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Determination of Mechanical Performance of Epoxy Composites with magnesium oxide (MgO) Addition

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Zaynab Miftah Alsaweeb*, Salma Al-Tohami Al-Ahwal
Education faculty, Misurata University- Libya
*Zineee1@gmail.com

Abstract

This study aims to determine the mechanical properties of epoxy-magnesium oxide composite through tensile, impact strength and hardness testing. The epoxy-magnesium oxide composite was prepared by adding varying weight fractions of magnesium oxide powder to an epoxy matrix. Tensile testing was conducted to evaluate the tensile strength and the composite's model. Impact strength testing was performed to assess the resistance of the composite to sudden shock loads. Rockwell hardness testing was done to determine the composite's resistance to indentation. Tensile testing results revealed that the addition of magnesium oxide powder increased the tensile strength of the epoxy-magnesium oxide powder composite. The composite with the weight ratio of 25 wt % of magnesium oxide powder exhibited the highest tensile strength value, equal to 0.48N/mm^2. Impact strength testing showed that the addition of magnesium oxide powder improved the composite's resistance to sudden shock loads. The composite with the weight ratio of 25 wt % of magnesium oxide powder exhibited the highest impact strength, equal to 1.01 J. Hardness testing indicated that the addition of magnesium oxide powder increased the overall hardness of the composite. The composite with the weight ratio of 25 wt % of magnesium oxide powder had the highest hardness value, equal to 1.93J.

Keywords: epoxy resin, mechanical tests, Composite materials, impact strength, tension strength, hardness.

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تحديد الأداء الميكانيكي للمركبات الإيبوكسية مع إضافة أكسيد الماغنيسيوم MgO

زينب مفتاح محمد السويب، سالمة التهامي عبد الحميد الأحول

كلية التربية، جامعة مصراتة – **ليبيا**

Zineeee1@gmail.com

الملخص:

تهدف هذه الدراسة إلى تحديد الخصائص الميكانيكية لمركب الإيبوكسي–أكسيد المغنيسيوم من خلال اختبار الشد، و اختبار قوة الصدمة، و اختبار الصلابة. حيث تم تحضير مركب الإيبوكسي–أكسيد المغنيسيوم عن طريق إضافة نسب وزنية متغيرة من مسحوق أكسيد المغنيسيوم إلى مصفوفة الإيبوكسي. تم إجراء اختبار الشد لتقييم مقاومة الشد ونموذج المركب. تم إجراء اختبار قوة الصدمة لتقييم مقاومة المركب للأحمال الصدمية المفاجئة. تم إجراء اختبار صلابة روكويل لتحديد مقاومة المركب للغرز. حيث أظهرت نتائج اختبارات الشد أن إضافة مسحوق أكسيد المغنيسيوم قد زاد من قوة الشد لمركب الإيبوكسي–أكسيد المغنيسيوم. أظهر المركب الذي يحتوي على نسبة وزن 25% من مسحوق أكسيد المغنيسيوم أعلى قيمة لقوة الشد، تساوي 0.48نيوتن/ متر^{2}. أظهرت اختبارات قوة الصدمة أن إضافة مسحوق أكسيد المغنيسيوم قد حسنت من مقاومة المركب للأحمال الصدمية المفاجئة. أظهر المركب الذي يحتوي على نسبة وزن 25% من مسحوق أكسيد المغنيسيوم أعلى قوة صدمة، تساوي 1.01 جول. أشارت اختبارات الصلابة إلى أن إضافة مسحوق أكسيد المغنيسيوم قد زادت من صلابة المركب بشكل عام. كان للمركب الذي يحتوي على نسبة وزن 25% من مسحوق أكسيد المغنيسيوم أعلى قيمة صلابة، تساوي 1.93جول.

الكلمات المفتاحية: راتنج الإيبوكسي، الإختبارات الميكانيكية، المواد المركبة، قوة الصدمة، قوة الشد، الصلابة.

