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Investigation of the Effect of Filling Ratio on Mechanical Properties of Pumice Filled Epoxy-Based Composites

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Anahtar Kelimeler

Epoksi
Pomza
Dolgulu Kompozit
Basma Testi

Graphical/Tabular Abstract (Grafik Özet)

In this study, unfilled and 10%, 20%, 30% pumice filled epoxy-based composites were produced by vacuum method and the effect of filling ratio on the mechanical properties of the composites was investigated. / Bu çalışmada, dolgusuz ve % 10, 20, 30 pomza dolgulu epoksi bazlı kompozitler vakum metodu ile üretilmiş ve dolgu oranının kompozitlerin mekanik özellikleri üzerindeki etkisi incelenmiştir.

Figure A*: Schematic representation of production and testing phases. /* ***Şekil A:*** *Üretim ve test aşamalarının şematik gösterimi.*

Highlights (Önemli noktalar)

- *The powders in the composites were dispersed with an ultrasonic mixer and air evacuated by vacuuming. / Kompozitlerdeki tozlar ultrasonik karıştırıcı ile dağıtılmış ve vakumlama ile hava tahliyesi yapılmıştır.*
- *The effect of filling ratio on mechanical properties was investigated with 3 different ratios of filled composite and control samples. / 3 farklı oranda dolgulu kompozit ve kontrol numunesi ile dolgu oranının mekanik özellikler üzerindeki etkisi incelenmiştir.*
- *Observations were made with an optical microscope to observe the fill distribution. / Dolgu dağılımı gözlemi için optik mikroskopla gözlemler yapılmıştır.*

Aim (Amaç): *The aim of this study is to determine the change in the mechanical properties of epoxy-based composites as a filling material with pumice powder. / Bu çalışmanın amacı pomza tozunun dolgu malzemesi olarak epoksi bazlı kompozitlerin mekanik özelliklerinde meydana getirdiği değişimi tespit etmektir.)*

Originality (Özgünlük): *The original aspect of the study is the use of pumice powder as a filled material. / Çalışmanın özgün yanı dolgu malzemesi olarak pomza tozunun kullanılmasıdır.*

Results (Bulgular): *Optimum mechanical values were found in 20% pumice filled composite. The maximum stress value of the 20% filled composite material was found to be 30.6 MPa and the equivalent unit strain at this point was 0.049% according to the mechanical test findings. / Optimum mekanik değerler %20 pomza dolgulu kompozitte bulunmuştur. %20 dolgulu kompozit malzemenin maksimum gerilme değeri 30,6 MPa ve bu noktadaki eşdeğer birim gerinim mekanik test bulgularına göre %0,049 olarak bulunmuştur.*

Conclusion (Sonuç): *As a result, it has been determined that the pumice filling significantly affects the mechanical properties of the epoxy-based filled composite and this change is directly related to the filling ratio. / Sonuç olarak pomza dolgusunun epoksi bazlı dolgulu kompozitin mekeanik özelliklerini önemli ölçüde etkilediği ve bu değişimin dolgu oranı ile doğrudan bağlantılı olduğu tespit edilmiştir.*

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Abstract

This study attempted to filled epoxy, a widely used industrial material, with pumice, a cheap volcanic rock, in order to form a composite material. The objective was to evaluate the worth of the pumice and improve the mechanical properties of the epoxy. Composite samples with no filler, 10%, 20%, and 30% filler were produced. An ultrasonic mixer during manufacture made sure the powder was dispersed properly, and vacuuming stopped air pockets from accumulating in the composite. The mechanical characteristics of the composites were evaluated by compression testing, and the post-production distribution of the powder was observed using optical microscope pictures. Finally, XRF analysis was used to establish the composition of the pumice powder. The outcomes demonstrated that adding filler greatly enhanced the maximum stress and unit strain values of the composites. Optimum mechanical values were found in 20% pumice filled composite. The maximum stress value of the composite material with 20% filler was found to be 30.6 MPa, and the equivalent unit strain at this point was 0.049%, according to the mechanical test findings.

