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RESEARCH ARTICLE / ARAŞTIRMA MAKALESİ

Recycled EPS and Epoxy Based Composite Materials: The Combination of Sustainability and Performance

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Abstract
Epoxy composites are high-strength and lightweight materials created by combining epoxy matrix with reinforcing materials. Such composites have a wide range of applications in aviation, automotive, energy, and many other industrial sectors. In this study, the effects of surface-coated expanded polystyrene (rEPS) bubbles added to epoxy matrix at different ratios (%1, %3, %7, %11, and %14) on material properties were investigated. Material properties such as density, hardness, surface gloss at a 60° angle, and Charpy impact strength were measured according to varying rEPS ratios. The results showed that rEPS bubbles reduced density, thereby reducing the weight of the material, affected surface gloss, and decreased impact strength. There was no significant difference in hardness values, but impact strength decreased with increasing rEPS content. The effects of homogeneous distribution of rEPS bubbles on material properties were examined, and it was emphasized that the use of rEPS should be optimized with appropriate production processes. This study has been an important step in understanding the performance of rEPS in epoxy composite materials and has provided a foundation for future research.
Keywords: Epoxy, Polymer Composites, Expanded Polystyrene, Sustainability, Recyled, Performance

Öz
Epoksi kompozitler, epoksi matris ve takviye edici malzemelerin bir araya getirilmesiyle oluşturulan yüksek mukavemetli ve hafif malzemelerdir. Bu tür kompozitler, havacılık, otomotiv, enerji ve birçok endüstriyel uygulamada geniş bir kullanım alanına sahiptir. Bu çalışmada, epoksi matrise farklı oranlarda (%1, %3, %7, %11 ve %14) eklenen yüzeyi PA ile kaplanmış genişletilmiş polistiren (rEPS) baloncukların malzeme özellikleri üzerindeki etkileri incelenmiştir. Yoğunluk, sertlik, yüzey parlaklığı ve Charpy darbe mukavemeti gibi malzeme özellikleri, farklı rEPS oranına göre ölçülmüştür. Sonuçlar, rEPS baloncuklarının yoğunluğu azaltarak malzemenin ağırlığını düşürdüğünü, yüzey parlaklığını etkilediğini ve darbe mukavemetini azalttığını göstermiştir. Sertlik değerlerinde belirgin bir farklılık bulunmamıştır. rEPS içeriği arttıkça darbe mukavemeti azalmıştır. rEPS baloncuklarının homojen dağılımının malzeme özellikleri üzerindeki etkileri incelenmiş ve uygun üretim süreçleri ile rEPS kullanımının optimize edilmesi gerektiği vurgulanmıştır. Bu çalışma, rEPS kullanımının epoksi kompozit malzemelerdeki performansını anlamak için önemli bir adım olmuş ve gelecekteki araştırmalar için bir temel sağlamıştır.
Anahtar Kelimeler: Epoksi, Polimer Kompozit, Genleştirilmiş Polistiren, Sürdürülebilirlik, Geri gönüşüm, Performans

I. INTRODUCTION

Expanded polystyrene (EPS) is a lightweight, cellular foam material that is produced by expanding polystyrene resin through a specialized manufacturing process, and it is widely used in various applications. EPS is produced by adding a gas (typically pentane) to polystyrene resin, which separates the polymer chains in the resin and creates a foam structure, increasing the volume of the material. This expansion process not only results in EPS having low density, but also makes the material lightweight and highly voluminous [1-3]. Due to its lightweight nature, high thermal insulation properties, excellent mechanical strength, high performance, and sustainable characteristics, EPS has become a preferred material for many industries.

EPS has a wide range of applications. In the construction sector, it is commonly used for thermal insulation, subfloor insulation, wall panels, roof coverings, and insulation boards. It is also used as an insulating material in the electronics sector, as components for automotive interiors and exteriors, in sports and recreational equipment, and in many other industrial and consumer products. In addition to these applications, EPS is also used as a lightweight and shock-absorbing packaging material in the packaging sector, due to its flexible structure, impact resistance, and mechanical durability, to protect products during storage, transportation, and installation. However, after its intended use, EPS becomes plastic waste. Although EPS is 100% recyclable, the challenges of recycling and processing processes have led researchers to explore alternative ways of valorizing EPS, which is becoming an increasing source of post-consumer waste. There are different methods for recycling EPS in its waste form. EPS can be recycled through mechanical and chemical recycling methods. In mechanical recycling, EPS materials can be granulated and used as raw material for the production

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of new products. In chemical recycling, EPS can be chemically processed and used for the production of new materials.