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1. Introduction

Epoxy composites have gained significant attention in recent years due to their excellent mechanical properties and wide range of applications in various industries (Cruz-Cruz et al., 2021; Ali et al., 2013).These composites are formed by combining epoxy resin with different reinforcing materials, such as fibers, nanoparticles, and fillers, to enhance their mechanical performance. Among the various reinforcing materials, magnesium oxide (MgO) has shown promising results in improving the mechanical properties of epoxy composites. One such reinforcing filler is magnesium oxide (MgO), which has shown promising results in improving the mechanical properties of epoxy composites. MgO is a white crystalline solid that possesses high thermal stability, excellent electrical insulation properties, and good mechanical strength. These properties make it an attractive candidate for reinforcing epoxy matrices (Hodul et al., 2021; Ray et al., 2020;Hull & Clyne, 1996;Mallick, 2007).

The mechanical properties of epoxy composites play a crucial role in determining their suitability for specific applications. Tensile strength, impact strength, and hardness are some of the key mechanical properties that are often evaluated to assess the performance of these composites (Ashby, 2011; Callister& Rethwisch, 2018; Ray et al., 2020; Hull & Clyne, 1996;Ratna, 2009).

A polymer is a large molecule, or macromolecule, composed of many repeated subunits. These subunits, known as monomers, are covalently bonded to form a chain-like structure. Polymers can be found in both natural and synthetic forms, with a wide range of properties and applications. Natural polymers include proteins, which are made of amino acid monomers, and nucleic acids, which are composed of nucleotide monomers. Cellulose and rubber are also examples of naturally occurring polymers. Synthetic polymers, on the other hand, include plastics like polyethylene and polypropylene, which are used in a vast array of products due to their versatility, durability, and low cost. The physical properties of polymers, such as their strength, elasticity, and resistance to

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chemicals, depend on the type of monomers they contain and how these monomers are arranged (Young& Lovell, 2011;May, 1988;Lancaster, 1999).Polymers can be categorized based on their source (natural or synthetic), their structure (linear, branched, or cross-linked), and their polymerization process (addition polymerization or condensation polymerization)(May& Jones, 2013).The study of polymers combines elements of chemical engineering, materials science, and chemistry, and it is a critical field for developing new materials that meet various industrial, medical, and environmental needs (Prolongo et al., 2014;Kinloch, 1987).

The researcher Rafqqa, investigated a polymer-based composite material. Epoxy resins were used as the base material while magnesium oxide powder (MgO) as the reinforcement at different fractures and were subjected to hardness test and also bending test. The results show that the value of the hardness increased with a non-linear rate as the weight fracture of the particles was raised. The values of the bending coefficient of elasticity as well as other values were also found to rise with the rising weight fracture (Rafqqa, 2014).

The researcher Fuaad, prepared polymer complexes of unsaturated poly styrene resin supported by micro-magnesium and nano-oxide. In the following weights (3, 6, 9, 12, 15) wt%, the results showed that the value of hardness increased with increasing concentration of (MgO) in the compound for all cases (Adding nano-magnesium oxide to the resin once and the magnesium oxide once again and mixing them again) The bending results showed that the deviation was directly proportional to the load applied to all samples and the bending coefficient was reduced by increasing the concentration of MgO for all samples (Fouad, 2016).

The researcher Zinah prepared a polymer blend matrix using epoxy resin (EP) mixed with unsaturated polyester resin (UP) in different ratios: 10, 20, 40, and 50 wt% for (EP/UP) blends. This blend was reinforced with magnesium oxide (MgO) powder in varying weight percentages: 0, 4, 8, and 12 wt%, forming a composite material. The mechanical properties (tensile strength,