Pomza Dolgulu Epoksi Esaslı Kompozitlerin Dolgu Oranının Mekanik Özelliklerine Etkisinin İncelenmesi

Makale Bilgisi

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Öz

Bu çalışmada yaygın olarak kullanılan ve endüstriyel bir malzeme olan epoksi, ucuz volkanik bir kayaç olan pomza ile doldurularak kompozit bir malzeme elde edilmeye çalışılmıştır. Amaç, pomzayı katma değeri yüksek olarak değerlendirmek ve epoksinin mekanik özelliklerini iyileştirmektir. Dolgusuz, %10, %20 ve %30 dolgulu kompozit numuneler üretilmiştir. Üretim sırasında bir ultrasonik karıştırıcı kullanılarak tozun homojen bir şekilde dağılması sağlanmıl ve vakumlama ile hava ceplerinin kompozitte birikmesi önlenmiştir. Kompozitlerin mekanik özellikleri basma testi ile tespit edilmiş ve tozun üretim sonrası dağılımı optik mikroskop resimleri kullanılarak gözlemlenmiştir. Son olarak, pomza tozunun bileşimini belirlemek için XRF analizi kullanılmıştır. Sonuçlar, dolgu maddesi eklenmesinin kompozitlerin maksimum gerilim ve gerinim değerlerini büyük ölçüde artırdığını göstermiştir. Optimum mekanik değerler %20 pomza dolgulu kompozitte bulunmuştur. %20 dolgulu kompozit malzemenin maksimum gerilme değeri 30,6 MPa ve bu noktadaki eşdeğer birim gerinim mekanik test bulgularına göre %0,049 olarak bulunmuştur.

1. INTRODUCTION (GİRİŞ)

The mechanical properties of composites are vital in determining their suitability to suit diverse applications [1]. Epoxy-based composites are known for their excellent mechanical properties, including high stiffness, strength, and toughness. In addition, epoxy-matrix composites exhibit low thermal conductivity and high temperature resistance, which make them widely used in various industries such as automotive, aviation, construction, marine, and other [2], [3]. Furthermore, epoxy-matrix composites are more durable and have longer lifetimes compared to other polymer-based materials. Therefore, it have become a preferred material for product design and engineering applications in many industries. However, the addition of fillers such as graphene, clay, carbon nanotube, SiC, SiO_2, B_4C pumice etc. can further enhance these properties while maintaining the low weight and ease of processing of the epoxy matrix [4]. Particle fillers are a widely

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used type of filler in composite materials. They could significantly influence the mechanical, thermal, surface, and fire resistance properties of composites. When added to a matrix material, particle fillers can induce changes in the properties of the matrix. Particle fillers offer numerous advantages, including low cost, high flexibility in comparison to high-density filler materials, high surface area, and low density. These fillers can be found in a variety of sizes and shapes and can be made from different materials. The use of particle fillers in composite materials is particularly preferred for their ability to decrease material costs, increase material properties, decrease weight, and provide performance characteristics that meet specific requirements.

Pumice is an attractive filler material due to its unique properties. It is a natural volcanic rock that is lightweight, porous, and abundant. Pumice is also low in cost, making it an appealing alternative to other fillers that may be more expensive. Pumice is a type of volcanic rock that is typically formed from the explosion of gas bubbles on the surface of lava [5]. It is a lightweight and porous material that can float on water. Pumice can be dark or light in color and, despite its lightweight and porous structure, it is quite durable. It is used in various fields such as construction, cosmetics and gardening [6]. The composition of pumice can vary depending on its source, but in general, it is primarily made up of volcanic glass with high amounts of silica (SiO_2), aluminum oxide (Al_2O_3), and other trace elements. It also contains numerous gas pockets or vesicles, which give it its porous and lightweight nature. To improve the mechanical properties of epoxy-based composites, low-density particle fillers, such as pumice, can be utilized. By providing a high surface area, particle fillers like pumice can improve the material properties and provide in the production of materials that meet specific performance requirements [7]. Apart from this, the fact that pumice is very cheap compared to other filling materials is also a remarkable feature. Below are some studies with pumice and epoxy, which were determined as a result of the literature review.

