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Investigation of the effect of the use of waste toys as recycling material in glass-fiber reinforced composites on mechanical properties

Atık oyuncakların geri dönüşüm malzemesi olarak cam-elyaf fiber takviyeli kompozitlerde kullanımlarının mekanik özelliklere etkisinin araştırılması

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Abstract

The aim of this study is to obtain fiber composite material by recycling old toys. For this purpose, waste toys were first collected and cleaned. The toy parts were then exposed to heat to melt and harden. The hardened pieces were then ground into powder filler material. This filler material was added to epoxy at different ratios to obtain composite materials. The strength values of these materials were measured experimentally. The data obtained as a result shows that the addition of waste toys as filler material to glass fiber reinforced composites by bringing them to micro size after heat treatment gradually decreases the mechanical properties. The addition of 2 wt% of waste toy powder gives the best results in terms of mechanical properties compared to other doped composites. This shows that the use of low particle size waste toys as fillers in fiber reinforced composites plays an important role in sustainable material use and waste management.

Keywords: Composite material, Mechanical properties, Recycling, Waste toys.

Öz

Bu çalışmanın amacı, eski oyuncakları geri dönüştürerek fiber kompozit malzeme elde etmektir. Bu amaçla, atık oyuncaklar önce toplanmış ve temizlenmiştir. Oyuncak parçaları daha sonra erimesi ve sertleşmesi için ısıya maruz bırakılmıştır. Sertleşen parçalar daha sonra öğütülerek toz dolgu malzemesi haline getirilmiştir. Bu dolgu malzemesi farklı oranlarda epoksiye eklenerek kompozit malzemeler elde edildi. Bu malzemelerin mukavemet değerleri deneysel olarak ölçüldü. Sonuç olarak elde edilen veriler, atık oyuncakların ısıl işlem sonrası mikro boyuta getirilerek cam elyaf fiber takviyeli kompozitlere dolgu malzemesi olarak katkısı kademeli olarak mekanik özellikleri düşürmektedir. Ağırlıkça %2 oranında atık oyuncak tozunun ilavesi katkılı diğer kompozitlere göre mekanik özellikler açısından en iyi sonuçları vermektedir. Bu da, düşük tanecik boyutlu atık oyuncakların dolgu malzemesi olarak fiber takviyeli kompozitlerde dolgu malzemesi olarak kullanılmasının sürdürülebilir malzeme kullanımı ve atık yönetimi açısından önemli bir rol oynadığını göstermektedir.

Anahtar kelimeler: Kompozit malzemeler, Mekanik özellikler, Geri dönüşüm, Atık oyuncaklar.

1 Introduction

Composite materials have many applications due to their advantages such as light weight, high strength, corrosion resistance and formability. Today, composites are widely used in many industries due to their light weight, high strength, chemical resistance and flexible design characteristics. New material combinations and manufacturing techniques are constantly being developed to improve the performance of composites. Composite materials are widely used in aerospace, automotive, construction, sports equipment and many other industries [1]-[2]. In summary, the history of composites is a multifaceted and constantly evolving process. As technology advances and industrial needs change, the uses and applications of these materials continue to expand. It is a new material formed by combining two or more materials at the microscopic level; it acts as a material that holds the reinforcing material together [3]. Its main function is to support the matrix structure forming the composite structure, to carry the applied load and to increase the volume of the material [4]. Polymer, metal and ceramic matrices are widely used and the use and importance of polymer-based composites is increasing daily. The use of plastics and composites creates waste and environmental problems due to the increasing consumption needs [5]. In this sense, the dimensions of environmental pollution require action plans to be made worldwide. Accordingly, plastic pollution, as one of the main causes of air pollution, has an important place in these action plans. An important step in reducing plastic pollution is the recycling of plastic waste. Plastic recycling refers to the collection, sorting and processing of plastic waste into new products. Many different applications and innovative methods are being developed worldwide [6]. Among these applications, the most widely used method is 'mechanical recycling', in which waste is processed through steps such as washing, grinding and melting into granules, powders or chips, and then reused as filling material. In the production of composite materials, epoxy material is one of the most widely used thermoset polymer materials and it is important to increase the strength values of this material [7], so it would be better to use the composite material by adding various fillers instead of using it alone [8,9]. If we look at the studies, the aim is to recycle and reuse by using many natural and non-natural additives as additives [10]-[15]. In addition, there are also studies using plastic waste [16]-[22]. In this sense, increasing the interfacial bond strength between the fiber, which is the load carrier in the composite, and the matrix material, which acts as a binder, and using micro- or nano-sized fillers play an important role in increasing the strength and other material properties [23]. Özmeral et al. [24]

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investigated the effects of epoxy matrix type and Almond Shell doped iobase composite materials on the mechanical, thermal and water sorption properties of composites according to filler ratios. Tensile strength and modulus of elasticity (e-modulus) values of almond shell and modified epoxy composites were found to be lower, while tensile elongation values were higher than pure epoxy/almond shell composites.

