Bitlis Eren Üniversitesi Fen Bilimleri Dergisi
BİTLİS EREN UNIVERSITY JOURNAL OF SCIENCE
ISSN: 2147-3129/e-ISSN: 2147-3188
VOLUME: 11 NO: 3 PAGE: 846-856 YEAR: 2022
DOI: 10.17798/bitlisfen.1126615

The Mechanical and Thermal Behavior of Electrostatic Powder Coating Waste Reinforced Epoxy Composites

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Keywords: Waste utilization, Epoxy, Composite, TGA, Mechanical Properties.

Abstract

The present study investigates the mechanical and thermal behavior of polyurethane electrostatic powder coating waste reinforced epoxy composites. Different percentages of electrostatic powder coating waste (3, 6, and 9 wt. %) reinforced epoxy composites were manufactured. The mixture of polyurethane powder coating waste and epoxy was mixed with a magnetic stirrer to ensure that the polyurethane powder coating waste was dispersed well in the epoxy, and then the mixture was placed under vacuum and air bubbles were removed. Tensile and three-point tests were performed to determine the changes in the mechanical properties of the materials, and thermogravimetric analysis was conducted to determine the thermal properties. In addition, images were taken with scanning electron microscopy for morphological features. The study revealed that the three-point flexural strength was increased by up to 8% and 15%, respectively, in the samples with 3 wt% and 6 wt% powder coating waste additives. The material's tensile strength decreased by up to 27% with powder coating waste reinforcement. However, the opposite trend was observed in the modulus of elasticity. Additionally, no significant difference was observed in the thermal properties of the materials. Also, from scanning electron microscopy analysis, it was observed that the inclusion of powder coating waste changed the damage mechanism of the material.

1. Introduction

In recent years, composite materials compared to traditional materials such as steel and aluminum have received considerable attention. Polymer matrix composites have replaced most traditional metals in numerous applications, mainly due to their advantages such as lightness, high stiffness, and high strength. Epoxy resins are thermoset polymer materials commonly used in polymer matrix composites. Epoxy resins have been around for nearly half a century. They are the most preferred high-performance thermosetting resins due to their properties such as low curing shrinkage, no volatile matter during curing, high strength, high durability, high adhesion capability, corrosion, and chemical resistance [1,2]. Many reinforcement materials, such as glass fiber and carbon fiber, are frequently used in epoxy polymer matrix composites. In addition, many researchers have carried out studies on natural fibers due to sustainability and cost concerns [3,4].

Recently, with the rapid growth of the industrial sector, many by-products have been produced and waste material has emerged, which has become a major problem [5,6]. For this reason, many researchers have turned their attention to the use of waste materials as reinforcement materials in polymer matrices. Disposal of processing waste is a difficult and costly task for industries. Due to strong environmental safety regulations and awareness, researchers are increasingly seeking new ideas for using industrial wastes such as fly ash, carbon black, metal, and powder coatings to manufacture polymer composites and other industrial applications [7,8].

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Received: 06.06.2022, Accepted: 23.09.2022

Babu et al. [8] collected waste wear debris during the processing of metallic materials, used it as reinforcement in epoxy material, and characterized it using EDS analysis. The physical, tribological, and viscoelastic behaviors of the prepared composites were evaluated using various tests, and the results were compared with pure epoxy. Ray and Gnanamoorthy [9] investigated the wear behavior of fly ash-filled vinyl ester matrix composites and pure resin. Wear behavior was investigated in weight loss, linear wear, and friction coefficient, and wear mechanisms under abrasive conditions were reported. Panchal et al. [10] investigated the effect of different environmental conditions on the erosion rate of eggshell reinforced epoxy composite. In another study, Ribeiro et al. [11] investigated the mechanical properties of polyester polymer reinforced with glass fiber reinforced plastic wastes obtained from shredding and grinding processes at different rates. Soharu et al. [12] examined the use of concrete waste debris for the manufacturing of fly ash bricks as a sustainable material.

Today, electrostatic powder paints are widely used. As the name suggests, the electrostatic powder coating technique is based on coating electrically conductive materials with powder coating [13,14]. These powder paints, produced by the extrusion method, are sprayed onto the material to be coated electrostatically with a spray gun. Due to the electrostatic attraction force between the material and the powder paint particles, the powder paint particles cling to the surface of the material. With this technique, even materials with very complex geometries can be easily coated to form a film of the desired thickness. However, the disadvantage of this method, which provides a great advantage, is that losses occur during coating. Kismet [13] stated that while a loss of approximately 30-35% occurs in each application in small and medium-sized coating companies, around 5% of waste occurs in mass production coating applications. These waste materials are disposed of by burning. However, researchers, after hydrolyzing this waste element, used it as a reinforcement element in thermoplastic materials such as PP [15], LLDPE [16], PA6 and POM [13], Acetal copolymers [17], and LDPE [18], and examined them thermally, mechanically, and morphologically.

Despite the relatively large amount of research on the use of recycled waste in polymer-based composite materials, no studies have focused on using electrostatic powder coating waste as additives in thermoset polymer materials. Therefore, this study explored a potential waste management solution for thermosetting polymer-based composite materials using powder coating waste as reinforcement or filler. For this reason, composite materials were produced using electrostatic powder coating wastes in different weight ratios in epoxy resin, which is in the thermoset polymer family, as reinforcement material. Pure, 3%, 6%, and 9% powder coating waste reinforced epoxy materials were produced and compared to the tensile test, three-point bending test, thermogravimetric analysis (TGA) results, and scanning electron microscope (SEM) images of the materials.