Koyuncu [8] explored the effect of adding pumice powder to corn shell reinforced with epoxy composites. The composites were prepared using different weight percentages of pumice powder through a hand lay-up technique, and their mechanical properties, including tensile strength, flexural strength, and water absorption, were evaluated through mechanical tests. The findings showed that the composites with 20% and 15% pumice powder have the best mechanical characteristics. Moreover, the addition of pumice powder has been found to improve the mechanical properties of the composites. The 20% and 15% pumice powder composites showed tensile and flexural strengths of 11.745 MPa and 11.250 MPa, respectively. Additionally, the 25% pumice powder composite has been observed to display superior resistance to water absorption compared to the other composites. Purohit at al., [9]conducted experiments with fly ash, which possesses a chemical composition akin to that of pumice. They explored the potential benefits of incorporating fillers such as glass fiber and fly ash into polymer composites for various applications. The main aim of their research was to investigete the impact of fly ash powder additions to the epoxy matrix on the properties of polymer matrix composites. Using the hand lay-up method, they produced composite materials with varying mass percent of fly ash particles. The composites were subsequently subjected to microstructural, tensile, impact, and flexural strength tests to determine how the introduction of fly ash affected their properties. In a study conducted by koyuncu et al., [10] the aim was to investigate the effect of adding pumice powder (20wt%) on the elongation and water absorption at break properties of epoxy-based composites reinforced with three different types of walnut husk particles. The composites were product using the hand lay-up method. The authors found that as the filler content increased, the water absorption of the composites decreased. The study concluded that adding pumice powder was effective in improve the performance of the walnut husk/epoxy composites due to the modification of the hydrophilic characteristics of the walnut husk particles. However, it was also discovered that the incorporation of pumice powder led to a significant decrease in the elongation at break of the composites. Fleischer at al., [11] introduced a method for manufacturing epoxy based composite panels by utilizing pumice stones and an epoxy binder in one of their studies. They evaluated the cost-effective and lightweight structure by conducting mechanical tests and explored its potential in energy absorption applications.

As it is known, epoxy-based composites are used in many areas in practice. However, a disadvantage of epoxy-based composites that limits the application areas is that they have insufficient ductility and therefore have a brittle structure. Many studies have been carried out to address this deficiency. One of the solutions for this area is powder filling of epoxy-based composites. However, some powders have a positive effect, some have a negative effect, and some may have a different effect according to the filling ratio. In this study, the effect of pumice filler and filler ratio on the mechanical strength and especially ductility of the epoxy-based composite was investigated. When using pumice as a filler material in epoxy-based composites, it is crucial to consider the filling ratio. The filling ratio determines the amount of pumice that is added to the epoxy matrix, and it can significantly impact the resulting composite's mechanical properties. Understanding how the filling ratio affects the mechanical properties of the epoxy-based composite is crucial for the intended application. For instance, a composite material designed for structural applications may require a high filling ratio to achieve the desired strength and hardness, whereas a material designed for impact resistance may require a lower filling ratio to enhance toughness and flexibility. To address these issues, this study investigates the influence of the filling ratio on the mechanical properties of pumice-filled epoxy-based composites. Overall, this study has significant implications for the development of high-performance polymer based composite materials that are cost-effective and environmentally friendly. The investigation of the effect of filling ratio on the mechanical properties of pumice-filled epoxy-matrix composites can contribute to the advancement of materials science and engineering and the development of innovative solutions for a range of applications.

2. MATERIALS AND METHODS (MATERYAL VE METOD)

In this study, the microstructure characterization and compressive mechanical strength of pumice-reinforced epoxy-matrix composite materials were determined using the following methods.

The production of pumice-reinforced epoxy matrix composite materials was the first step of this study, which is visualized schematically in Figure 1. Hexon LR160 resin and MGS LH160 hardener were used. Acidic pumice was washed, dried, ground, separated by sieves and used. XRF analysis of the pumice we used was performed and the results are listed in Table 1. The dimensions of the pumice powder used are approximately 45 microns. Pumice powder was mixed with epoxy resin in weight percentages of 10%, 20%, and 30% during the production process. The mixing process was carried out for 30 minutes using an ultrasonic mixer, and then left under vacuum for 10 minutes to ensure homogeneity. The mixture was then poured into cylindrical molds and cured at room temperature for 24 hours. This process was repeated for each pumice-reinforced epoxy matrix composite material. In addition, an unfilled epoxy specimen was produced as a control specimen.

The use of ultrasonic mixers in the production of composites aimed to improve the quality and properties of the composite materials. Ultrasonic mixers use high-frequency ultrasonic vibrations to mix the materials and provide a homogeneous distribution. This is a crucial feature because uneven distribution of powders can lead to irregularities and differences in the properties of the composite materials. By providing a homogeneous distribution of the powder, ultrasonic mixers lead to improve important properties of the composite material, such as strength, and other properties. Additionally, ultrasonic mixers are more efficient and mix materials in a shorter time, which helps to reduce the production time.