impact resistance, and hardness) and thermal conductivity were tested both before and after reinforcement. After reinforcement, the impact resistance and tensile strength increased. The hardness also increased, though not proportionally to the MgO content. Additionally, as the MgO ratio increased, there was a notable rise in thermal conductivity. (Zinah & Suad, 2019).
Shi Zhihao et al. Studied micro- and nano-sized magnesium oxide (MgO) particles affect the mechanical properties of carbon fiber/epoxy composites. By incorporating different amounts of MgO into an epoxy resin matrix, researchers measured the impact and flexural strengths using Charpy impact tests and three-point bending experiments. The results indicated that the impact strength was increased by adding micro-MgO particles, the flexural strength was decreased by adding micro-MgO particles(Shi et al., 2022).
The aim of the current study is to investigate the effect of introducing magnesium oxide particles as fillers in epoxy resin on the mechanical properties. This will help in developing polymeric composite products made from epoxy reinforced with powders that are suitable for their specific applications within an integrated system. The properties can be utilized, allowing it to replace metal parts under certain conditions such as good durability, high performance, and its resistance to internal and external stresses affecting it, in addition to its resistance to surrounding conditions such as temperature, pressure, and others, along with its lightweight.

2. Experimental details

2.1 Samples Preparation

The hand lay-up molding method has been adopted for the preparation of samples. It has been used a silicone mold with special treatments to prevent the models from sticking as shown in figure (1).The samples were poured in symmetrical conditions, where the mixture was mixed for 8 to 10 minutes, then poured into the adapted mold. The samples were left for 24 hours to complete the full curing process at a temperature between 15 and 23 degrees Celsius, and then left for 15 days to complete the polymerization process completely before starting the examination of the samples. After completing these operations, samples of superimposed materials with a thickness of approximately 2 cm was obtained, which were then smoothed using zero degree smoothing sheets. Four samples were prepared for each of the prepared ratios to reduce the error rate and obtain more accurate results as shown in figure (2).

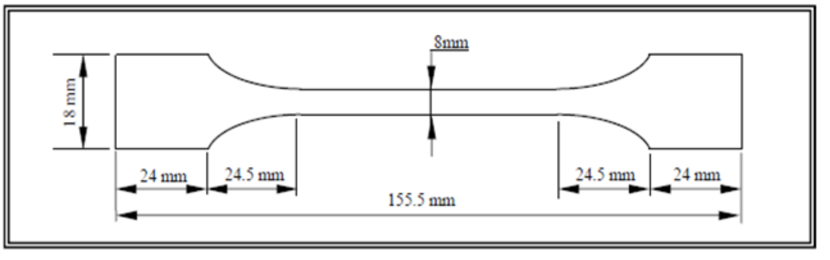

Figure (1): Mechanical testing model

Figure (2): Epoxy samples added with magnesium oxide powder in different weight ratios.

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The epoxy resin manufactured by Al-Madina Misurata Company for the manufacture of Libyan coating and pastes was used as a base material for the preparation of polymeric overlays. The resin is in a liquid state, and it can be converted toa solid state by adding the Hardener manufactured by the same company. The hardener is a light liquid with low viscosity, density and a transparent yellow to white color. The hardener is added to the resin in a ratio of (3:1) and mixed by hand. Magnesium Oxide (MgO) powder, which is a ceramic material with a density of 3.58 g/cm³, was added to the base material (matrix) in different weight ratios (0, 5, 10, 15, 20, and 25 wt%).

2.2 Mechanical testing

2.2.1 Tensile Test

The tensile properties of the epoxy-MgO composite were evaluated using a universal testing machine which made by (DEEPAK POL YPLAST) company. Rectangular-shaped specimens with standard dimensions were prepared for the tension test, where thesample width was 10mm and its thickness 10mm. The specimens were carefully mounted in the UTM grips, ensuring proper alignment of the load axis with the specimen's longitudinal axis. The tensile test was conducted at a constant crosshead speed of 50 mm/min until specimen failure occurred. Load and displacement data were recorded throughout the test, allowing the determination of stress-strain curves, ultimate tensile strength (UTS), and Young's modulus.

2.2.2 Impact Strength

This test is to determine the properties of the composite material under Izod impact of a hammer weighing 25.62 kg, with a length of 0.65 m and a lift angle of 143.5 degrees. The general testing device from Wuxi Serve Real Technology Co. Ltd, model AIV-3, was used in accordance with BS 812-112 standards, available at the Misrata Plastic Pipe Manufacturing Factory. The following relationship was used to calculate the Impact Strength by knowing the fracture angle in the sample.

