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# ENHANCEMENT OF MECHANICAL PROPERTIES, WEAR RESISTANCE AND EDM PERFORMANCE OF BIODEGRADABLE MAGNESIUM ALLOY MMC

In this study the mechanical, wear, and electrical discharge machining (EDM) performance of biodegradable WE43 magnesium alloy was enhanced by adding ceramic reinforcement like silicon carbide, aluminium oxide, and boron carbide. Two hybrid composite specimens were fabricated in this investigation with WE43 MMC 1 is reinforced with 6 wt.% reinforcement (2% SiC, 2% $Al_2O_3$, and 2% $B_4C$) and WE43 MMC 2 with 10 wt.% reinforcement (3.5% SiC, 3.5% $Al_2O_3$, and 3% $B_4C$). The weight % of ceramic reinforcement content is increased, the yield strength is enhanced from 158.69 MPa to 211.47 MPa, ultimate tensile strength is improved from 241.25 MPa to 285.36 MPa, and hardness from 65.8 to 89.4. However, there was a drop-in ductility, with elongation falling from 6.52% to 3.25%, showing that there is a trade-off between strength and plasticity. The hard-ceramic content made the material more resistant to wear and are expected to make EDM easier by reducing electrode wear and improving surface quality because they are more thermally stable. SEM and EDS analysis are carried out in this study to evaluate the microstructural and surface topography of WE43 MMC. The result of this study demonstrates that the WE43 MMC 2 are promising candidates for high-performance applications in biomedical and aerospace sectors requiring lightweight materials with superior mechanical and EDM-compatible properties.

*Keywords:* WE43 magnesium alloys; mechanical properties; EDM; biodegradable materials; Wear

## 1. Introduction

Magnesium alloys play an important role in orthopaedic surgery Magnesium alloys, especially WE43, are known for their high specific strength, good corrosion resistance and ability to withstand temperatures up to 250°C.These properties make them good candidates for use in structures and biomedical applications. However, its limit in wear resistance and mechanical properties make them less useful in general, especially for parts that have to deal with mechanical load or wear environment [1]. The magnesium matrix composites were produced to solve these problems by adding ceramic reinforcement particles that make the material stronger, such as silicon carbide (SiC), aluminum oxide ($Al_2O_3$), and boron carbide ($B_4C$). In general, incorporating these reinforcements can make the WE43 alloy much harder, stronger, and more resistant to wear. Adding SiC particles, for instance, makes the matrix stronger, makes it harder to wear and creep, and keeps it easy to machine [2]. Adding $B_4C$ to WE43 alloys [3] has been shown to improve the grain structure and make the alloys even stronger in terms of tensile and yield strength, as well as hardness, especially after hot rolling. The composite can reach ultimate tensile strengths of up to 284 MPa, yield strengths of about 259 MPa, and hardness of up to 97 HB, but its ductility goes down. Magnesium alloys, especially the WE43 grade, are known for their high specific strength, good resistance to creep, and ability to resist corrosion up to 250°C. These properties make them good candidates for use in structures and biomedical applications [4,5]. Adding SiC particles, for instance, makes the matrix stronger, makes it harder to wear and creep, and keeps it easy to machine. naturally hard, adding more of these ceramic reinforcements makes the material harder and more resistant to wear. This is good for uses that need to be able to resist wear and tear and damage to the surface. But as the amount of these reinforcements increases, the alloy's ultimate tensile strength and elongation can go down. The ceramic particles make the material more brittle, which makes it less ductile. This may also cause interfacial phases to form, which could be places where cracks start [6]. The yield strength usually stays the same or gets

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a little better because of the load-bearing reinforcement, but too much ceramic content can make the material less tough and less plastic. On the microstructural level,adding more $Al_2O_3$, $B_4C$, or SiC makes the grain structure finer and the hard particles more evenly distributed throughout the matrix. This makes the material stronger, but it also makes it more porous or have more defects at the interface if processing is not carefully controlled [7,8].

