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Study of the Mechanical Properties of Polymers and Their Comparison Using Epoxy and Polyester Mixtures

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Abstract. This study investigates the effect of varying mixing ratios between epoxy resin and unsaturated polyester resin on the mechanical and morphological properties of hybrid polymer composites. Six different blend ratios were prepared, ranging from 100% epoxy to 100% polyester. Abrasion resistance was evaluated using a Pin-on-Disc device under applied loads ranging from 500 g to 2500 g. The results showed that increasing the epoxy content significantly enhanced wear resistance. Under a 2500 g load, the residual weight increased from 0.3283 g for the 20% epoxy sample to 1.6947 g for the 100% epoxy sample, indicating reduced material loss due to the higher hardness and crosslink density of epoxy. Compressive strength was measured using a bold harris No. 36110 hydraulic press, following ASTM D695. The highest compressive strength was observed in the 100% epoxy sample (6.1 MPa), while the lowest value (0.6 MPa) was recorded for the 40% epoxy / 60% polyester blend, indicating weak interfacial bonding and poor structural compatibility. Scanning electron microscopy (SEM) analysis revealed features such as phase separation, particle agglomeration and microcracks in the hybrid samples, suggesting inadequate resin compatibility and non-uniform mixing. Overall, the results highlight that optimizing the epoxy-to-polyester ratio is essential to enhance both the mechanical performance and structural integrity of hybrid polymer composites.

Keywords: epoxy resin, unsaturated polyester resin, hybrid polymer composites, wear resistance, compressive strength, scanning electron microscopy (SEM), morphology

Introduction

Polymers are macromolecules formed by the repeated linking of small molecular units called monomers (Nemaha *et al*., 2022). These materials have become increasingly important in industrial and structural applications due to their light weight, low cost and versatile properties (Jasmin and Fadhil, 2018). Polyester, a widely used polymer, is known for its chemical resistance and ease of processing (Mahdi *et al*., 2017). Among synthetic polymers, epoxy resins are especially valued for their excellent adhesion and mechanical strength (Aleabi and Yahyaa, 2022). Over the past decade, significant research has focused on modifying and improving polymer properties through blending (Abbas, 2020), reinforcement or nanoparticle incorporation. These modifications aim to enhance mechanical performance and resistance to environmental degradation. Polymers have also found applications in biomedical devices (Jarboo'a and Alsarraf, 2020), including prosthetics, due to their lightweight nature and biocompatibility. Blending different types of resins, such as epoxy and unsaturated polyester (UPE) (Farhan *et al*., 2019; Hussein and Rasheed, 2019), has been explored as a method to create hybrid polymer blends or hybrid resin systems with improved or tunable properties, rather than traditional composites reinforced with fibres or fillers. These hybrid blends aim to combine the advantages of both resins at the molecular level to produce materials with e (Abd Aljabbar *et al*., 2012; Alhareb and Ahmad, 2010). Enhanced mechanical and morphological characteristics. Furthermore, combination and mixing processes contribute significantly to improving polymer properties (Noor Ameer and Hussein, 2019). In a study conducted by Jahani (2007) titled "The effect of epoxy-polyester hybrid resin on mechanical properties, rheological behavior and water absorption of polypropylene wood flour composites" the effect of blending epoxy resin with polyester was investigated without the use of any reinforcing materials. The results showed that incorporating epoxy into the resin system led to improvements in certain mechanical properties, such as modulus, although tensile strength decreased with increasing epoxy content. Additionally,