Secondly, the compressive mechanical strengths of the composite specimen were determined in accordance with the ASTM D695 standard. To this end, the specimen geometry and dimensions are depicted in Figure 2. The compression tests were conducted using a universal testing machine at a speed of 2 mm/min. For each specimen, three repetitions were carried out, and the average were calculated. The ASTM D695 standard is generally used to test the compressive properties of hard polymers. In accordance with this standard, the cylindrical sample dimensions are commenly determined as 12.5 mm in diameter and 25 mm in height, which enables the samples to be tested in accordance with appropriate testing equipment and standards. It is substantial to prepare and test the specimen properly in order to obtain accurate results. Therefore, post-production adjustments in the sample dimensions were made using a wet cylindrical cutting method.

Figure 1. Schematic representation of production and testing phases (Üretim ve test aşamalarının şematik gösterimi)

Finally, an optic microscope (OM) was employed to investigate the internal structures of the composite samples produced. The resulting images were then analyzed to evaluate the compatibility between the pumice powder and the epoxy matrix, as well as the impact of the filling ratio on the fracture mechanism and potential defects.

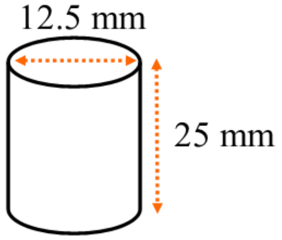

Figure 2. Filled specimen geometry and dimensions (Dolgulu kompozit numune geometrisi ve boyutları)

Table 1. XRF analysis results of ground and separated pumice powder (Öğütülmüş ve yabancı maddelerden arındırılmış pomza tozunun XRF analiz sonuçları)

SiO_2	Al_2O_3	Fe_2O_3	CaO	Na_2O	K_2O
74.43%	12.83%	1.83%	1.56%	4.37%	4.37%

3. RESULTS AND DISCUSSION (BULGULAR VE TARTIŞMA)

In this study, the mechanical properties of unfilled, 10%, 20%, 30% pumice reinforced epoxy-based composites were investigated by compression tests. Compression tests of epoxy-based composites reinforced with pumice reinforcement at different rates were carried out. The test results provide detailed information on the mechanical strength of each composite. In this section, the analysis of the results obtained for each pumice reinforcement ratio presented and the results discussed.

The stress-strain curves for each composite are depicted in Figure 3. The results showed that the unfilled composite material's fracture point was 24.33 MPa. The amount of unit deformation during the peak stress was 0.032%. After the maximum load, the unfilled material exhibited no strength and abruptly fell. Based on these observations during the test, it was determined that the sample was extremely brittle. The graph shown in Figure 2 shows that during the compression test, the composite material with 10% pumice filler showed a maximum stress value of 29.7 MPa and a corresponding unit strain of 0.05%. According to the findings, the maximum stress value increased when compared to the unfilled composite. In particular, the unit strain increased by 56.2 % while the maximum stress value increased by 22.1 % as compared to the unfilled composite. These results indicate that the maximum stress value and unit strain significantly increased after 10% pumice was added to the epoxy-based composite. These results are impressive and show the potential advantages of using pumice in composite materials.

The maximum stress value of the composite material with 20% filler was found to be 30.6 MPa, and the equivalent unit strain at this point was 0.049%, according to the mechanical test findings. The maximum stress value increased when compared to the unfilled and 10% filled composites, but only when compared to the unfilled composite did the increase become statistically significant. Furthermore, when compared to the 10% filled composite, it was discovered that the increase in the maximum stress value was quite minimal. Compared to the unfilled composite, the unit strain values increased, but when compared to the 10% filled composite, they essentially stayed the same. The maximum stress value for the composite material with 30% pumice filler was determined to be 30.4 MPa, and the equivalent unit strain at this point was 0.046% when the values of the composite material with this filler were analyzed. The results obtained imply that the mechanical properties of the epoxy-based composite material were greatly enhanced by the inclusion of pumice filler. The fact that both the maximum stress value and unit strain increased as a result of this makes it more notable. The lack of a discernible variation in the mechanical characteristics of the composites with 10%, 20%, and 30% fillers implies that a 10% filler ratio is adequate to get the best results. Because to the micro porous nature of pumice and the vacuum-assisted impregnation of epoxy during manufacture, the mechanical properties have probably improved.