Recycled Expanded Polystyrene (rEPS) can increase the use of EPS in construction materials and reduce the environmental impact of waste EPS. By reducing the density of concrete, rEPS helps make building materials lighter and more sustainable [2, 4, 5]. Additionally, the high thermal insulation properties of EPS can improve energy efficiency in buildings and reduce energy consumption. The use of rEPS as a material also contributes to the conservation of natural resources and minimizes environmental impacts by reducing waste. rEPS is also used in the shaping of thermoplastic and thermoset materials through polymer processing methods. Castro et al. [6] prepared mixtures by blending rEPS into pure EPS through injection molding process at variousratios (10%, 15%, and 20%). They reported that the material compressive strength, impact resistance, glass transition temperatures, and thermal diffusion changed very little, while tensile strength, flexural strength, and thermal conductivity decreased. The researchers concluded that rEPS could be used in products such as cases and packaging. Serin and Yildizhan [7] produced low-density and high-modulus composites using glass fiber, EPS, and epoxy, and indicated that these new composites could be used in non-load-bearing applications. Smorygo et al. [8] produced ultra-low-density epoxy/polystyrene foam composites with high specific strength and pseudo-plastic behavior, and found that the composite components exhibited a synergistic response. Aydogmus et al. [9] produced epoxy biocomposites reinforced with waste EPS and reported a 9% reduction in production cost in biocomposite production with the use of waste EPS.

Composite materials made by combining recycled expanded polystyrene (rEPS) and epoxy resins represent an important class of materials that offer a combination of sustainability and performance [4]. These composite materials are considered as a solution for using environmentally friendly materials, leveraging the lightweight, high thermal insulation, and excellent mechanical strength properties of EPS, as well as the durability, chemical resistance, and low viscosity of epoxy resins. The production of composite materials by combining rEPS with epoxy resins helps reduce waste generation and offers a sustainable solution in terms of recycling. In addition, the lightweight, high thermal insulation properties, and excellent mechanical strength of rEPS contribute to the improved sustainability and performance of the composite materials. The fields of application for composite materials made by combining recycled EPS and epoxy resins are extensive. They can be used in the construction sector for applications such as thermal insulation panels, subfloor insulation, roof coatings, and structural elements. Moreover, they have potential uses in the automotive industry for interior and exterior components, packaging sector, sports and recreation equipment, and many other industrial and consumer products. The use of composite materials made by combining recycled EPS and epoxy resins promotes an environmentally friendly approach by reducing waste and encouraging sustainable material usage. The use of such materials may contribute to the conservation of natural resources, energy savings, and reduction of carbon footprint.

Samsudin et al. [10] coated EPS beads with epoxy resin and then hardened them at high temperature, resulting in a shrunk hollow structure. Reemas and Maheswaran investigated the effect of EPS volume fraction on the buoyancy properties of EPS/epoxy sandwich composites and observed that buoyancy properties improved with increasing EPS ratio [11]. Inoue et al. [12] developed an absorber capable of absorbing millimeter wavelength by adding PS bubbles to an epoxy matrix. The researchers found that the absorber could be transformed into various shapes, such as chips and pyramids, and could be used to protect telescopes from scattered light. Li et al. [13] added PS additives at specific ratios to improve the mechanical properties of carbon fiber reinforced epoxy composites. The optimum PS additive ratio was found to be 2.5%, and at this dosage, the tensile strength, tensile modulus, flexural strength, flexural modulus, and impact strength of the adhesive increased, while the PS particles deformed significantly and absorbed energy when the matrix fractured. Vaitkus et al. [14] examined the effect of average bead size on the density of EPS samples. It was observed that the pressure on the EPS sample affected the structure and the durability and stability were related to stress. Wang et al. [15] created controlled void defects on EPS modified epoxy resin samples and examined their mechanical behavior using digital image correlation and image-based finite element method. Experimental results showed that void defects had an effect on the tensile, compressive, and deformation properties of the samples, and influenced the mechanical behavior of epoxy resin.