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an increase in complex viscosity and moisture absorption was observed, indicating interaction between the components of the polymer system. These findings suggest that blending epoxy and polyester resins can significantly influence the mechanical performance of hybrid polymer blends, even in the absence of reinforcement, making this study an important reference for understanding the behavior of binary resin systems in engineering applications (Jahan, 2007). In a study by Singh and Kumar (2015) titled "Mechanical properties of epoxy and unsaturated polyester resin blends without reinforcement", the authors investigated the mechanical behavior of hybrid polymer composites prepared by blending epoxy resin with unsaturated polyester (UPE) resin at various ratios, without any fibre or nanoparticle reinforcement. The results showed that blending epoxy with UPE led to an improvement in the toughness and impact resistance of the composites compared to the pure resins. However, tensile strength and modulus showed a slight decrease with increasing polyester content, likely due to differences in crosslink density and phase separation. The study also reported changes in morphological features, indicating partial compatibility between the two resins. This work demonstrates that even without reinforcement, epoxy-polyester hybrid polymer blends can be tailored to achieve balanced mechanical properties suitable for applications requiring moderate strength and improved toughness (Singh and Kumar, 2015). Despite the advances in studying epoxy-polyester blends, there is still a lack of comprehensive understanding regarding how varying the ratio between these two resins affects the corrosion resistance, microstructural characteristics, and compressive strength of the resulting hybrid polymer blends. This study aims to systematically investigate these effects by preparing different epoxy-polyester ratios and analyzing their mechanical and morphological behavior. Due to their lightweight nature, adjustable mechanical properties, and good biocompatibility, these hybrid polymer blends have promising potential applications in biomedical fields, particularly in the fabrication of prosthetic devices and implants.

Material and Methods

In this study, six different hybrid polymer blends were prepared by combining epoxy resin and unsaturated polyester resin at varying weight ratios, as detailed in Table 1. The preparation process began by mixing each resin system with its respective hardener. The epoxy resin was blended with its hardener in a 3:1 weight ratio, while the unsaturated polyester resin was mixed with its hardener (methyl ethyl ketone peroxide) in a 2:98 ratio. The required amounts of each resin and hardener were measured accurately. After preparing the individual resin-hardener mixtures, the epoxy and polyester systems were combined according to the ratios listed in Table 1 and mixed thoroughly using a magnetic stirrer for 5 to 7 min to achieve a homogeneous blend. The blended systems were then cast into silicone molds designed according to the requirements of each test. The mold dimensions were as follows: Compressive strength test: 20 mm × 10 mm × 10 mm, wear test: 10 mm × 10 mm × 20 mm, scanning electron microscopy (SEM) analysis: 5 mm × 5 mm × 20 mm. The samples were cured at room temperature (approximately 25 ± 2 °C) for 24 h to ensure full solidification. Once cured, they were demolded and stored under standard laboratory conditions until testing.

Results and Discussion

Wear test. Samples under various loads. The following loads were applied: 500, 1000, 1500, 2000 and 2500 grams (g). The weights of the samples before and after the test were measured in g to determine the amount of material worn due to friction. The test was performed at room temperature using a Pin-on-Disc device, following the international standard ASTM G99

Table 1. Composition ratios of epoxy (EP) and unsaturated polyester (UPE) polymer blends

Sample no.	Epoxy resin	The hardener	Unsaturated polyester resin	The hardener
100%EP + 0% UPE	7.5	2.5	0	0
80%EP + 20% UPE	6	2	1.96	0.04
60%EP + 40% UPE	4.5	1.5	3.92	0.08
40%EP + 60% UPE	3	1	5.88	0.12
20%EP + 80% UPE	1.5	0.5	7.84	0.16
0%EP + 100% UPE	0	0	9.8	0.2

(Neamah and Mahdi, 2023; Hussain and Al Sarraf, 2023). Table 2 summarizes the sample weights before and after wear testing under varying loads (500-2500 g). Results show a clear trend of decreasing residual weight with increasing load and higher unsaturated polyester content. Samples with higher epoxy ratios exhibit better wear resistance, retaining more mass after testing due to epoxy's superior hardness and molecular cohesion. The results from Table 2 clearly indicate that wear resistance increases with increasing epoxy content in the sample. When a load of 2500 g was applied, sample 1 (100% epoxy) retained a weight of 1.6947 grams, while sample 5 (20% epoxy) decreased to 0.3283 g, indicating significant material loss due to wear. This improvement in wear resistance is attributed to the excellent mechanical properties of epoxy, such as the high density of molecular interlocking and surface hardness, which reduce the effect of frictional forces. Conversely, samples with a higher content of unsaturated polyester showed greater mass loss due to weaker molecular bonds and lower hardness compared to epoxy. It was also observed that frictional forces decreased with increasing unsaturated polyester content. This is attributed to its relatively soft and elastic surface nature (Aleabi and Jasim, 2019; Ai *et al*., 2015), which reduces the coefficient of friction but increases wear. To calculate the wear rate, equation (1) was used:

$$\text{Wear rate} = \Delta WL\backslash L \quad \text{..... (1)}$$

where: ΔW = the weight loss due to wear (g), L = the total sliding distance during the test (cm). In Fig. 1, the different series correspond to samples with varying epoxy-to-unsaturated polyester ratios. For example, Series 1 represents 100% epoxy, series 3 corresponds to 60% epoxy and series 5 depicts 20% epoxy. This consistent labeling across figures ensures clear comparison of wear behaviors.