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$$Impact\ Strength = WL(cosB - cos \propto) \qquad (1)$$

Where: **W** is a hammer weighing, **L** is a hammer length, **B** is a fracture angle and $\propto$ is a lift angle.

2.2.3 Hardness Test

Rock well hardness test to determine the properties of the composite material under the influence of a tungsten ball weighing 15.45 kg and with a diameter of 8 cm. The general testing device from ALIBABA-AICEYI, made in India, was used and is available at the iron and steel factory.

3. Results and discussion

3.1 Tensile Strength Results

The purpose of this study was to investigate the effect of weight ratios on tension strength in the epoxy-MgO composite. The weight ratios examined in this study were 0%, 5%, 10%, 15%, 20%, and 25wt%. Tension strength was measured and recorded for each weight ratio. The tension strength values obtained for each weight ratio are summarized in Table 1.

Table1: tensile Strength Results for epoxy-MgO composites with Different Weight Ratios.

Weight Ratio (wt %)	tensile Strength (N/mm^2)
0%	0.07
5%	0.2
10%	0.29
15%	0.36
20%	0.44
25%	0.48

As shown in figure 3 (a, b), it can be observed that as the weight ratio increased from 0% to 25 wt%, the tension strength increased from 0.07 to 0.48N/mm^2. At a weight ratio of 0 wt%, the recorded tensile strength was 0.07 N/mm^2. This value is considered a baseline measurement, indicating the potential strength of the

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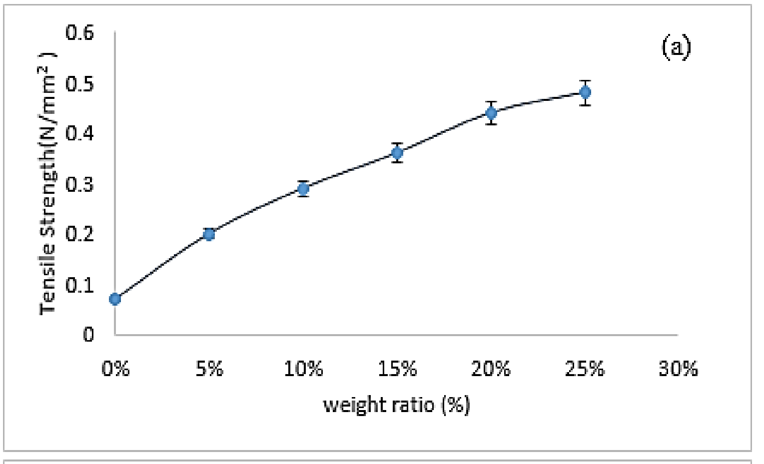
material in the absence of any additional weight. The low tensile strength at this ratio indicates limited structural integrity, which is typical for materials lacking reinforcement. With an increase in the weight ratio to 5 wt%, a noticeable increase in tensile strength is observed, rising to 0.20 N/mm². It appears that increasing weight ratios at this level enhances the material's ability to withstand tensile forces, likely due to the initial integration of reinforcement components or additives that contribute to overall structural cohesion. The increase continues with a weight ratio of 10 wt %, where the tensile strength reaches 0.29 N/mm². These gradual improvements suggest that the material's response to severe stress becomes more favorable with the increased ratio of magnesium oxide, possibly due to improved bonding between surfaces or stress distribution across a larger volume of material. At a weight ratio of 15 wt %, the tensile strength increases to 0.36 N/mm², indicating that the material's capacity to withstand load increases with the increase in weight ratios of the supporting material, thereby improving the tensile performance. The largest increase occurs at a weight ratio of 20 wt %, where the tensile strength rises to 0.44 N/mm², suggesting that the material is likely to reach its maximum performance capacity. Finally, at a weight ratio of 25 wt %, the tensile strength reaches the highest recorded value of 0.48 N/m², as the tension strength increases with the increase in the ratio of added particles, where magnesium oxide particles occupy a larger volume within the resin, allowing for better distribution of the applied load (Al-Mosawi 2011). Nagachandrika et al. studied the mechanical properties of epoxy magnesium oxide nanocomposites and observed the tensile strength increasing of MgO-added epoxy nanocomposite and above which a marginal reduction is observed (Nagachandrika et al.2019). Wetzel et al. studied the mechanical properties of epoxy nanocomposites containing Al_2O_3 and TiO_2 nanoparticles and observed improved modulus and strength with an increasing in particle volume fraction (Wetzel et al.2006).