Surface gloss is an important factor that affects the appearance, quality, and usability of epoxy composites [16]. A smooth and glossy surface enhances the aesthetic value of the composite and provides a more appealing appearance [17]. Surface gloss depends on various factors such as the quality of the epoxy resin and curing agents used, type and ratio of reinforcement materials, production method, processing conditions (temperature, humidity, etc.), surface preparation, and final finishing steps [18]. High surface gloss in epoxy composites is desired in decorative and aesthetic applications (coatings, flooring, furniture, decorative items, etc.) as it enhances the attractiveness and professional appearance of the product [19, 20]. In fields such as automotive and aerospace, high surface gloss can improve aerodynamic performance and reduce air friction [21]. Moreover, high surface gloss allows for easy cleaning, maintenance, and visual inspection of composite parts [22-25].

The importance of sustainability and environmentally friendly approaches is increasing in today's world. Therefore, it is expected that the use of composite materials combining recycled EPS and epoxy resins will increase. Research and technological advancements are encouraging the widespread use of rEPS and epoxy resins in composite materials, leading to potential applications in various industries such as automotive, aerospace, construction, packaging, marine, electronics, and others. This could be a significant step towards a sustainable future. Due to the superior properties of both epoxy resins and EPS, it is expected that the use of rEPS and epoxy resins in composite materials will increase [26, 27].

In this study, changes in the properties of density, surface gloss, hardness, and impact resistance of the material will be investigated by adding rEPS to epoxy matrix at different ratios. Additionally, the aim is to create economic value by recycling non-recycled rEPS, designing and producing new composite products with epoxy as sustainable and environmentally friendly alternatives, reducing waste quantity, preventing environmental pollution, and promoting sustainable use of natural resources.

II. MATERIALS AND METHODS

2.1. Materials and Preparation Techniques

The commercial code ERA 4000 (Teknomarin) two-component solvent-free epoxy system was used as the matrix material in the study. The technical specifications of ERA 4000 epoxy system are given in Table 1.

Table 1. Technical specifications of ERA 4000 epoxy system

Technical Specifications	Unit	Value
Volume Solids	%	100
Density	g/cm^3	1.1
Color	-	Clear
Gloss	-	Glossy
Dry Film Thickness	µ	200 µ
Theoretical Coverage	°C	5 (200 µ) - 2 (500 µ)
Application Range	m^2/lt	+15 ~ +35
Initial Cure (20°C)	hour	1
Full Cure (20°C)	hour	6
Ready for Service	hour	24
Mixing Ratio (by weight)	wt. %	2A/1B
Mixing Ratio (by volume)	vol.%	2A/1B
Pot Life (20°C)	minute	35

It has been obtained from packaging waste used for protective purposes, specifically EPS beads, added to epoxy to reduce weight. The surface area was calculated by separating EPS particles/bubbles. The mass, surface area, and volume of the EPS bead were modeled in SolidWorks software. One EPS bubble has an average diameter of 2.4 mm, a surface area of 15.67 mm^2, and a volume of 5.29 mm^3. The drawing of the EPS bubble modeled in SolidWorks software is given in Figure 1.

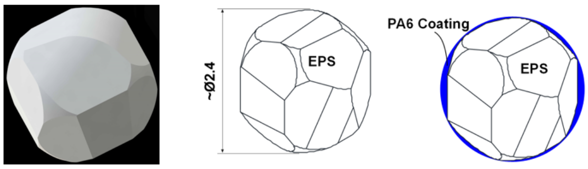

Figure 1. The modeling of the EPS bubble in SolidWorks software

To improve the interfacial properties between epoxy and EPS, and to prevent voids and crack formation due to the geometry of EPS particles/bubbles, liquidized PA6 obtained from injection runner waste and dissolved in formic acid solution was used to coat the surface of EPS particles/bubbles. The density of PA6 is 1.14 g/cm³, the melting temperature is 221 °C, and the relative viscosity (in 1% H_2SO_4 (96%) solution at 20 °C) is 2.7. Prior to the dissolution process, PA6 was pulverized and converted into powder form using a Lavion HC500 Y brand grain mill, as shown in Figure 2, to shorten the processing time.

