentrations from 0 to 10%, then dried at 85 °C for about 1 to 2 h, with a moisture content of less than 0.03%, followed by injection molding. An injection molding machine, Haitian MA120, was used to create samples. The pieces were subjected to a tensile test according to the ISO 527 standard on the Testometric M500-50 testing machine, using winTest™ Analysis software. The microstructure of the samples was observed using a Hitachi TM4000Plus electron microscope and analyzed with TM4000/TM4000Plus version 1.5 analysis software.

3. Results and Discussion

Figure 1 shows the stress–displacement diagram of the PBT/PA6/AC blend samples. It can be seen that the curve of the AC0 sample is very different from those of the AC2, AC4, AC6, AC8, and AC10 samples. The mechanical properties change markedly with the addition of AC to the PBT/PA6 mixture. Specifically, the AC2, AC4, AC6, AC8, and AC10 samples show curves when they reach the top, then brake suddenly, indicating that they are very brittle. Although these samples have higher tensile strengths, they are easy to break. Compared with these samples, the curve of the AC0 sample is not broken, so it is very flexible. The tensile stress of an object includes many factors, such as two essential factors, namely, the substances that make up the material and particle size. By adding AC to the PBT/PA6 mixture at different ratios, the tensile stress of the mixture is gradually improved. Because AC is difficult to dissolve in the PBT/PA6 mixture, the pressure in the cavity decreases when the AC ratio increases, causing the shrinkage of the specimen to increase. Therefore, the higher the proportion of AC in the mixture, the smaller the sample area because the high shrinkage causes the tensile stress to decrease. Thus, when AC is added to the PBT/PA6 mixture, the bending stress can be stabilized even though the AC percentage changes.

Figure 2 illustrates the average breaking strain of the PBT/PA6/AC samples. When the percentage of AC in the blend increases, the breaking strain decreases gradually. The breaking strain drops sharply from 79.9 to 12% when the percentage of AC increases from 0 to 2%. When the percentage of AC increases from 2 to 4%, the breaking strain decreases slightly from 12 to 10.7%. The breaking strain does not change severely when the percentage of AC increases from 4 to 6%. After that, the breaking strain continuously declines but not much, decreasing by 9.2% when the percentage of AC is improved to 10%.

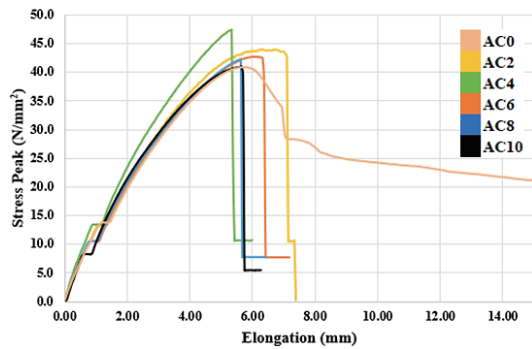


Fig. 1. (Color online) Stress–displacement diagram of PBT/PA6/AC blend samples.

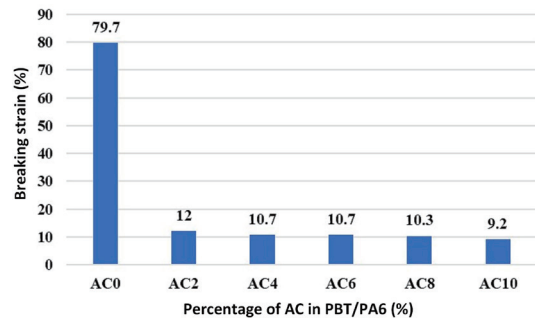


Fig. 2. (Color online) Average breaking strain of PBT/PA6/AC blend.