In Figure 4, optical microscope images of the unreinforced and 10%, 20%, and 30% filled composite samples are sequentially presented. As can be seen from the images, the distribution has been nearly homogeneous. Additionally, it was found that the volcanic rock, pumice, has a sharp-edged structure and its geometry allows for a good interfacial bond with the epoxy matrix.

Figure 5 shows the samples' visual representations both before and after testing. It is clear from these figure that the filled samples behave more ductile and fracture and shatter in a less brittle manner than the unreinforced sample does. Particularly noteworthy is the fracture of the 20% filled composite, which displays ductile material behavior at a 45-degree angle. The unfilled sample is completely dispersed under compression load, the fracture type changes as the filling ratio increases. While it shattered by controlled breaking in 30% and 10% reinforced samples, no fragmentation was observed in the 20% filled sample. In addition, while the unreinforced sample has a transparent appearance, it is seen that there is a darkening in the sample colors as the filling ratio increases. This color change is homogeneous throughout the sample. This shows that the mixture is close to homogeneous.

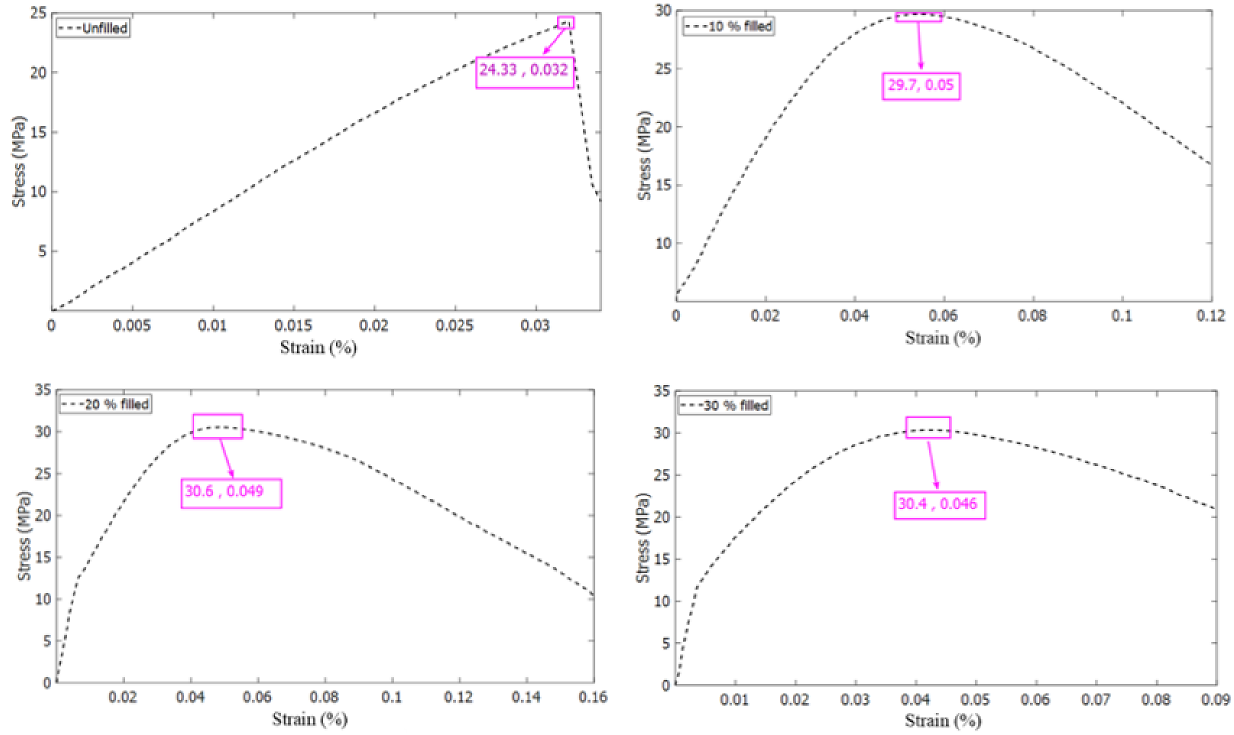

Figure 3. Compression test results of unreinforced, 10%, 20%, 30% filled pumice/epoxy composites
(Takviyesiz, %10, %20, %30 dolgulu pomza/epoksi kompozitlerin basma testi sonuçları)