2. Material and Method

2.1. Material Production

This study used polyurethane (P-Pur) powder coating wastes as reinforcement material. These powder coating wastes were first hydrolyzed using water and alcohol, and thus, the brittle wastes took on a more ductile and elastic structure. Water and trace amounts of alcohol to be used for hydrolysis were mixed for approximately 30 minutes in a magnetic stirrer at room temperature. Powder coating wastes were added to this prepared mixture liquid in a one-to-one ratio. For hydrolysis, the waste materials were kept in the mixing liquid for 60 minutes at approximately 100 °C. The alcohol in the mixing liquid allows all surfaces of the powder coating wastes to be completely hydrolyzed with water. The powder coating wastes, whose structure was changed due to the hydrolysis process, were left to dry at room temperature for 24h and then ground into a powder [14]. The scanning electron microscope (SEM) image of the polyurethane powder coating waste (Pur-PCW) is given in Figure 1.

A two-component epoxy material system consisting of F-1564 FIBERMAK epoxy and hardener was used as the matrix material. The manufacturer recommends the ratio of epoxy and hardener as 3/1. The ratio of polyurethane powder coating waste used as reinforcement was chosen as 3%, 6%, and 9% by weight. As a result of the tests performed, a higher waste ratio was not used because the mechanical properties of the samples reinforced with 9% by weight of polyurethane powder coating wastes were observed to decrease significantly. First of all, the required amount of epoxy-hardener and polyurethane powder coating wastes were taken into a container and mixed with a magnetic stirrer at 30 °C and 100 rpm for 60 minutes to obtain the desired mixture. In the next step, the mixture was kept under a vacuum for 20 minutes to remove the air bubbles in the mixture. After the vacuum process, the mixture was poured into molds produced for tensile and bending specimens. Then, the materials poured into the molds were cured at room temperature for 48 hours and cured in an oven at 80 ^{o}C for 4 hours. This process has been applied to all materials, and the production steps are shown in Figure 2.

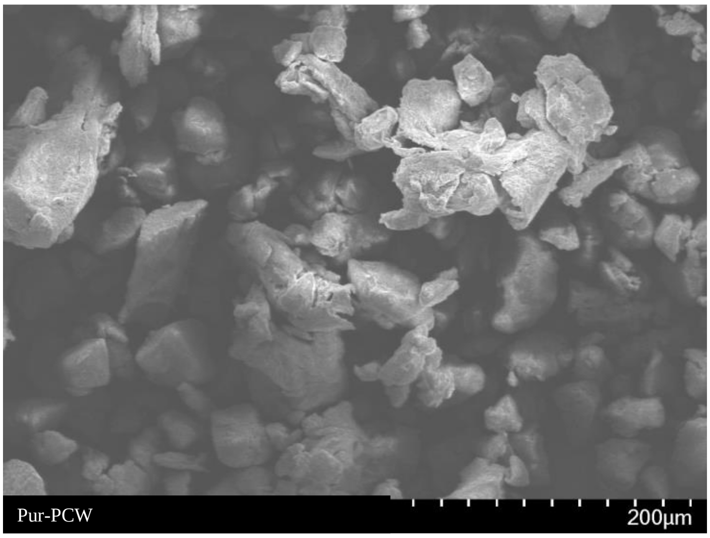

Figure 1. SEM image of polyurethane powder coating waste

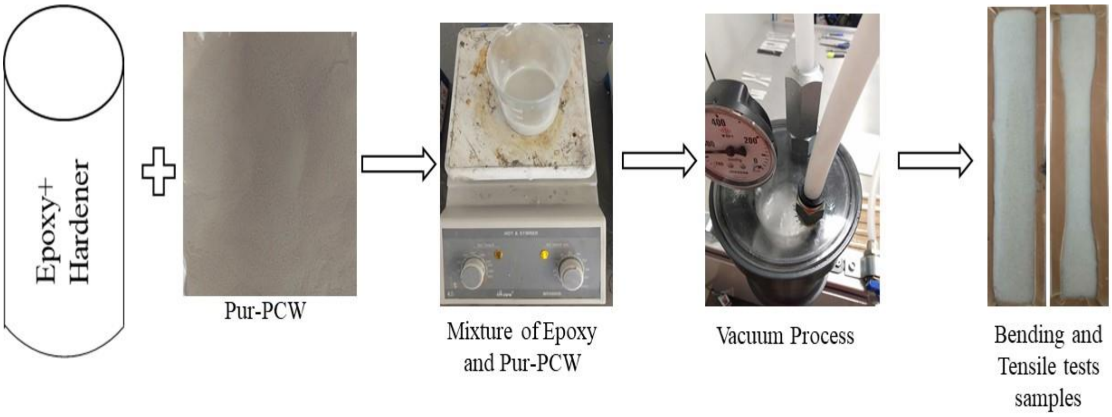

Figure 2. Production of Pur-PCW reinforced Epoxy composite

2.2. Tensile Test

For the tensile test specimens, molds were prepared in a three-dimensional printer following the ASTM D-638 [19] test standard and then covered with adhesive Teflon tape. The dimensions of tensile test specimens are given in Figure 3. Tensile tests were carried out in a Shimadzu brand AG-IC model universal tensile testing device with a load capacity of 100 kN in the mechanical engineering laboratory of Munzur University. The tensile test speed was chosen as 2 mm/min. Figure 4 shows the image taken during the tensile test. The tensile tests were repeated at least 4 times for each material type, and the tensile strength, elasticity modulus, and maximum elongation values of the materials were obtained.