These improvements in mechanical properties of magnesium metal matrix composite reinforced with SiC, $Al_2O_3$, $B_4C$ also have positive effects on the performance of Electric Discharge Machining (EDM). This is because ceramic-reinforced magnesium composites are expected to be easier to machine and more accurate in size during EDM because they are stronger and more resistant to wear. So, using SiC, $Al_2O_3$, and $B_4C$ reinforcements with WE43 magnesium alloys is a promising way to make advanced, high-performance [9] .

EDM is important for the materials that have ceramic particles in them, like SiC, $Al_2O_3$, and $B_4C$. The addition of ceramic particle to the magnesium alloy WE43 to make WE43 MMC stronger, more resistant to wear, and better overall. When using EDM to machine magnesium matrix composites, it is very important to choose the right tool electrode materials, which are usually copper and brass [10]. The electrode selection in EDM is important for machining results like the rate of material removal (MRR), the quality of the surface, and the wear on the electrodes. EDM makes it easier to make complicated, small parts out of reinforced magnesium alloys, but it also solves the problems that come up when ceramic reinforcements make the parts harder and more brittle. The better results in machining performance and surface properties, the process parameters and electrode materials must be carefully adjusted. Although WE43 magnesium alloys and ceramic-reinforced magnesium MMCs have been studied individually, a combined investigation involving mechanical properties, tribological behavior, and EDM machinability of WE43 MMC reinforced simultaneously with SiC, $Al_2O_3$, and $B_4C$ at two different reinforcement levels has not been adequately reported. Furthermore, the novelty lies in correlating reinforcement content with EDM performance parameters (MRR and TWR) using copper and brass electrodes, which provides new insight into the machinability of ceramic-reinforced WE43 MMCs for lightweight and biodegradable engineering applications.

In this research, WE43 Magnesium alloy reinforced with 6 and 10 wt.% of Ceramic materials were fabricated through stir casting and tested to identify the improvement in mechanical properties, wear resistance and its compatibility to make it suitable for biodegradable applications such as screws, nuts and weight saving application such as aerospace, racing cars.

## 2. Materials and methods

### 2.1. Fabrication of WE43 MMC

The WE43 alloy is loaded into a crucible and heated in an induction furnace. The temperature is maintained at 700 and 750°C, in a protective gas atmosphere, $CO_2$, to keep WE43 MMC from oxidizing. SiC, $Al_2O_3$, and $B_4C$ powders with particle size of 20 μm are added as reinforcement in correct weight % which was selected to ensure effective load transfer, uniform dispersion within the WE43 magnesium matrix, and reduced risk of particle agglomeration during stir casting . These particles are heated up to 500°C in a muffle furnace to get rid of moisture and make them easier to wet with the molten Mg alloy. The preheated ceramic powders are slowly added to the vortex of the melt after the WE43 alloy has completely melted and been degassed. A graphite or steel impeller is used to stir the mixture mechanically for 5 to 10 minutes at a speed of 400 to 600 rpm. This creates the vortex. Mechanical stirring evenly spreads the reinforcements and makes the bond between the particles and the matrix stronger [8].

It is quickly poured into metal molds that have already been heated to keep the composite melt from hardening too soon and to keep the porosity low. Billets were heat-treated after casting to make their microstructure and mechanical properties better [17]. The ceramic reinforcement in MMC stop the dislocation movement and grain boundary sliding, which makes the WE43 matrix harder and more resistant to wear. To avoid problems like particle clustering or porosity, it is important to carefully control the process parameters to make sure that the interfacial bonding is strong. Different Ceramic weight percentage of reinforcement in WE43 MMC is shown in TABLE 1.

TABLE 1

WE43 MMC Reinforcement weight %

| Composites | SiC | $Al_2O_3$ | $B_4C$ | Matrix |
|---|---|---|---|---|
| **WE43 MMC 1** | 2 % | 2% | 2% | 94% |
| **WE43 MMC 2** | 3.5 % | 3.5% | 3% | 90% |

The amount of reinforcement has been selected in order to make the reinforcement work and at the same time to avoid problems with the magnesium matrix WE43. The addition of less than 5 wt. of reinforcement usually does not make the material stronger or more durable. On the other hand, adding more makes the melt stronger, keeps the particles together and makes the material less resistant. So we've selected 6 wt. percentage and 10 wt. percentage of total reinforcement content to show that they can sustain more weight and remain stable.