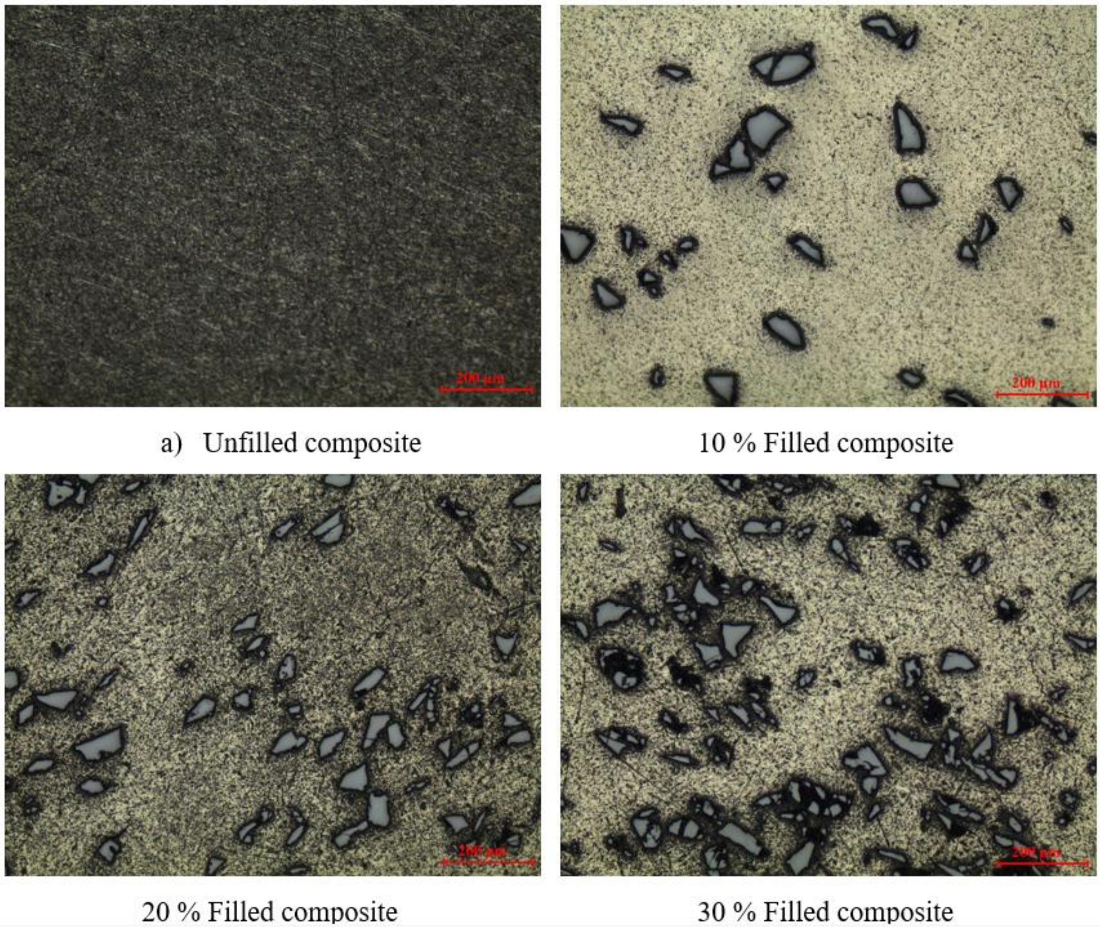

Figure 4. Optical microscope images of unreinforced, 10%, 20%, 30% filled pumice/epoxy composites
(Takviyesiz, %10, %20, %30 dolgulu pomza/epoksi kompozitlerin optik mikroskop görüntüleri)