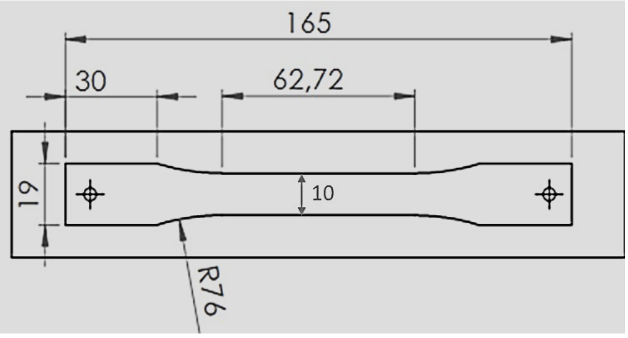

Figure 3. Dimensions of Tensile test samples (Dimension in mm)

Figure 4. Tensile test sample and apparatus

2.3. Three-Point Bending Test

For three-point bending tests, molds with 80 mm in length, 10 mm in width, and 4 mm in depth were prepared, and test specimens were prepared. In addition, three-point bending tests were performed with a Shimadzu brand AG-IC model universal tensile testing device with a load capacity of 100 kN in the mechanical engineering laboratory of Munzur University, as in the tensile tests. Figure 5 shows the three-point bending test specimen and test apparatus. The distance between the supports is 64 mm, and the support diameters are 10 mm. Three-point bending tests were performed at a speed of 1 mm/min and were repeated at least 3 times for each material group. Thanks to this test, the material’s bending strength and deflection values were obtained and are given in the result section.

2.4. Thermogravimetric analysis TGA / DTA

TGA/DTA analyses of the samples were carried out using a Shimadzu brand "DTG 60" model device to determine the thermal behavior of the hydrolyzed polyurethane powder coating waste reinforced epoxy materials. Results are reported for the pure sample and reinforced by weight filler with 3%, 6%, and 9%. The changes in the mass of the materials were investigated depending on the temperature change. The samples were heated from room temperature to 600 ºC with a temperature gradient of 10 ºC/min, and the measurements were made under air atmosphere. The mass losses that occur with the increase in temperature are shown with graphics.

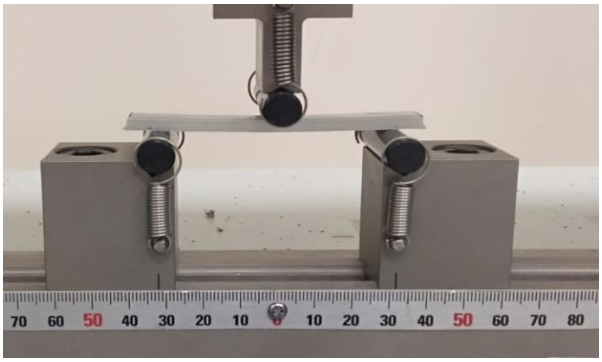

Figure 5. Three-point bending test sample and apparatus

3. Results

3.1. Tensile Test Results

The stress-strain curves obtained during the tensile test are given in Figure 6. As stated above, the tensile test for each material was repeated at least 4 times. The curves given here are those closest to the average of the curves obtained during the tensile test. As can be seen in the figure, the percentage elongation of the materials decreased sharply with the increase of the reinforcement material. Likewise, a decrease in the stress values occurred with the increase in reinforcement material. The linear region, in other words, the Hooke region, gives the material's modulus of elasticity. Here, between 0 and 20 MPa can be considered the elastic region. Looking at the curves, the slope of the curves has increased with the increase of the reinforcement material. Thus, the elastic modulus of the materials has increased with the reinforcement material. Also, the mean values and standard deviations are shown in Table 1. In addition, images of damaged samples obtained at the end of the tensile test are given in Figure 7.