Figure 2. Lavion HC500 Y brand grain mill was used to pulverize and convert PA6 into powder for

2.2. Dissolution of PA6 and Coating of EPS Surface

For the dissolution process, a formic acid concentration of 90% was prepared. The pulverized and converted PA6, as shown in Figure 2, was added to the prepared mixture. The mixture was then stirred at 80°C and 200 rpm for 6 hours using a Heidolph heated magnetic stirrer to dissolve PA6 and convert it into liquid form. An image of the dissolution process is given in Figure 3.

Coating of EPS surfaces with PA6 in granular form was carried out using a custom-made mixer device with a rotating drum and air blowing at 40 °C, as shown in Figure 4. The drum of the mixer was rotated, and the dissolved PA6 solution was sprayed onto the EPS bubbles inside the drum every two minutes (5 times) in a mist form, ensuring a homogeneous coating of EPS bubble surfaces with PA6 for a duration of ten minutes. Care was taken to ensure that the PA6 solution was sprayed evenly onto the styrofoam bubbles throughout the process. After these steps, the hot air blower of the mixer was turned on, and the EPS+PA6 solution was stirred for an additional 10 minutes at 40 °C to dry. To prevent moisture-related molding defects during the preparation of composites, to protect the coated surfaces, and to prevent PA6 from absorbing moisture, the coated EPS particles were allowed to dry in an oven at 40 °C for 24 hours after the application.

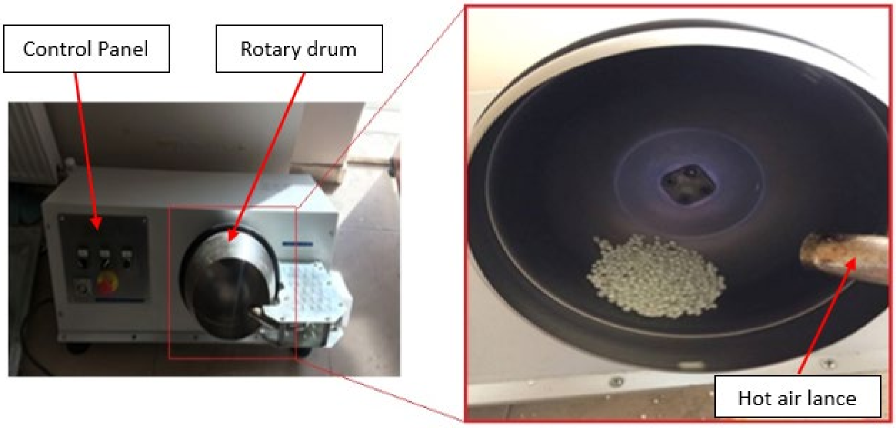

Figure 4. Hot air blown and rotary drum mixer

2.3. Preparation of Epoxy/PS(+PA6) Composites

Epoxy resin (A) and hardener (B) components were weighed in a 2:1 ratio using a precise balance. The mixture was thoroughly mixed for about five minutes until a homogeneous consistency was achieved. The mixing process was done quickly to prevent the formation of air bubbles. Petri dishes with a diameter of 80 mm and a thickness of 3 mm were used as casting molds for the samples. Mold release agent was applied to the surfaces of the petri dish to facilitate easy removal of the cured epoxy from the mold. The mixed epoxy and hardener mixture was poured into the mold. Air bubbles formed in the resin were removed using a spatula, and EPS bubbles coated with PA6 were placed in the epoxy resin according to the volume calculation using forceps. After the process, the epoxy was left to cure for 24 hours. After curing, the cast parts were removed from the mold. Epoxy/PS(+PA6) composites were prepared by adding PA6-coated EPS bubbles to the epoxy in volume ratios of 3%, 7%, 11%, and 14%. The products were coded with the first letter of the epoxy word, EPS, and the volumetric EPS ratio. For example, the E/EPS03 code indicates that the epoxy contains 3% volumetric EPS bubbles. The images of the prepared products are shown in Figure 5.