The aim of this study is to recycle toy materials as fillers by mechanical recycling and to experimentally calculate and report the effect on the strength values of the composite material and its usability in composite materials. From this point of view, it provides important information on the environmental and economic dimensions of toy waste in terms of its usability as filler material in the production of fiber-reinforced composites. There is no direct study on this subject in the literature. By addressing the gaps in existing research and clearly defining its objectives, this study aims to provide a comprehensive understanding of the potential of waste toys as a recycling material in GFRCs. The findings will not only advance scientific knowledge but also offer practical solutions for waste management and sustainable material development.

2 Materials and methods

In this study, raw toy material was subjected to various processes in order to be used as filler material in fiber reinforced composite material. Plastic toy parts are made of Acrylonitrile Butadiene Styrene (ABS). First, the toy materials were melted in an iron-based crucible and then poured into a silicone mold. After solidification, the plastic mass was removed from the mold and broken into smaller pieces with a hammer. The resulting plastic powder filler material is in the range of 325 mesh and has an average width of 75 microns. Figure 1 shows the melting process.

Figure 1. The melting process of waste toys.

The plastic pieces were ground in an alumina crucible at a ball/powder ratio of 2:1 in a Retsch model PM100 planetary grinder at 300 rpm for 16 hours. The ground plastic powder was sieved and separated from the coarse particles. The equipment used for the grinding process and the ground filler material are shown in Figure 2. The size of the particles obtained after the grinding process was attempted to be determined and recorded in microns and below.

Figure 2. Blending of melted waste plastic.

In the experiments, F-1564 epoxy and F3487 hardening chemical materials were used. For production of composites, the epoxy/toy powder mixture was obtained manually with a mechanical mixer to ensure homogeneous dispersion of the toy material powder in full compatibility with the epoxy. plastic powders were first added to the epoxy resin at 2, 4 and 8% by weight. The hardener was then added and mixed again. For the samples without additives, the mixing was done directly with the hardener. The prepared mixes were applied to 250 x 250 mm glass fibers cut by hand lay-up method and cured at 100 °C for 2 hours. The glass fiber fabric used was selected as unidirectional with a density of 300 g/m^2. The fiber arrangement of the composites was selected as [0/90/0/90] s. The thickness of the produced composites was measured to be 2.3 mm. The composites were prepared by vacuum infusion as shown in Figures 3 and 4.

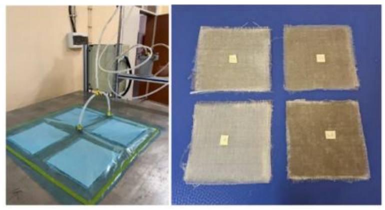


Figure 3. Vacuum infusion setup.

Figure 4. Produced composites.

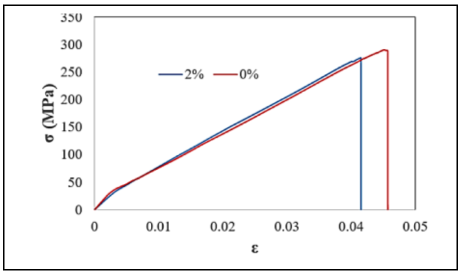
The 250 x 250 mm composite plates were laser cut to 20 x 185 mm for use in the tensile tests. Tensile tests were carried out in accordance with ASTM 3039 using a Shimadzu AG-X 250 kN universal tensile compression tester (Figure 5).

Figure 5. Shimadzu AG-X 250 kN model universal tensile-test machine.

Tensile tests were performed at 2 mm per minute according to ASTM D3039 Standards. The data obtained from the tensile test and the graphs generated were used to investigate how the use of plastic powder additive obtained from toy materials in glass fiber epoxy composites will affect the material strength.

3 Results and discussion

Figure 6 shows the strain (ε) - stress (σ) plots of the composites doped with 2 wt%, 4 wt% and 8 wt% compared to the undoped sample. Looking at the graphs in Figure 5, it can be seen that the slope of the curve in the linear region, which is an indicator of the Young's modulus, is similar at 2 wt% doping levels. However, the elongation at break decreases compared to the undoped sample. As the doping rate increases, the elongation at break and the slope of the curve decrease.