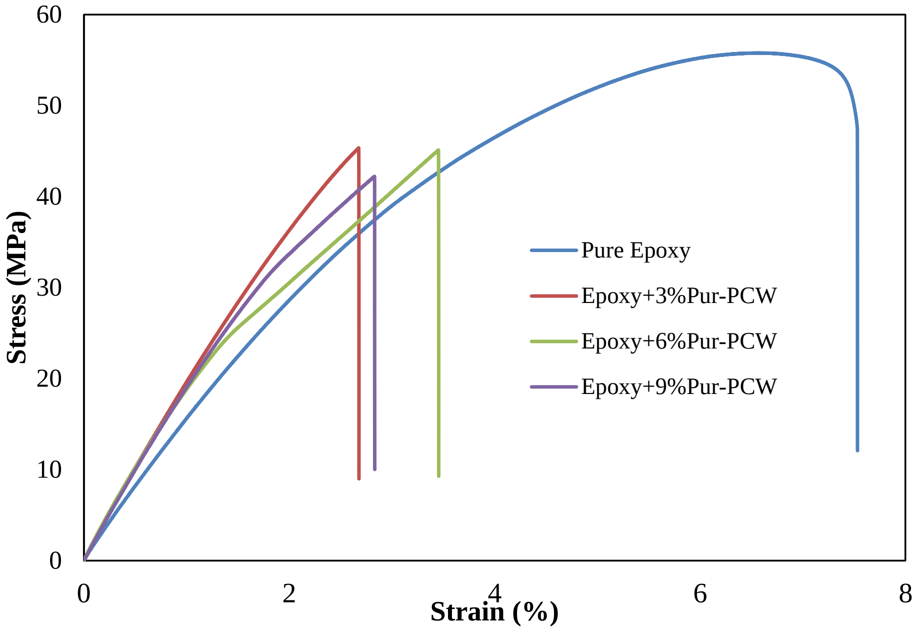

Figure 6. Stress-Strain curves of samples under tensile tests

Figure 7. Images of samples subjected to tensile test

Table 1. Mechanical properties obtained as a result of the tensile test

	Tensile Strength (MPa)	Standard Deviation	Maximum Strain (%)	Standard Deviation	Elastic Modulus (MPa)	Standard Deviation
Pure Epoxy	56.10	0.95	7.56	0.06	1520	15
Epoxy + 3% Pur-PCW	42.86	1.15	2.72	0.09	1812	27
Epoxy + 6% Pur-PCW	44.96	1.54	3.29	0.32	1773	30
Epoxy + 9% Pur-PCW	40.66	1.85	2.74	0.44	1696	46

As seen in Table 1, the tensile strength of pure epoxy material was 56.10 MPa, while the tensile strength of 3%, 6%, and 9% Pur-PCW reinforced epoxy materials was 42.86, 44.96, and 40.66 MPa, respectively. Compared to the pure epoxy material, the tensile strength of the 3% Pur-PCW reinforced material decreased by approximately 23%. Also, the decrease in tensile strength of 6% and 9% Pur-PCW reinforced materials was determined as 20% and 27% compared to pure epoxy material. Similar to the tensile strength, the maximum strain values decreased with the increase of reinforcement material. The maximum strain rates of pure, 3%, 6%, and 9% Pur-PCW reinforced epoxy material were measured at 7.56, 2.72, 3.29, and 2.74, respectively. However, the elasticity modulus of samples increased with the increase of reinforcement material. While the modulus of elasticity of pure epoxy was 1520 MPa, the modulus of elasticity of 3%, 6%, and 9% Pur-PCW reinforced materials were obtained as 1812, 1773, and 1696 MPa, respectively. Dao et al. [20] investigated the mechanical properties of the cerium oxide reinforced epoxy material and obtained similar results. As the porous structure increases due to air gaps and interfacial adhesion defects in particle reinforced composite materials, ductility and strength decrease. For highly porous materials, the tensile stress is below the yield strength. Also, the strain value decreases [21]. Another reason for this decrease is the weak interface adhesion strength between the additives and the matrix material [22].

In Figure 8, SEM images of the damaged surfaces formed after the tensile test are given. As can be seen from the figure, the pores and voids increased with reinforcement material, especially in the 9% Pur-PCW reinforced material. Rana et al. [23] stated that the interface is the weakest phase in composite materials. With the increase of reinforcement, the interface area increased, which caused a decrease in the tensile strength [24]. Poor interfacial bonding creates partially separated micro-voids, which inhibits tension propagation between the reinforcement material and the matrix [25]. As the reinforcement material increases, the degree of this obstacle increases, increasing the material's stiffness [7,8]. The increase in the modulus of elasticity can be explained by the above case.