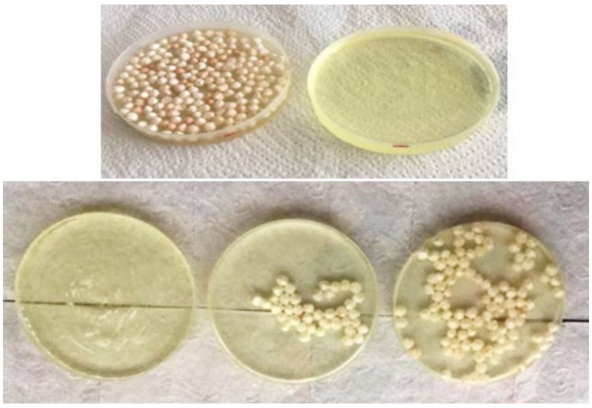

Figure 5. Appearance of epoxy composite samples

2.4. Density Measurement

Density measurements of prepared Epoxy/PS(+PA6) composites were conducted by first weighing the samples on a precision balance. Then, the composite samples prepared at different ratios were immersed in a precise water container filled with alcohol, ensuring complete submersion. The level of the water container was recorded. After removing the sample from the alcohol, the level to which the alcohol dropped was also recorded. The densities were calculated using the equation provided in Eq.1, where the mass change represents the change in weight of the water container when the sample is immersed, and the changing volume represents the difference between the levels to which the alcohol rises and drops.

$$Density = \frac{Mass\ change}{Change\ in\ volume\ of\ liguid} \quad (1)$$

2.5. Hardness Measurement

According to ASTM D2240 standard, hardness measurements are commonly used in many industrial applications such as evaluating the mechanical properties of materials, ensuring quality control processes, and predicting product performance. Shore D scale and Loyka Brand hardness measurement device were used to measure the hardness of the samples in accordance with ASTM D2240 standard.

2.6. Charpy Impact Test

A V-notch Charpy impact test was conducted on samples using a 5.0 J pendulum hammer according to ISO179-1 standard on an Instron-120D model machine. V-notches with a radius of 0.1 were created on the samples in accordance with ISO 294-1. Pictures of the specimens used for the impact test casting are provided in Figure 6.

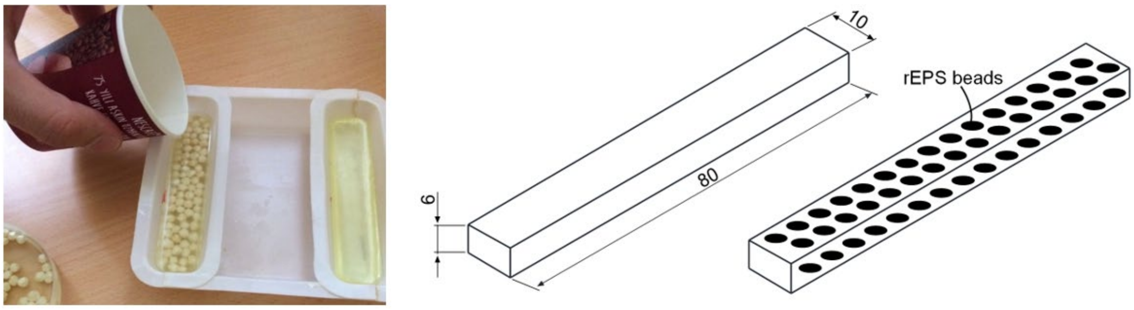

Figure 6. Production of Charpy impact test specimens

2.7. Surface Gloss Measurement

Surface gloss measurements were performed using an Elcometer brand micro-gloss meter at a projection angle of 60° to evaluate the surface's ability to reflect light. A 60° projection angle is commonly used for gloss measurements of paints, coatings, plastics, and other surface coatings.