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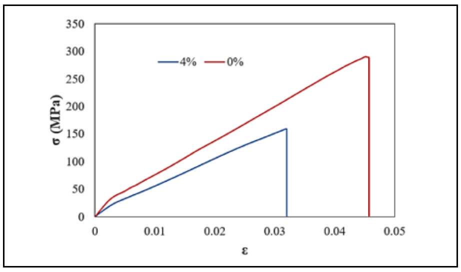

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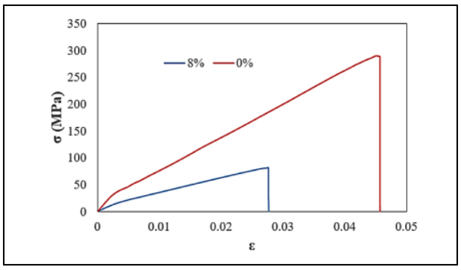

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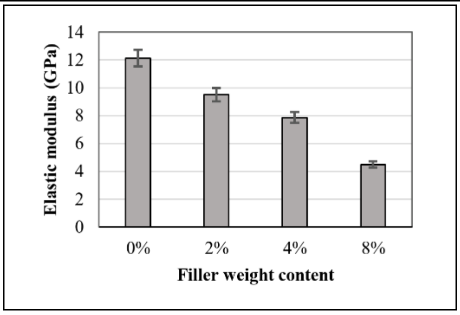
Figure 6. Variation of stress-strain values. (a): 2wt%. (b): 4wt%. (c): 8wt%.

The values of maximum tensile stress, modulus of elasticity and elongation at break are given in Table 1 and Figure 7. It was observed that these values decreased with increasing doping ratio. In addition, the decrease in values was more pronounced with increasing loading ratios. For example, the sample containing 8% plastic powder additive has significantly lower maximum tensile stress, modulus of elasticity and elongation at break than the sample without additive. The decrease in doping rate as a function of the amount of micro particles added can be interpreted as a degradation of the particle/epoxy interface and the consequent decrease in strength value. These interfacial distortions reduce the load carrying capacity between the epoxy and the fiber and lower the material properties.

Table 1. Values of maximum tensile stress, modulus of elasticity, and elongation at break.

Sample	Maximum (MPa)	Elastic GPa	Breaking %
0%	287.20	12.1	4.363
2wt%	274.59	9.5	4.321
4wt%	171.97	7.7	3.434
8wt%	84.36	4.4	2.735



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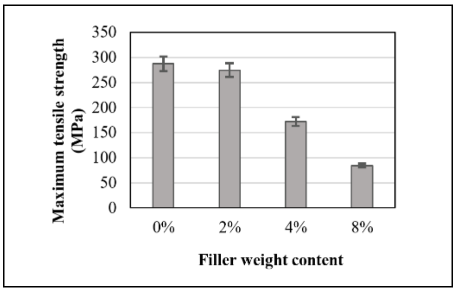

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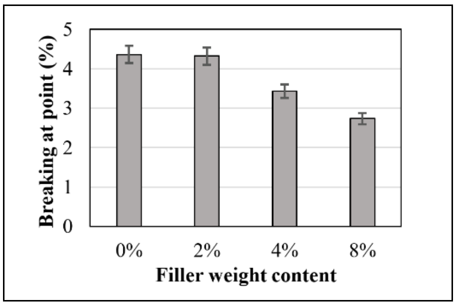

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Figure 7. Tensile test results. (a): Maximum tensile stress. (b): Modulus of elasticity. (c): Elongation at break.