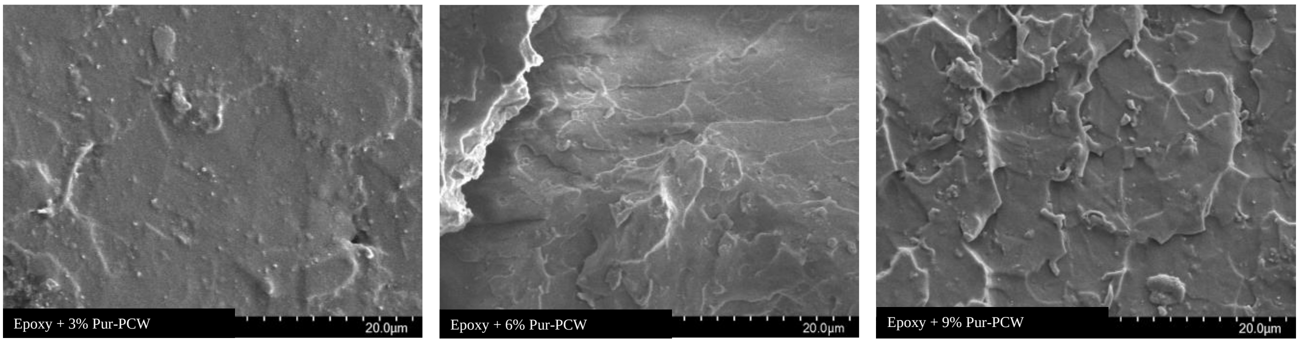

Figure 8. SEM images of the damaged surfaces obtained after the tensile test

3.2. Three-Point Bending Test Results

The stress-strain curves obtained by the three-point bending test of the materials are given in Figure 9. As seen in the figure, the maximum stress value of the 3% Pur-PCW reinforced epoxy material increased slightly. The increase in maximum stress is visible when the reinforcement material is increased to 6%. However, the maximum stress value of 9% Pur-PCW reinforced epoxy material is lower than that of pure epoxy material. Therefore, epoxy materials reinforced with a higher rate of reinforcement material were not produced. Despite the increase in the maximum stress, the deflection values of all Pur-PCW reinforced samples decreased compared to pure epoxy. While the deflection value of pure epoxy material is approximately 19 mm, this value is 13, 14.5, and 9 mm for 3%, 6%, and 9% reinforced epoxy materials, respectively. Figure 10 shows the variation of the average values of three-point flexural strengths with the reinforcement material. The flexural strength of pure epoxy is 101 MPa, while it is 109 MPa for 3% reinforced material and 116 MPa for 6% reinforced material. The flexural strength of 3% and 6% Pur-PCW reinforced samples has increased by 8% and 15% compared to pure epoxy, respectively. However, the flexural strength of 9% Pur-PCW reinforced epoxy samples was measured at 91 MPa, decreased by approximately 10% compared to pure epoxy material. When the standard deviation values were examined, it was observed that this value increased with the increase of the reinforcement material.

Similar results were seen in the mechanical properties of powder coating waste reinforced polyolefin materials investigated by Kısmet [15]. Increasing the reinforcement material increases the interfacial adhesion zone between the matrix-reinforcing material. Thus, possible interfacial adhesion defects increase, and the homogeneous distribution of the reinforcement material in the matrix material decreases. In addition, images of damaged samples obtained at the end of the three-point bending tests are given in Figure 11.