III. RESULTS AND DISCUSSION

3.1. Density Measurement Results

The density measurement results of the prepared Epoxy/PS(+PA) composites are given in Table 2 and their graphical comparison is shown in Figure 7. Comparing the densities given in the table, the sample coded as E/EPS00 has the highest density (1.10 g/cm³), while the sample coded as E/EPS14 has the lowest density (0.87 g/cm³). The other samples can be ranked in terms of density between these two samples. Therefore, the sample coded as E/EPS00 can be considered as the most dense, and the sample coded as E/EPS14 can be considered as the least dense. It can be observed that the addition of EPS(+PA) bubbles into epoxy reduces the density of epoxy and consequently reduces the weight of the material. When 3% EPS(+PA6) is added into epoxy, the density of the sample decreases by approximately 11% compared to pure epoxy. When 7% EPS(+PA6) is added, the density of the sample decreases by approximately 14.5% compared to pure epoxy. When 11% EPS(+PA6) is added, the density of the sample decreases by approximately 19% compared to pure epoxy, and when 14% EPS(+PA6) is added, the density of the sample decreases by approximately 21% compared to pure epoxy.

Reducing the density of a material can provide some advantages in specific applications or designs. Especially in areas where weight is critical, such as automotive, aerospace, space, and defense industries where composites made of epoxy are used and lightweight is important, adding EPS bubbles into epoxy can achieve the desired effect [14,15]. Factors such as the requirements of the application, performance expectations, cost factors, and production processes should be taken into consideration in such applications. Each material has its unique properties, and it should be remembered that density is just one factor that affects the field of use and performance of a material.

When the results are examined in terms of weight, it is observed that when 3% EPS(+PA6) is added to epoxy, the weight of the specimen decreases by approximately 13% compared to pure epoxy. Similarly, when 7% EPS(+PA6) is added, the weight of the specimen decreases by approximately 17% compared to pure epoxy. When 11% EPS(+PA6) is added, the weight of the specimen decreases by approximately 21% compared to pure epoxy, and when 14% EPS(+PA6) is added, the weight of the specimen decreases by approximately 23% compared to pure epoxy. There are many important advantages of weight reduction with additives in epoxy composites [28-30]. These include performance improvement, energy efficiency, cost reduction, environmental sustainability, and ease of use. For these reasons, the use of lightweight epoxy composite materials is preferred in many industries, especially in aviation, automotive, aerospace, marine, and wind energy sectors [31, 32]. The use of lightweight materials can contribute to increased performance, reduced energy consumption, lower costs, support for environmental sustainability, and ease of use.

Table 2. Density measurement results

CODE	EPS(+PA) (wt.%)	Total Weight (g)	Density (g/cm^3)
E/EPS00	-	115.20	1.10
E/EPS03	3	100.16	0.98
E/EPS07	7	96.04	0.94
E/EPS11	11	91.02	0.89
E/EPS14	14	89.11	0.87