The average tensile strengths of the samples are shown in Fig. 3. It can be seen that the tensile strength of the PBT/PA6 blend is 40.93 MPa, the tensile strength of PBT/PA6/2% AC is the highest (45.13 MPa), and the tensile strength of PBT/PA6/10% AC is the lowest (39.79 MPa). Thus, when adding 2% AC, the tensile strength of the PBT/PA6 blend increases markedly to 45.13 MPa. This result proves that AC increases the tensile strength of the PBT/PA6 blend. When adding more AC such as from 4 to 8%, the tensile strength decreases slightly compared with that at 2%, but still higher than that of the PBT/PA6 blend. This result shows that the suitable AC content to add to the PBT/PA6 blend ranges from 2 to 8%. If this concentration is exceeded, AC will not be effective. This result is demonstrated at the rate of 10% with 39.79 MPa, which is lower than that (40.93 MPa) of the PBT/PA6 blend. This result shows that the effect of AC varies when combined with various resins, demonstrating that with AC and PP, the percentage of AC and the tensile stress increase, according to Salleh *et al.*⁽¹⁷⁾

Figure 4 indicates the average tensile moduli of the PBT/PA6/AC blend samples. Incorporating AC into the PBT/PA6 blend significantly improved the modulus of elasticity. All the samples with AC have higher results than the PBT/PA6 blend (930.35 MPa). When the AC volume fraction is small, AC incorporation has a slight effect on AC reinforcement (up to 4%) and the impact of AC aggregation on AC reinforcement becomes significant (1162.43 MPa). However, when the percentage of AC is 6%, the elastic modulus of the mixture decreases again as the percentage of AC increases. When the percentage of AC is increased to 8–10%, the elastic modulus of the cross is increased again. This result can be due to the decreased AC aggregation with an increased number of filler particles. Hu *et al.* said that this can narrow the intergranular space.⁽¹⁸⁾ The molecules between two adjacent carbon particles are strongly expanded owing to their separation accompanied by sliding and molecular orientation.⁽¹⁸⁾

The microstructure of the PBT/PA6/AC blend is revealed in Fig. 5, which shows circular holes with hemispherical shapes due to the poor surface alignment between the PBT matrix and PA6 particles. This phenomenon explains the tensile strength results mentioned above. Microcracks quickly develop into large cracks, causing rapid and unstable destruction. When AC is added to the PBT/PA6 mixture, the number of PA6 particles increases, the PA6

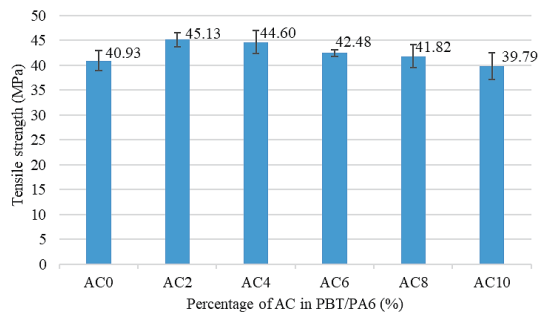


Fig. 3. (Color online) Average tensile strength of PBT/PA6/AC blend.

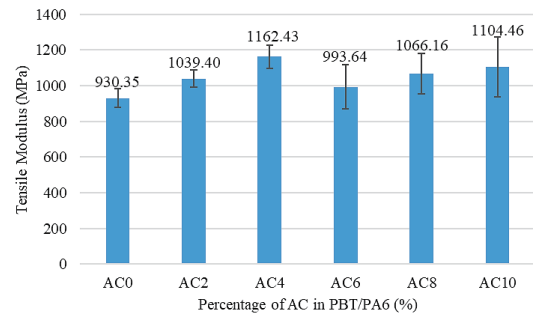


Fig. 4. (Color online) Average tensile modulus of PBT/PA6/AC blend.