Scanning electron microscope (SEM). In Fig. 2, scanning electron microscopy (SEM) analysis was conducted to examine the surface morphology and microstructural characteristics of the epoxy/polyester hybrid polymer blends samples. The purpose of this analysis was to assess the homogeneity of the polymer blend, identify phase separation, particle agglomeration and surface defects (e.g., cracks or protrusions) (Abd El-Baki *et al*., 2023; Moawad and Jain, 2009), which are important factors influencing the hybrid polymer blends' mechanical and wear behavior (Kadhim *et al*., 2019). The analysis was performed using a TESCAN MIRA3 SEM (TESCAN, Czech Republic) operated at an accelerating voltage of 20 kV. A secondary electron (SE) detector was utilized to capture high-resolution two-dimensional images. Prior to imaging, the specimens were coated with a thin layer of gold using a vacuum sputter coater to enhance electrical conductivity and prevent surface charging. The samples used for SEM had dimensions of 5 × 5 × 20 mm, prepared specifically for morphological analysis. The first image (20,000× magnification) reveals fine surface protrusions ranging

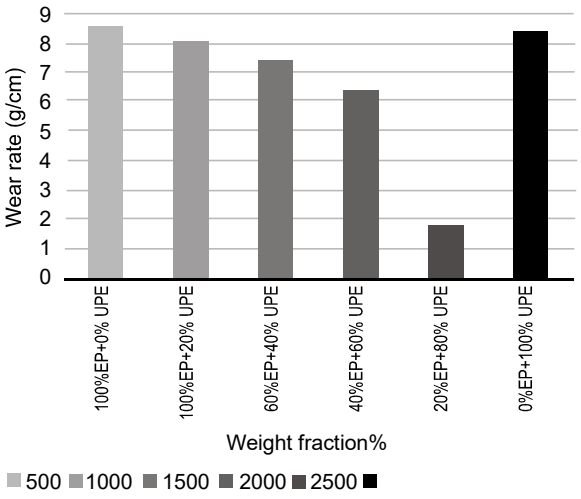
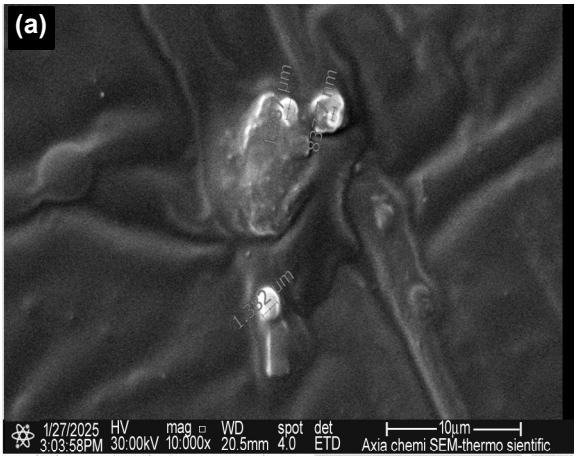


Fig. 1. Relationship between applied load and residual weight of EP/UPE polymer blend samples.

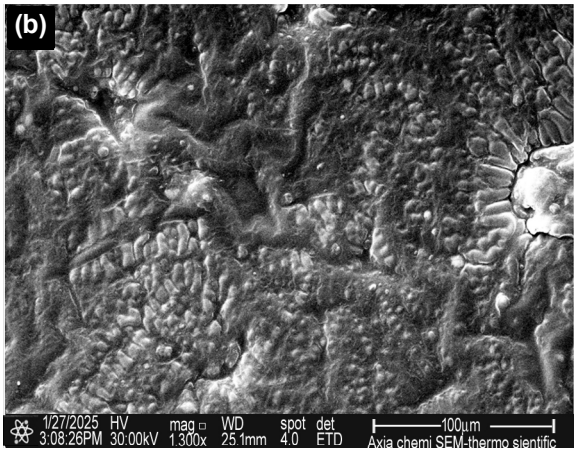
Table 2. Sample weights and applied load ratios for EP/UPE polymer blends in wear testing