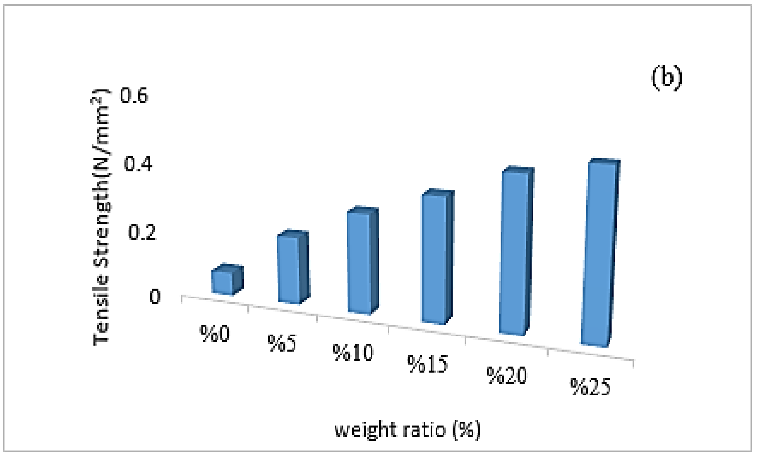


Figure3 (a, b): tensile Strength for Different Weight Ratios of Magnesium Oxide (MgO).

3.2 Impact Strength Results

The impact strength of the material at different weight ratios is presented in Table 2. This study examines the relationship between the weight ratio and the impact strength of a specific material.

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Table2: Impact Strength Results for epoxy-MgO composites with Different Weight Ratios.

Weight Ratio (wt %)	fracture angle	Impact Strength	
		J	N
0%	141	0.44	4.316
5%	140	0.63	6.18
10%	139	0.82	8.044
15%	138	1.01	9.908
20%	138	1.01	9.908
25%	137	1.21	11.870

As shown in figure 4 (a,b), the impact strength of the material increased as the weight ratio increased. Initially, at a weight percentage of 0 wt%, the material exhibits an impact strength of 0.44 J, which serves as the baseline for comparison. As the weight percentage increases to 5 wt%, a noticeable increase in impact strength occurs, reaching 0.63 J, indicating that a small addition of magnesium oxide significantly enhances the material's durability. The trend continues with a gradual increase in impact strength, peaking at 1.21 J at a weight percentage of 25 wt%. These continuous improvements suggest that the addition of filler enhances the material's capacity to absorb energy upon impact, thereby reducing the likelihood of fracture. Additionally, the observed fracture angles indicate a reduction in brittleness, as lower angles are typically associated with more ductile behavior in materials. Interestingly, the impact strength stabilizes at weight percentages of 15 wt% and 20 wt%, with each displaying an impact strength of 1.01 J. The reason for this is that a large portion of the impact energy applied to the resin is absorbed by the oxidative particles, which improves this resistance. Thus, the impact resistance increases with the increasing percentage of the added oxide (Al-Mosawi et al.,2010;Al-Mosawi,2011)