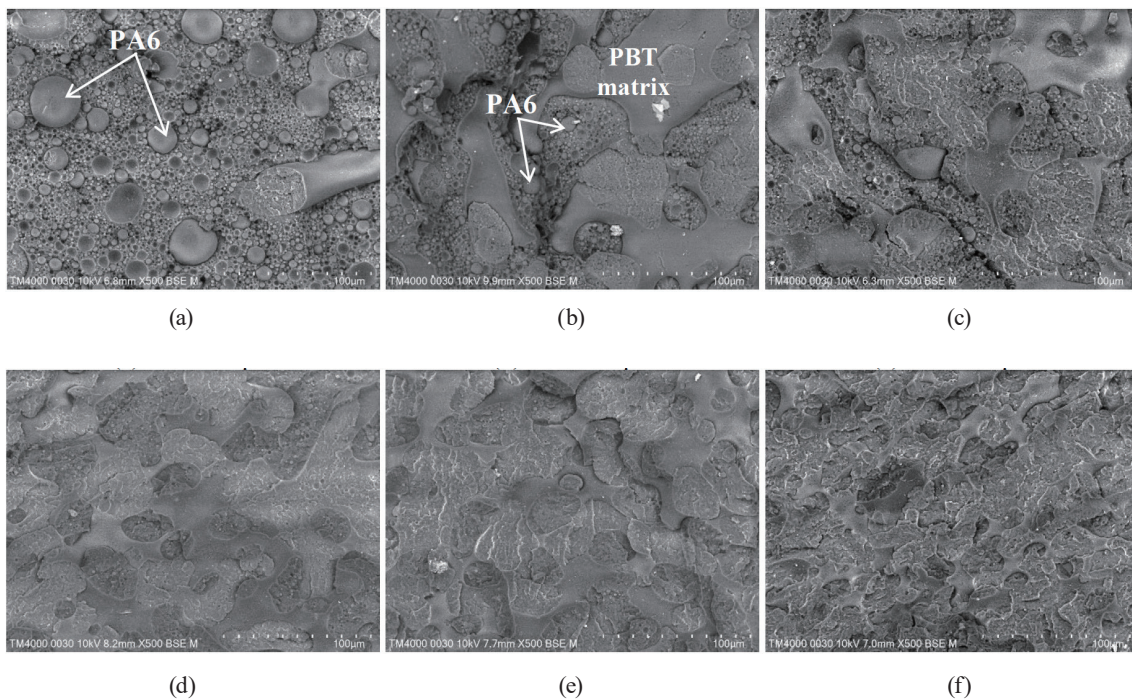


Fig. 5. Microstructure of PBT/PA6/AC blend. (a) AC0 sample, (b) AC2 sample, (c) AC4 sample, (d) AC6 sample, (e) AC8 sample, (f) AC10 sample.

particle size decreases, and black holes gradually thin out and disappear. The surface of the mixture becomes smoother than that of the AC0 sample, enhancing the cohesion and improving the mechanical properties. Salleh *et al.* clearly showed the presence of AC in the PP/AC mixture, thereby showing the scattered and uneven distribution of AC, which partly affects the general mechanical properties.⁽¹⁷⁾ AC particles can create a conductivity blend. Therefore, the blend can be used as a potential material for sensing applications.^(14–19) Further investigations should be conducted to determine this capacity.

4. Conclusions

In this study, we assessed the tensile strength of a PBT/PA6 mixture supplemented with AC. The PBT/PA6/AC blend's tensile strength is mostly increased by the addition of AC. The highest tensile strength of 45.13 MPa, or 10.3% more than that without AC, is achieved by the PBT/PA6/AC combination at 2% AC. However, the tensile strength of the PBT/PA6/AC blend gradually decreases as the percentage of AC is increased from 4 to 10%. The tensile modulus increases sharply from 930.35 to 1162.43 MPa when 4% AC is added to the PBT/PA6/AC blend. When adding AC to the PBT/PA6 mixture, the number of PA6 particles increases, the PA6 particle size decreases, and the microstructure becomes smaller and finer, enhancing the cohesion and improving the mechanical properties. The PBT/PA6 blend can be recycled into conductive polymer composites with a small quantity of AC, a potential material for sensor applications, and needs further investigation.

Acknowledgments

We acknowledge the Ho Chi Minh City University of Technology and Education, and Material Testing Laboratory. They gave our research team an opportunity to join their team and access the laboratory and research machines.