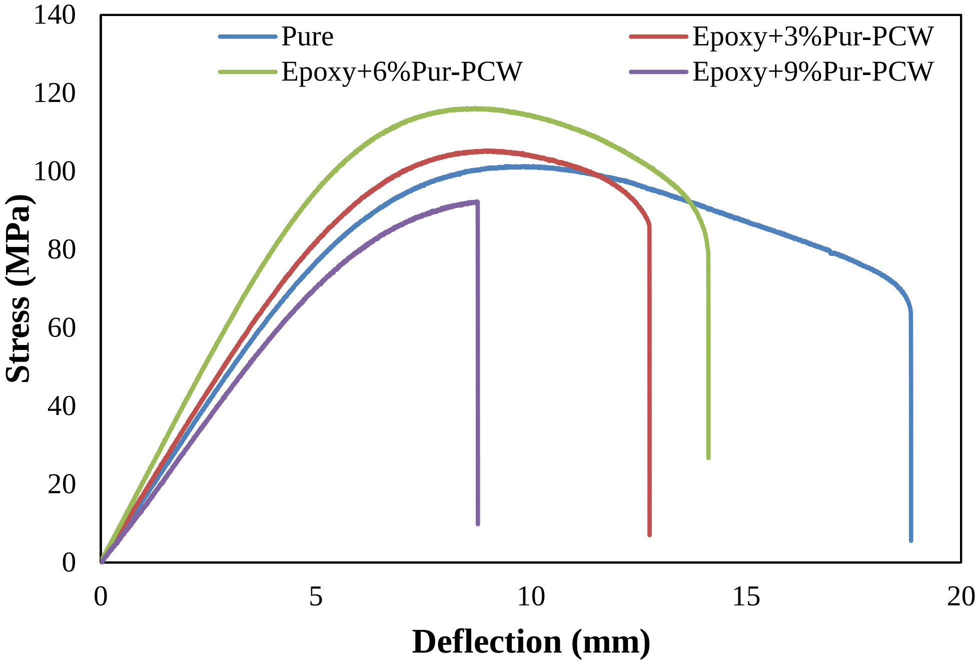

Figure 9. Stress-deflection curves of Three-Point bending tests

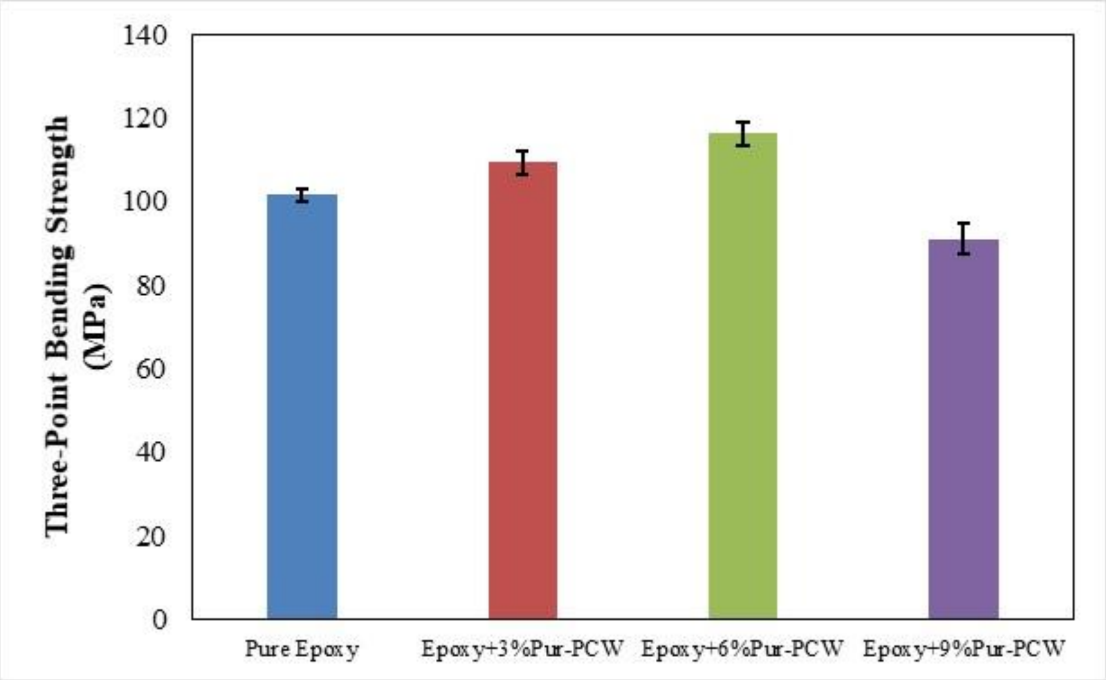

Figure 10. Variation of Bending Strength with reinforcement material

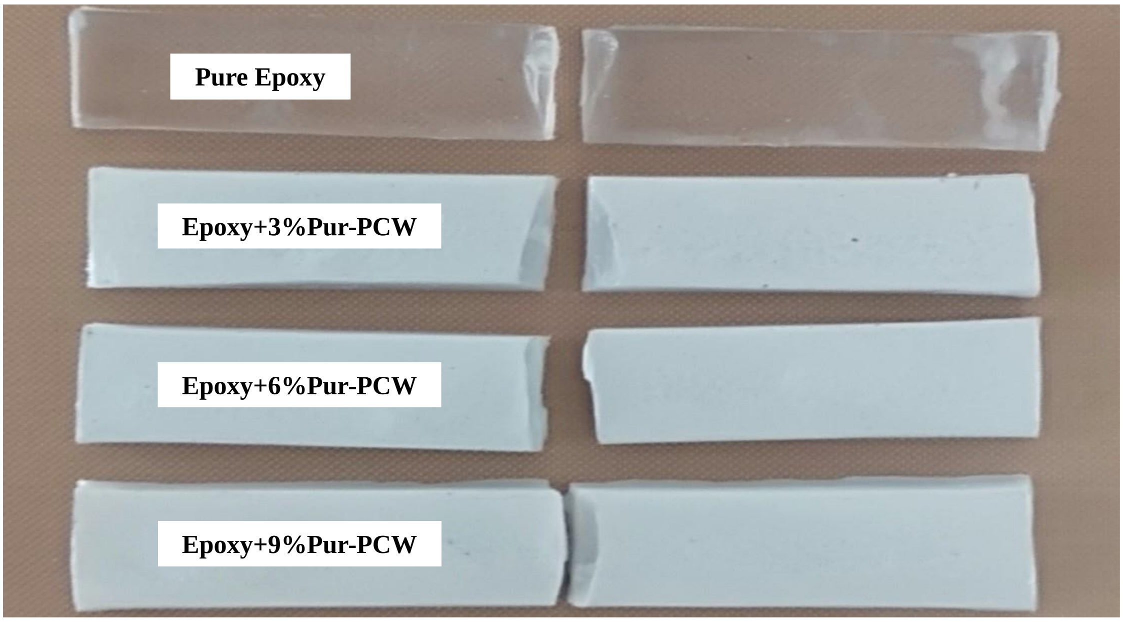

Figure 11. Images of samples subjected to Three-Point bending test

3.3. Thermogravimetric analysis TGA / DTA

One of the most important methods for investigating the thermal stability of materials is thermo-gravimetric analysis (TGA). In this analysis, the variation of the mass-loss with temperature increase is used to determine the materials' thermal stability. Pure epoxy and hydrolyzed powder coating waste reinforced epoxy materials at different weight ratios were subjected to TG analysis, and the graphs obtained are shown in Figure 12. In this TG analysis, the exothermic direction is upwards. From graphs, for pure epoxy and reinforced epoxy materials, thermal degradation does not occur before 270 ^{o}C. The weight loss (1-1.5%) before this temperature is due to the evaporation of moisture from the surface [26-27]. When TGA curves are examined, it is seen that thermal degradation occurs in three steps. A mass loss of about 8% occurred in all materials when the temperature was increased from 270 ^{o}C to 350 ^{o}C. At this step, it can be concluded that weak bonds in the polymer are affected, and there is a low heat output. The second step ends at 460 ^{o}C with a mass loss of 58%, and the third step ends at 600 ^{o}C with a mass loss of 27%. In the first stage, the decomposition rate of the epoxy cross linking network of the resin chain is much higher than carbon-carbon bond breaking. An increase in activation energies and decomposition entropies has been observed in the second stage since the decay rate will be much higher in the second stage. A similar trend in the first phase was also observed in the final phase [28]. As shown in the DTA curves, heat energy passed from the materials to the environment at 360 ^{o}C, forming an exothermic peak. When thermoset materials cure, that is, when they harden, they release heat energy due to reactions. Above this temperature, it is seen that a rapid deterioration occurs in the material by absorbing heat energy from the environment up to 460 ^{o}C. Considering the degradation rate of the materials, it is seen that there is no significant difference, and the deterioration trend is the same.