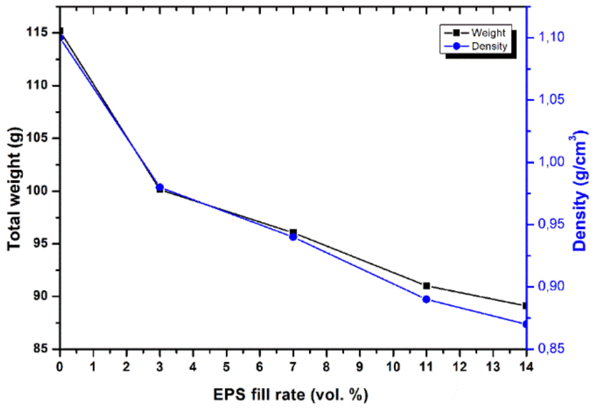

Figure 7. Variation of density and weight according to EPS filling ratio

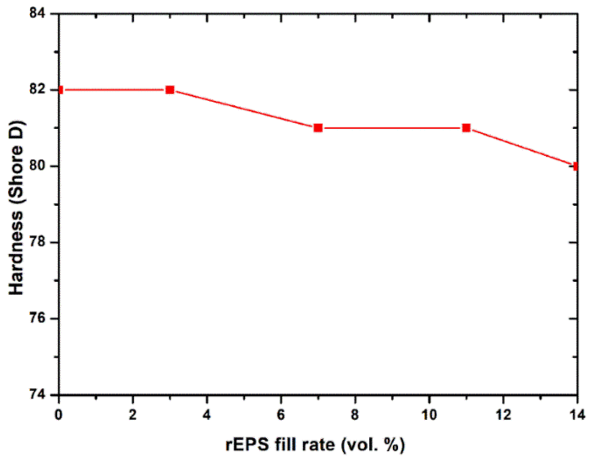

Figure 8. Variation of hardness according to EPS filling ratio

3.2. Hardness Measurement Results

The hardness measurement results of the prepared Epoxy/PS(+PA) composites are given in Table 3 and compared graphically in Figure 8. When the results in the table are examined, it can be seen that there is no significant difference in hardness among the epoxy composite samples. These results indicate that the hardness values of the samples are similar and within a close range. The hardness values of the samples coded as E/EPS00 and E/EPS03 are the same, measured as 82 Shore D. The hardness values of the other samples range between 80-81 Shore D. As the additive ratio increases, the differences in hardness measurement values also increase. In areas where EPS(+PA6) bubbles are present within the matrix, the epoxy thickness is relatively lower compared to other regions. As a result, measurements taken on the surfaces with EPS (+PA6) bubbles indicate lower hardness values. Although there are no significant differences in hardness within the sample, it is thought that there is a difference in hardness, and the EPS(+PA6) bubbles are considered to be effective in this difference [33, 34].

3.3. Surface Gloss Measurement Results

The measurement results of surface glossiness obtained at a 60° projection angle using an Elcometer brand micro-gloss meter are given in Table 3 and compared graphically in Figure 9. According to the results, surface glossiness values in Gloss Units (GU) are specified for samples coded as E/EPS00, E/EPS03, E/EPS07, E/EPS11, and E/EPS14. The surface glossiness values were measured as 95.8 GU, 87.4 GU, 81 GU, 77.6 GU, and 64.0 GU, respectively. According to the results, the E/EPS00 sample falls into the very high glossiness class, E/EPS03 sample falls into the high glossiness class, E/EPS07 sample falls into the medium glossiness class, E/EPS11 sample falls into the low glossiness class, and E/EPS14 sample falls into the very low glossiness class. These values indicate that the surface glossiness of the samples is different and decreases in a specific order. The sample coded as E/EPS00 has the highest glossiness value of 95.8 GU and has a shinier surface compared to other samples. The samples coded as

E/EPS03, E/EPS07, E/EPS11, and E/EPS14 have surface glossiness values of 87.4 GU, 81 GU, 77.6 GU, and 64.0 GU, respectively, which are lower than the E/EPS00 sample. The results show that the surface glossiness of the samples may vary depending on factors such as material composition, processing, or surface treatment, and there is a specific pattern among the samples. Surface glossiness is an important characteristic depending on the appearance, aesthetic value, and intended use of materials, and it stands out as a parameter that needs to be controlled in production processes [35].

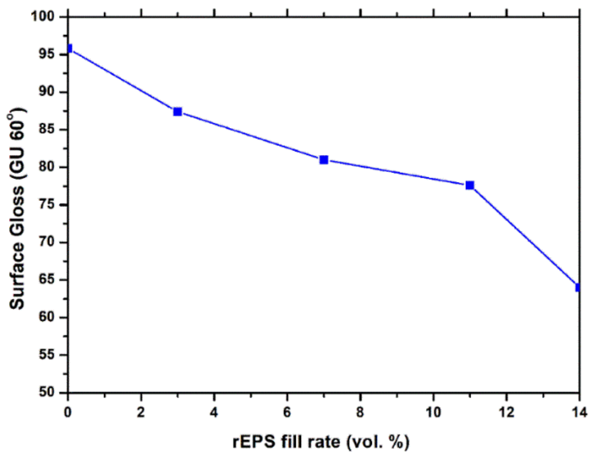

Figure 9. Variation of surface gloss according to EPS filling ratio

Table 3. Hardness and surface gloss measurement results

CODE	EPS(+PA) (wt.%)	Hardness (Shore D)	Surface Gloss (GU 60°)
E/EPS00	-	82±1 (0.7)*	95.8
E/EPS03	3	82±1 (0.5)*	87.4
E/EPS07	7	81±2 (0.3)*	81.0
E/EPS11	11	81±2 (0.4)*	77.6
E/EPS14	14	80±2 (0.3)*	64.0