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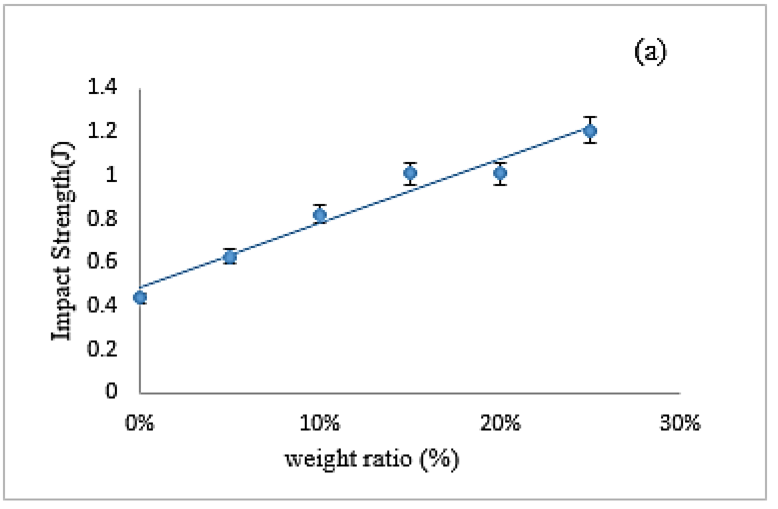

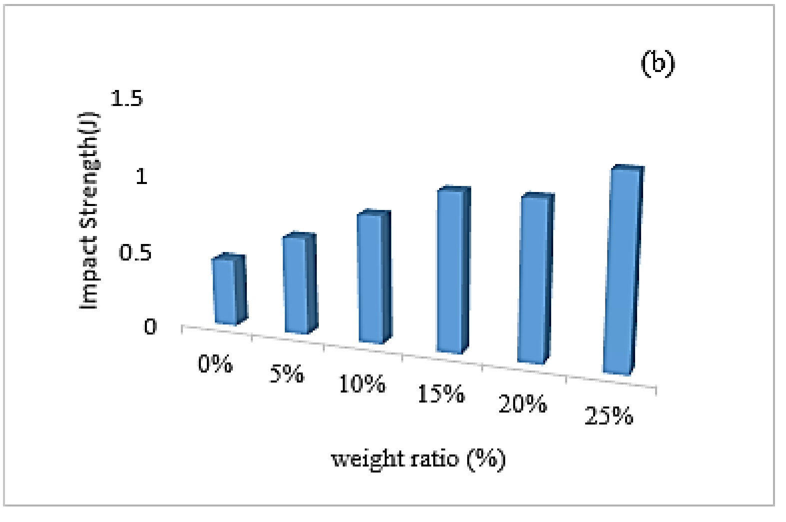

Figure 4 (a,b): Impact Strength for Different Weight Ratios of Magnesium Oxide (MgO).

3.3 Hardness Resistance Results

The Rockwell hardness values for each weight ratio are presented in Table 3.

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Table 3: Hardness values for epoxy-MgO composites with different weight ratios.

Weight Ratio (wt %)	Rockwell Hardness (J)
0%	1.28
5%	1.31
10%	1.4
15%	1.53
20%	1.75
25%	1.93

The hardness resistance of the epoxy-MgO composites varies with the weight ratio of MgO as shown in figure 5 (a,b). At the increase in weight ratios from 0 wt% to 25wt%, there is a continuous rise in Rockwell hardness, from 1.28 J at 0wt% to 1.93 J at 25wt%. This trend indicates that the introduction of additional weight ratio significantly enhances the hardness of the material. It is observed that all hardness values of the compounds for all weight ratios are higher than the hardness of epoxy (Rafqqa, 2014). At low weight ratios, particularly at 0 wt% and 5wt%, the hardness values are relatively low, suggesting that the material's structure may not yet have been optimized for strength. However, as the weight ratio increases, the hardness values show a notable improvement. The increase from 1.31 J at 5 wt% to 1.4 J at 10 wt% indicates that even a small addition of magnesium oxide begins to cause a change in the structure of matter, which may lead to increased atomic bonding and a more robust crystalline arrangement. The largest increase in hardness occurs between weight ratios of 15 wt% and 25wt%, where Rockwell hardness rises from 1.53 J to 1.93 J. This significant jump suggests that at higher concentrations, the material may reach a saturation point where the weight distribution enhances its mechanical properties.