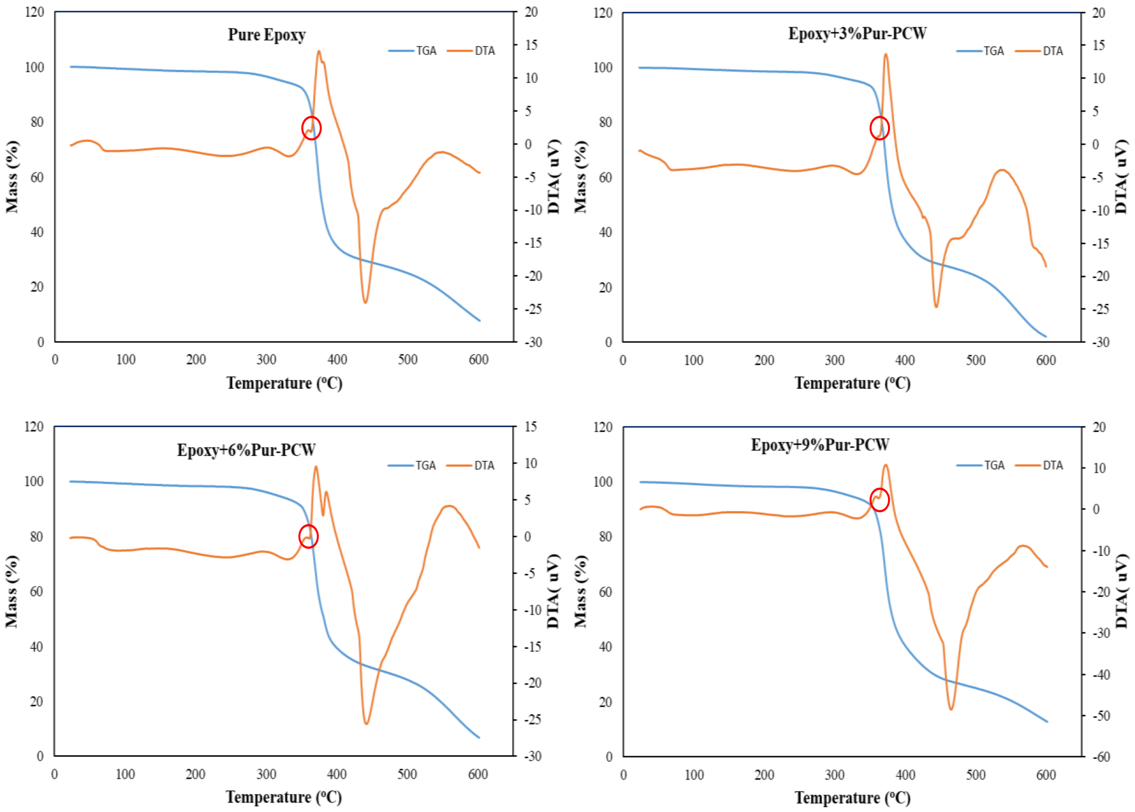

Figure 12. TGA (Blue) and DTA (Yellow) curves of materials

4. Conclusion

In this study, various experiments were carried out to determine the mechanical and thermal behavior of electrostatic powder coating waste reinforced epoxy material. The epoxy materials that were reinforced with three different rates of powder coating waste were produced. Tensile test, three-point bending test, and thermogravimetry analysis were performed. Based on the results obtained, the following conclusions can be drawn:

- A decrease was observed in the tensile strength and elongation values of epoxy materials reinforced with electrostatic powder coating waste compared to pure epoxy material. However, there was an increase in the modulus of elasticity.
- Compared to pure epoxy material, it was observed that there was a significant improvement in the three-point bending strength of epoxy materials reinforced with 3% and 6% electrostatic powder coating waste. However, a significant decrease in strength value occurred when the reinforcement material was increased to 9%.
- In the results of TGA and DTA analyses performed on pure and electrostatic powder coating waste reinforced thermoplastic materials, it can be said that the reinforcement element does not have any negative effect on thermal stability in these thermoset composites.

The findings of this study showed a suitable technological option for the disposal of powder coating waste by using thermoset polymer materials. Thus, it will allow the temporary recycling of powder coating wastes and their use in the production of epoxy-based products. However, the mechanical properties of this composite material can be improved by applying various improvements to increase the interfacial adhesion to the electrostatic powder coating waste.

Contributions of the Authors

All authors contributed equally.

Conflict of Interest Statement

There is no conflict of interest between the authors.

Statement of Research and Publication Ethics

The study is complied with research and publication ethics

References

[1] A.H. Karle, M.R Nukulwar, V.B. Tungikar, "Evaluation of mechanical and thermal properties of epoxy composites reinforced with CaSiO3 particulate fillers*," Materials Today: Proceedings*, vol. 46, pp. 325-330, 2021.

[2] A. Dogan, "Single and repeated low-velocity impact response of E-glass fiber-reinforced epoxy and polypropylene composites for different impactor shapes," *Journal of Thermoplastic Composite Materials*, vol. 35, no. 3, pp. 320-336, 2022.

[3] Y. Kısmet, A. Dogan, "Characterization of the mechanical and thermal properties of rape short natural-fiber reinforced thermoplastic composites*," Iranian Polymer Journal*, vol. 31, no. 2, pp. 143-151, 2022.

[4] O. Faruk, A.K. Bledzki, H.P. Fink, M. Sain, "Biocomposites reinforced with natural fibers: 2000–2010," *Progress in Polymer Science*, vol. 37, no. 11, pp. 1552-1596, 2012.

[5] A. Erdoğan, M.S. Gök, V. Koc, A.Günen, "Friction and wear behavior of epoxy composite filled with industrial wastes," *Journal of Cleaner Production*, vol. 237, 117588, 2019.

[6] S. Singh, S. Ramakrishna, M.K. Gupta, "Towards zero waste manufacturing: A multidisciplinary review," *Journal of Cleaner Production, vol.* 168, pp. 1230-1243, 2017.