Sample no.	500(g)	1000(g)	1500(g)	2000(g)	2500(g)	500(g)
100%EP + 0% UPE	1.7218	1.7192	1.7178	1.7081	1.6947	1.7218
80%EP + 20% UPE	1.6228	1.6196	1.6181	1.6052	1.5889	1.6228
60%EP + 40% UPE	1.4931	1.4888	1.4872	1.4715	1.4524	1.4931
40%EP + 60% UPE	1.2896	1.284	1.2823	1.264	1.2539	1.2896
20%EP + 80% UPE	0.3723	0.3674	0.3657	0.3494	0.3283	0.3723

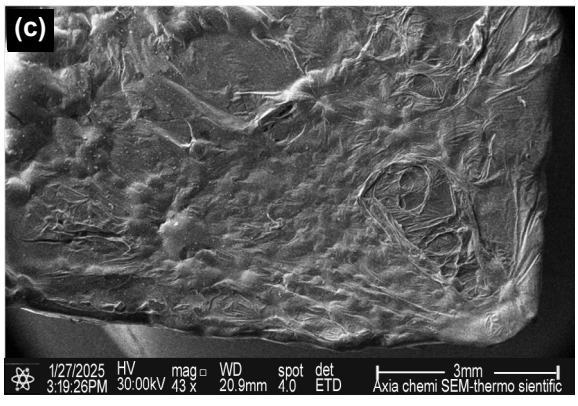
between 244 and 265 nm, likely representing nanostructures formed due to partial compatibility and interfacial contrast between epoxy and polyester phases. The second image (30,000× magnification) shows quasi-spherical aggregates approximately 1 μm in size, along with fine cracks, which may result from internal stresses, rapid solidification or non-uniform mixing during sample preparation. The third image (15,000× magni-fication) depicts a rougher surface with irregularly sized aggregates ranging from hundreds of nanometers to several microns, suggesting phase separation or filler agglomeration within the hybrid polymer blends. The fourth image displays different regions of the hybrid polymer blends surface with varying contrast levels. The lighter areas correspond to regions of higher electron density, which may indicate the presence of filler particles or phases containing elements with higher atomic numbers. In contrast, the darker regions represent the polymer matrix, composed primarily of the epoxy and unsaturated polyester blend. This contrast aids in distinguishing dispersed particles or agglomerates from the surrounding polymer matrix, providing insight into the distribution and compatibility of the hybrid polymer blends components. These observations provide valu-able insight into the microstructural interactions within the hybrid polymer blends and support the interpretation of their mechanical and wear performance.



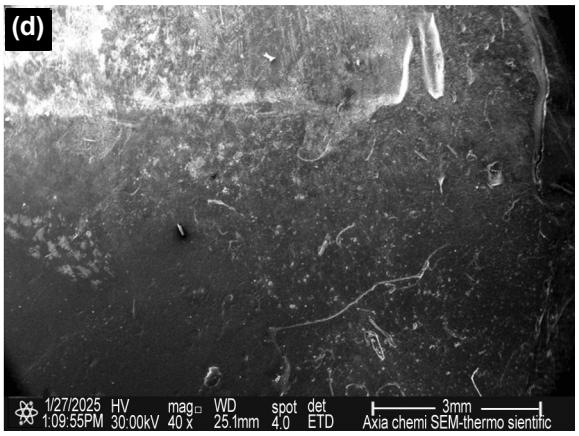
(a) SEM image showing sample pores with an average diameter of 20.5 μm



(b) SEM image showing sample pores with an average diameter of 25.5 μm



(c) SEM image showing sample pores with an average diameter of 20.9 μm



(d) SEM image showing sample pores with an average diameter of 25.1 μm

Fig. 2. Scanning electron microscopy (SEM) image of EP/UPE polymer blend surface.