The decrease in elongation at break indicates that the addition of micro particles causes the material to loosen and break quickly. Therefore, the use of toy material as a filler in glass fiber reinforced composites as an additive material would be the right step in terms of cost reduction at low additive ratios. For example, compared to the glass fiber samples without additives, the samples doped with 2 wt% micro particles had 4.3% lower tensile stress and 21% lower modulus of elasticity. It is concluded that the softness of the material is increased and the maximum compressive strength is reduced to an acceptable level. Similar findings were reported by Zhang et al. [25], who observed a 10-15% decrease in tensile strength when incorporating recycled plastic waste into glass-fiber composites. The decrease in tensile strength in our study aligns with these results, suggesting that the inclusion of recycled materials, even after processing, can compromise the structural integrity of the composite. The tensile strength of the composites incorporating waste toys showed a moderate decrease compared to traditional glass-fiber reinforced composites. This reduction can be attributed to the inhomogeneous distribution of the waste toy particles within the matrix, which may act as stress concentrators. A study by Kumar et al. [26] on the use of recycled polyethylene in composites reported a 20% reduction in flexural strength, which is consistent with our findings. The brittleness of the recycled material appears to be a common challenge in such applications, limiting its use in load-bearing structures. It was found that he flexural strength of the composites exhibited a more pronounced reduction compared to tensile strength. This is likely due to the brittle nature of the waste toy material, which may not bond as effectively with the glass fibers and resin matrix. Similar results were observed by Patel et al. [27], who found that the inclusion of recycled rubber particles in composites improved impact resistance by up to 12%. This suggests that waste toys, particularly those made from elastomeric materials, could be beneficial in applications requiring impact resistance. Interestingly, it was found that the impact strength of the composites showed a slight improvement compared to traditional glass-fiber composites. This could be due to the energy-absorbing properties of the waste toy material, which may help dissipate impact energy more effectively.

The failure surfaces of the composites after the tensile test is shown in Figure 8.

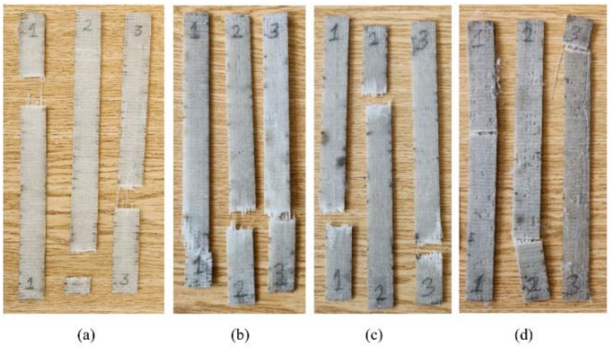

Figure 8. Damage mechanisms after tensile test. Image of (a): Un-modified. (b): 2wt%. (c): 4wt%. (d): 8wt% modified specimens.

As shown in Figure 8, all specimens exhibited brittle fracture behavior. Although the doped specimens exhibited a more brittle behavior due to the increase in elastic modulus ratio with the increase in doping ratio, the specimens fractured close to the compression jaws. Fracture photographs showed increased delamination and fiber breakage in the fracture zone. It is concluded that this increase in damage mechanisms is due to the disruption of the load balance between epoxy and fiber by the addition of micro particles. It is suggested that a contribution rate of less than 2wt% may be beneficial for mechanical performance. This implies that a small amount of filler additive could enhance properties such as strength, stiffness, or toughness without negatively impacting the material's overall performance. The article explores the mechanisms behind this improvement. For instance, at low concentrations, the filler might act as a reinforcement, improving load transfer or reducing stress concentrations. Alternatively, it might enhance interfacial bonding between the matrix and filler, leading to better mechanical properties. If the experiment is conducted with more than 2wt% additives, the results differ significantly. At higher concentrations, filler particles may agglomerate, creating weak points or stress concentrators in the material. In other way, excessive toy filler content might disrupt the continuity of the matrix, leading to reduced strength or ductility.

4 Conclusion

In this study, an experimental study was carried out on the production of composites with 2, 4 and 8 wt% plastic powder additives to epoxy resin and the contribution of recycling to the tensile strength values. After the experiments, a gradual decrease in the strength values of glass-fiber/epoxy composites mixed with micro particles obtained with waste toy material was observed. At a doping level of 2 wt%, the tensile strength decreased by 4.3% while the modulus of elasticity decreased by 21%. It was concluded that while this decrease was acceptable in terms of tensile strength, it was detrimental in terms of elastic modulus. As a result, it was concluded that the use of micro particles obtained from e-waste toys as a filler material with less than 2% by weight compared to epoxy will provide a positive advantage in terms of tensile strength, considering the recycling of e-waste toy material and its contribution to the environment. For future studies it may be recommended to try different amounts of additives below 2%. In addition, different tests can be applied to the produced materials and their other properties can be studied.

5 Author contribution statements

In this study, Mehmet Bulut contributed to the conceptualization, supervision, experimental design, data collection, and writing of the original draft participated in conceptualization, experimental design, and writing the original draft, involved in experimental design, data collection, and writing the original draft.

6 Ethics committee approval and conflict of interest statement

“There is no need to obtain permission from the ethics committee for the article prepared”.

“There is no conflict of interest with any person / institution in the article prepared”.

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