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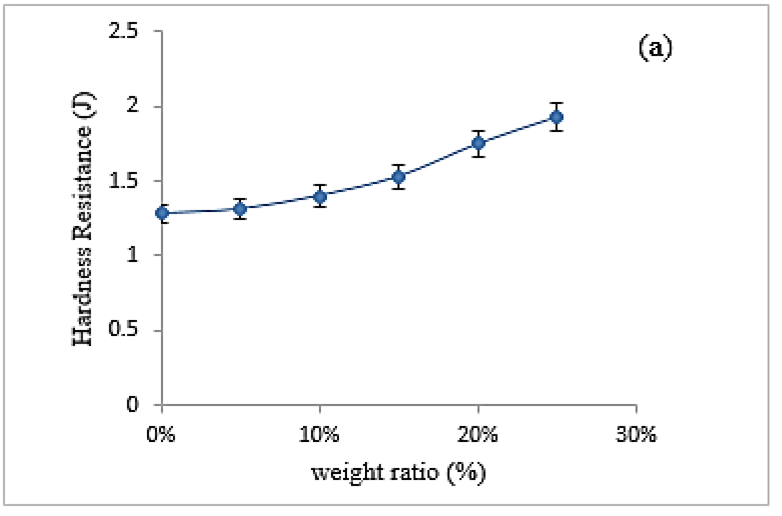

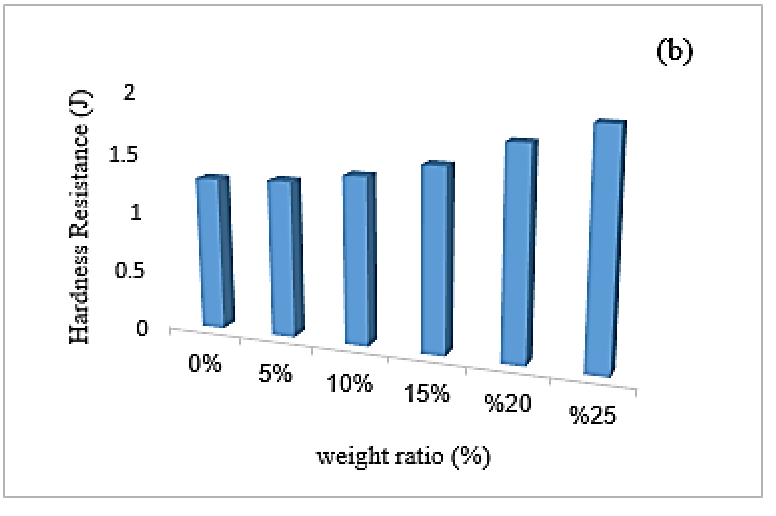

Figure 5 (a,b): Hardness Resistance for Different Weight Ratios of Magnesium Oxide (MgO).

4. Conclusion

Based on the results obtained from the mechanical tests applied to the epoxy resin before and after the addition of magnesium oxide, several conclusions were reached:

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1. Overall, the results of this study demonstrate the positive effect of increasing weight ratios on tension strength. As the weight ratio increased, the tension strength of the material increased significantly, highlighting the importance of reinforcement in enhancing material performance.
2. The impact strength of the material increased as the weight ratio increased. The highest impact strength was observed at 25 wt% weight ratio, while the lowest impact strength was observed at 0wt% weight ratio. These findings provide valuable insights into the impact resistance of the material and can inform the development of materials with improved impact strength properties.
3. The results indicate that the weight percentage of MgO plays an important role in determining the hardness of the composite material. An increase in hardness was observed with an increasing addition of MgO. The reason for this improvement is the strong bonding between the epoxy matrix interface and the MgO particles, leading to enhanced load transfer and resistance to deformation. Further research is needed to explore the underlying mechanisms responsible for the observed trends and to optimize the weight ratio for achieving desired hardness properties in epoxy-MgO composites.

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