Compressive test. Compressibility is defined as the ability of a material to withstand compressive loads without collapsing or undergoing permanent structural deformation. This property is one of the most critical mechanical characteristics used to evaluate the performance of polymer-based hybrid materials in structural applications. (Mahdi *et al.*, 2024). In this study, hybrid polymer blend samples were fabricated by mixing epoxy resin as the primary matrix with varying proportionsof unsaturated polyester (UPE) to produce different formulations. Compression testing was carried out using a Bold Harris No. 36110 hydraulic press, under a constant compressive load, following the ASTM D695 standard (Hussein *et al*., 2025; Lutfi and Jassim, 2023). The test specimens were prepared with standardized dimensions suitable for compressive strength evaluation. The maximum compressive strength before failure was recorded for each sample, as shown in Table 3 and Fig. 3. The sample made from 100% epoxy exhibited the highest compressive strength (6.1 MPa), reflecting its inherent stiffness and strong molecular network. However, as the proportion of unsaturated polyester increased, the compressive strength decreased significantly, reaching 0.6 MPa at the 40% EP/60% UPE formulation. Interestingly, the sample made from 100% polyester exhibited relatively high strength (4.7 MPa), suggesting that hybridization, if not optimized, may lead to performance degradation. This reduction in compressive strength with hybridization is a critical finding. It indicates that poor interfacial bonding and phase incompatibility between epoxy and polyester resins can lead to weak load transfer and an increased likelihood of microstructural defects such as phase separation and particle agglomeration, as observed in SEM analysis, while hybridization can be used to tailor specific properties, these results demonstrate that it may negatively affect mechanical integrity if the two phases are not sufficiently compatible. Therefore, careful selection of resin ratios and enhanced interfacial engineering are essential for developing high-performance hybrid materials. These findings provide insight into the mechanical limitations of hybrid systems and emphasize the need to balance flexibility and cost-effectiveness with structural strength.

Table 3. Measured compressive strength values of epoxy (EP) and unsaturated polyester (UPE) blend samples

Sample no.	compressive strength (Map)
100%EP+ 0% UPE	6.1
80%EP+ 20% UPE	5.7
60%EP+40% UPE	1.1
40%EP+ 60% UPE	0.6
20%EP+ 80% UPE	3.2
0%EP+100% UPE	4.7

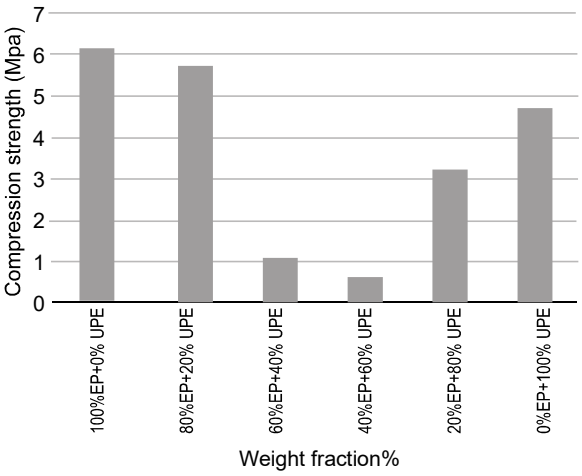


Fig. 3. Compressive test of EP/UPE polymer blend samples.

Conclusion

This study aimed to investigate the mechanical and tribiological properties of hybrid polymer blends made from varying ratios of epoxy and unsaturated polyester (UPE) resins. The goal was to evaluate the influence of blend composition on wear resistance, compressive strength and surface morphology to determine their suitability for potential structural or biomedical applications. Scanning electron microscopy (SEM) revealed that higher epoxy content resulted in more uniform and homogeneous microstructures with fewer defects. Some phase separation and agglomeration were observed in samples with higher UPE content, indicating limited compatibility at certain ratios. Wear testing demonstrated that increasing the epoxy content improved wear resistance, with the 100% epoxy sample retaining the highest residual mass (1.6947 g) under a 2500 g load, compared to 0.3283 g for the 20% epoxy blend. This is attributed to epoxy's higher surface hardness and cohesive molecular structure. Compression testing showed a similar trend, with the 100% epoxy sample achieving the highest compressive strength (6.1 MPa),

while the 40% EP / 60% UPE blend had the lowest (0.6 MPa). These results confirm that hybridization with UPE reduces compressive performance unless phase compatibility is optimized. Overall, the findings indicate that although blending epoxy with UPE offers tunability in friction and flexibility, it compromises mechanical strength and structural integrity unless interfacial bonding is improved. Future work should focus on compatibilizers or surface treatments to enhance phase interaction.

Conflict of Interest. The authors declare that they have no conflict of interest.

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