[7] T. Väisänen, A. Haapala, R. Lappalainen, L. Tomppo, "Utilization of agricultural and forest industry waste and residues in natural fiber-polymer composites: A review," *Waste Management*, vol. 54, pp. 62-73, 2016.

[8] N.B. Karthik Babu, T. Ramesh, S. Muthukumaran, "Physical, tribological and viscoelastic behavior of machining wear debris powder reinforced epoxy composites," *Journal of Cleaner Production*, vol. 272, 122786, 2020.

[9] D. Ray, R. Gnanamoorthy, "Friction and wear behavior of vinylester resin matrix composites filled with fly ash particles," *Journal of Reinforced Plastics and Composites*, vol. 26, no. 1, pp. 5-13, 2007.

[10] M. Panchal, G. Raghavendra, M.O. Prakash, S. Ojha, "Effects of environmental conditions on erosion wear of eggshell particulate epoxy composites," *Silicon*, vol. 10, no. 2, pp. 627-634, 2018.

[11] M.C.S. Ribeiro, A. Fiúza, A.C.M. Castro, F.G. Silva, M.L. Dinis, J.P. Meixedo, M.R. Alvim, "Mix design process of polyester polymer mortars modified with recycled GFRP waste materials," *Composite Structure*, vol. 105, pp. 300-310, 2013.

[12] A.Soharu, B.P. Naven, A. Sil, "Fly ash bricks development using concrete waste debris and self-healing bacteria," *J Mater Cycles Waste Manag*, vol. 24, no. 3, pp. 1037-1046, 2022.

[13] Y. Kısmet, "Investigation of the changes in melt flow indexes (MFI) and densities of polyamide 6 (PA6) and polyoxymethylene (POM) related with hydrolyzed powder coating waste amount," *Pamukkale University Journal of Engineering Sciences*, vol. 22, no. 4, pp. 241-245, 2016.

[14] Y. Kismet, "Entwicklung eines Verfahrens für die Verwertung von Pulverlackrecyclaten," Ph.D. dissertation, Universitätsverlag der TU Berlin, Berlin, Germany, 2012.

[15] Y. Kismet, "Change of mechanical properties of powder recyclate reinforced polyolefin based on gamma radiation," *Polymers*, vol. 9, no. 9, 384, 2017.

[16] Y. Kismet, M.H. Wagner, "Enhancing the potential of employing thermosetting powder recyclates as filler in LLDPE by structural modifications," *Journal of Polymer Engineering*, vol. 37, no. 3, pp. 287-296, 2017.

[17] Y. Kismet, M.H. Wagner, "Mechanical, thermal, and morphological properties of powder coating waste reinforced acetal copolymer," *Polymer Testing*, vol. 82, 106322, 2020.

[18] Y. Kismet, A. Dogan, M.H. Wagner, "Thermoset powder coating wastes as filler in LDPE–Characterization of mechanical, thermal and morphological properties," *Polymer Testing*, vol. 93, 106897, 2021.

[19] Standard Test Method for Tensile Properties of Plastics, ASTM D-638, 2014.

[20] N.N. Dao, M. Dai Luu, Q.K. Nguyen, B.S. Kim, "UV absorption by cerium oxide nanoparticles/epoxy composite thin films," *Advances in Natural Sciences: Nanoscience and Nanotechnology*, vol. 2, no. 4, 045013, 2011.

[21] D. Bourell, J.P. Kruth, M. Leu, G. Levy, D. Rosen, A.M. Beese, A. Clare, "Materials for additive manufacturing," *CIRP annals*, vol. 66, no 2, pp. 659-681, 2017.

[22] X. Zhang, G. Liao, Q. Jin, X. Feng, X. Jian, "On dry sliding friction and wear behavior of PPESK filled with PTFE and graphite," *Tribology International*, vol. 41, no. 3, pp. 195-201, 2008.

[23] S. Rana, M. Hasan, M.R.K. Sheikh, A.N. Faruqui, “Effects of aluminum and silicon carbide on morphological and mechanical properties of epoxy hybrid composites,” *Polymers and Polymer Composites*, vol. 30, 09673911211068918, 2022.

[24] S. Afsara, M. Hasan, “Effect of peacock feather and rose stem fibre hybridisation on mechanical properties of polystyrene composites,” *Advances in Materials and Processing Technologies*, pp.1-14, 2020.

[25] H.S. Yang, H.J. Kim, H.J. Park, B.J. Lee, T.S. Hwang, “Water absorption behavior and mechanical properties of lignocellulosic filler–polyolefin bio-composites,” *Composite Structures*, vol. 72, no. 4, pp. 429-437, 2006.

[26] Y.Q. Li, S.Y. Fu, Y.W. Mai, “Preparation and characterization of transparent ZnO/epoxy nanocomposites with high-UV shielding efficiency,” *Polymer*, vol. 47, no. 6, pp. 2127-2132, 2006.

[27] M.K. Lila, G.K. Saini, M. Kannan, I. Singh, “Effect of fiber type on thermal and mechanical behavior of epoxy based composites,” *Fibers and Polymers*, vol. 18, no. 4, pp. 806-810, 2017.

[28] S.A. Al-Bayaty, N.J. Jubier, R.A. Al-Uqaily, “Study of Thermal Decomposition Behavior and Kinetics of Epoxy/Polystyrene Composites by using TGA and DSC,” *Journal of Xian University of Architecture & Technology*, vol. 12, no. 3, pp. 1331-1341, 2020.