References

- 1 K. A. Deshmukh, S. Chopra, P. Khajajji, A. Deshmukh, and D. R. Peshwe: *Polym. Bull.* **79** (2022) 381. <https://doi.org/10.1007/s00289-020-03501-z>
- 2 F. Tischer, B. Düsenberg, and J. Kaschta: *Polymers* **14** (2022) 810. <https://doi.org/10.3390/polym14040810>
- 3 D. L. Francisco, L. B. Paiva, and W. Aldeia: *Polym. Compos.* **40** (2019) 851. <https://doi.org/10.1002/pc.24837>
- 4 N. T.-H. Pham: *Polym. Sci. A* **63** (2021) 800. <https://doi.org/10.1134/S0965545X21060080>
- 5 N. T.-H. Pham and V.-T. Nguyen: *Adv. Mater. Sci. Eng.* **2020** (2020). <https://doi.org/10.1155/2020/8890551>.
- 6 N.-T. Tran and N. T.-H. Pham: *Int. J. Polym. Sci.* **2021** (2021). <https://doi.org/10.1155/2021/7635048>
- 7 K. S. Randhawa: *Ceram. Int.* **48** (2022) 29340. <https://doi.org/10.1016/j.ceramint.2022.05.370>
- 8 W. A. Pisani, D. N. Wedgeworth, M. R. Roth, J. K. Newman, and M. K. Shukla: *J. Phys. Chem. C* **125** (2021) 15569. <https://doi.org/10.1021/acs.jpcc.1c03410>
- 9 E. Esmizadeha, A. Vahidifarb, S. Shojaiehb, G. Naderic, M. R. Kalaeid, and T. H. Mekonnena: *Mater. Today Commun.* **26** (2021) 102027. <https://doi.org/10.1016/j.mtcomm.2021.102027>
- 10 H. Li, J. Wang, G. Li, Y. Lu, N. Wang, Q. Zhang, and X. Qu: *Polym. Adv. Technol.* **28** (2017) 699. <https://doi.org/10.1002/pat.3969>
- 11 P. Sapsrithong, T. Sritapunya, S. Tuampoemsab, A. Rattanapan, and M. Nithitanakul: 6th Int. Conf. on Advanced Engineering and Technology (ICAET 2019) **811** (2020) 012019. <https://doi.org/10.1088/1757-899X/811/1/012019>
- 12 A. S. Luyt: *Polyolefin Compounds and Materials* (Springer, 2016) pp. 107–156. https://doi.org/10.1007/978-3-319-25982-6_5
- 13 N. A. A. Aziz, M. Mohamed, M. Mohamad, M. H. M. Amini, M. S. A. Aziz, H. Yusoff, and Z. I. Rizman: *ARPN J. Eng. Appl. Sci.* **10** (2015) 376.
- 14 B. Sun, X. Hou, D. Li, Y. Gou, F. Hu, W. Li, and X. Shi: *J. Electrochem. Soc.* **166** (2019) B1644. <https://doi.org/10.1149/2.1141915jes>
- 15 Z. Xu, D. Zhang, X. Liu, Y. Yang, X. Wang, and Q. Xue: *Nano Energy* **94** (2022) 106881. <https://doi.org/10.1016/j.nanoen.2021.106881>
- 16 M. M. Radhi, W. T. Tan, M. Z. B. Ab Rahman, and A. B. Kassim: *Sci. Res. Essays* **7** (2012) 790. <https://doi.org/10.5897/SRE11.1286>

- 17 Z. Salleh, M. M. Islam, M. Y. M. Yusop, and M. A. Mun'aim M. Idrus: APCBEE Procedia **9** (2014) 92. <https://doi.org/10.1016/j.apcbee.2014.01.017>
- 18 X. L. Hu, Y. Ouyang, X. Zhou, and W. B. Luo: Adv. Mat. Res. **284–286** (2011) 1969. <https://doi.org/10.4028/www.scientific.net/AMR.284-286.1969>
- 19 Z. Salleh, M. Y. M. Yusop, M. M. Islam: 12th Int. Conf. Frontiers of Polymers and Advanced Materials (2013) 86.