* The values within parentheses represent the standard deviation

3.4 Charpy Impact Test Results

The impact strength of pure epoxy (E/EPS00) was determined to be 5.3 kJ/m^2. For the samples labeled as E/EPS03, the impact strength was found to be 4.8 kJ/m^2, while for E/EPS07, E/EPS11, and E/EPS14 samples, the impact strength values were 4.8 kJ/m^2, 2.9 kJ/m^2, and 1.1 kJ/m^2, respectively.

Upon examining the impact strength values of epoxy samples, it is observed that the impact strength decreases with an increase in rEPS content. E/EPS00 and E/EPS03 samples exhibit higher impact strength, whereas E/EPS07, E/EPS11, and E/EPS14 samples show lower impact strength, in accordance with literature [36]. The decrease in impact strength with an increase in rEPS content is believed to be attributed to the relatively larger size of rEPS particles [37,38]. Smaller particle sizes generally improve impact strength by increasing contact points, enhancing resistance to external forces, and improving load transfer and stress distribution. Larger particles, however, can create stress concentration points, weaken the material, and hinder proper interlocking and bonding, reducing its ability to absorb and dissipate energy during impact [39-41].

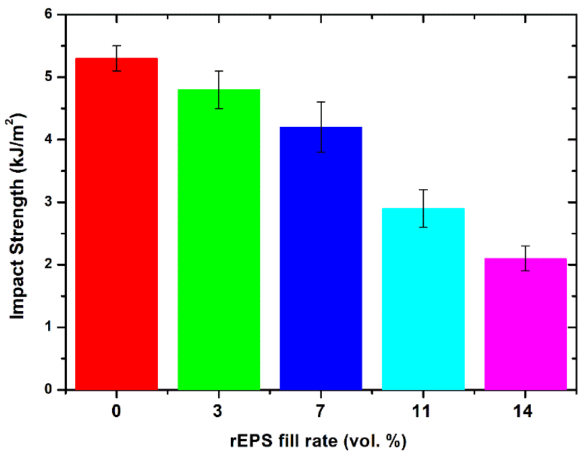

Figure 10. Variation of Charpy impact strength according to EPS filling ratio

IV. CONCLUSION

In this study, density, hardness, and surface gloss of epoxy composites prepared using epoxy matrix and varying amounts of rEPS were measured, and impact testing was performed on the samples. The results showed that the use of rEPS in epoxy composite materials has specific effects on material properties. Material properties such as density, hardness, and surface gloss vary depending on the rEPS content. The general findings obtained from this study are as follows:

1. It was observed that rEPS bubbles reduce the density and weight of epoxy composite materials, which can provide advantages in areas where lightweight materials are used, such as aviation, automotive, and energy.
2. Surface gloss of the samples varies depending on the rEPS bubble content.
3. There were no significant differences in hardness values among the samples. However, partial changes in hardness are thought to occur especially in regions where rEPS bubbles are present. Therefore, it is recommended to carefully select the material and rEPS bubble content considering application requirements and usage conditions.
4. According to the impact strength test results of epoxy samples, it was observed that impact strength decreases with increasing rEPS content. Samples coded as E/EPS00 and E/EPS03 have higher impact strength, while samples coded as E/EPS07, E/EPS11, and E/EPS14 have lower impact strength. These results are in accordance with the literature, indicating that the increase in the amount of large-sized rEPS in epoxy can negatively affect impact strength. The reasons for this decrease should be investigated in more detail. Understanding the effect of rEPS content on impact strength can help to properly evaluate the use of composite materials in structural applications.
5. Production processes should be carefully adjusted for ensuring homogeneous distribution of rEPS additives in composite materials. Achieving homogeneous distribution can contribute to achieving desired material properties.
6. It was concluded that the use of rEPS has an effective impact on the material properties of epoxy composite materials, but positive results can be obtained through proper selection, production processes, and performance testing. This study encourages further research on the use of rEPS in epoxy composite materials.

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