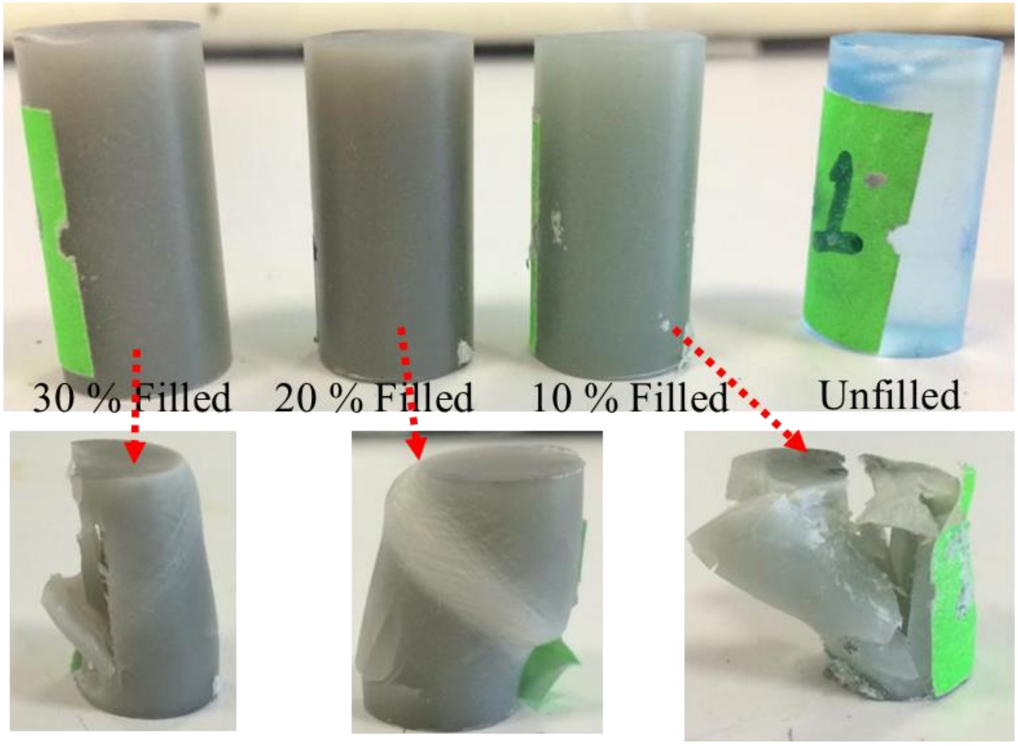

Figure 5. The images before and after testing of filled composites (Dolgulu kompozitlerin test edilmesinden önceki ve sonraki görüntüler)

4. CONCLUSIONS (SONUÇLAR)

This study sought to characterize the pumice-reinforced epoxy-matrix composite materials' microstructure and compressive mechanical strength. In-depth information about the creation of composite materials was provided, and it was demonstrated that using ultrasonic mixers enhanced their quality and properties. The ASTM D695 standard was used to determine the compressive mechanical strengths of the composite specimens, and the resulting stress-strain curves for each composite were examined. In addition, XRF analysis was performed on the cleaned, dried, ground and sieved pumice powders for the determination of the pumice mineral content used in composite materials and it was determined that it mainly contained SiO_2. The results of the compression tests demonstrated that the maximum stress value and unit strain of the composites were greatly increased by the addition of pumice. When 10% pumice was added to the composite, the unit strain increased by 56.2% and the maximum stress value by 22.1%. The maximum stress value and unit strain were both improved by the inclusion of 20% and 30% pumice, although these improvements were not statistically different from those of the 10% filled composite. The distribution of pumice was virtually uniform, and the optical microscope images showed that it had a strong interfacial bond with the epoxy matrix. Additionally, compared to the empty sample, the filled samples had a more ductile behavior. These results imply that pumice may be a useful and affordable filler for enhancing the mechanical characteristics of composite materials.

DECLARATION OF ETHICAL STANDARDS (ETİK STANDARTLARIN BEYANI)

The author of this article declares that the materials and methods they use in their work do not require ethical committee approval and/or legal-specific permission.

Bu makalenin yazarı çalışmalarında kullandıkları materyal ve yöntemlerin etik kurul izni ve/veya yasal-özel bir izin gerektirmediğini beyan ederler.

AUTHORS' CONTRIBUTIONS (YAZARLARIN KATKILARI)

***Ertan KÖSEDAĞ*:** He conducted the experiments, analyzed the results and performed the writing process.

Deneyleri yapmış, sonuçlarını analiz etmiş ve maklenin yazım işlemini gerçekleştirmiştir.

CONFLICT OF INTEREST (ÇIKAR ÇATIŞMASI)

There is no conflict of interest in this study.

Bu çalışmada herhangi bir çıkar çatışması yoktur.

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