### 2.2. Microstructure analysis

The scanning electron microscope (SEM) with EDS is used to examine the surface morphology for the presence of intermediate metallic phases. The phase compositions are identified by energy-dispersive spectroscopy (EDS). The elemental composition of WE43 MMC materials are computed with the EDS investigation.

The WE43 magnesium alloy matrix is not as hard as the ceramic reinforcement phases (SiC, $Al_2O_3$, and $B_4C$) that are embedded in it. These phases are much harder and stiffer. The hard particles in the softer magnesium matrix make it stronger and more resistant to plastic deformation. Grinding is usually the first step in preparation. This is done under a coolant, like a 1:3 mixture of glycerol to ethanol instead of water, to lower the risk of fire from magnesium dust and keep the magnesium alloys from corroding, since they are very sensitive to water. During polishing it start with rough abrasives and work your way up to finer ones until the last one. After the last polishing, cleaning is done with ethanol instead of water to keep the microstructure from changing. A etch-polish-etch cycle can be used to make the microstructure clearer. These methods create a smooth surface that will not rust and can be used to look at magnesium matrix composites under a microscope and test their strength.

### 2.3. Tensile tests

The tensile test was carried out using universal testing machine with 1000 KN machine capacity.

The specimen size is carefully marked and machined according to ASTM E8/E8M [12] for WE43 MMC. Three specimens of each material composition were tested under the same conditions. The tensile properties presented in this study represent the average of the measurement. Before testing, the original length and diameter of the gauge are measured and then each specimen is put into a universal testing machine with standard grips or threaded ends. The tensile test is then carried out by applying uniaxial tension until the specimen break. During the test, information like load and elongation is collected. Extensometer were used to measure the strain measurement. After the break, the yield strength, ultimate tensile strength, and percentage elongation are found by measuring the final gauge length and the smaller diameter at the break.

### 2.4. Hardness

The Brinell hardness (HB) of WE43 MMC with 6 and 10 wt.% of ceramic reinforcement was found using a hardness testing machine. WE43 MMC 1 & 2 was tested at three different locations on the sample surface.

### 2.5. Wear Test

The pin on disk wear test method was utilized to carried out wear test on specimen made up of WE43 MMC 1 with 6% and WE43 MMC 2 with 10% ceramic materials. The standard specimen has a cylindrical pin that is 6 mm wide and 25-30 mm long. The sliding face of the pin is flat and perpendicular to its axis. Wear Test were done by pushing the pin against a polished steel disk while controlling the normal load and sliding speed. Test provide precise values for wear parameters such as coefficient of friction, wear rate, and volume loss. Test will help to determine how much material was lost and how it was worn, surface and dimension measurements are made both before and after testing.

### 2.6. EDM

Electric discharge machining is carried out using hole drilling EDM. Copper and brass is chosen as electrode material with electrode size of 3 mm, deionized water is chosen as dielectric liquid.

## 3. Results and discussion

### 3.1. SEM and EDS analysis

Fig. 1 illustrates a SEM image characterized by uneven topography and distinct tearing ridges, which are indicative of a predominantly ductile fracture mechanism with localized brittle features. The presence of micro void and plastic flow lines shows a plastic deformation prior to failure, a typical characteristic of ductile fracture in magnesium alloys due to the relatively flat region and sharp cleavage along some grain boundaries point to a mixed mode fracture, influenced by microstructural inhomogeneities such as intermetallic particles or segregated phases that act as stress concentrators. These features are common in rare-earth magnesium alloys like WE43, where strengthening mechanisms such as grain refinement and precipitate hardening improve strength but often reduce ductility, leading to such hybrid fracture surfaces. According to [15], the addition of rare earth elements in Mg alloys can enhance mechanical strength but also promote intergranular fracture under certain loading conditions, a behaviour reflected in the present microstructure.

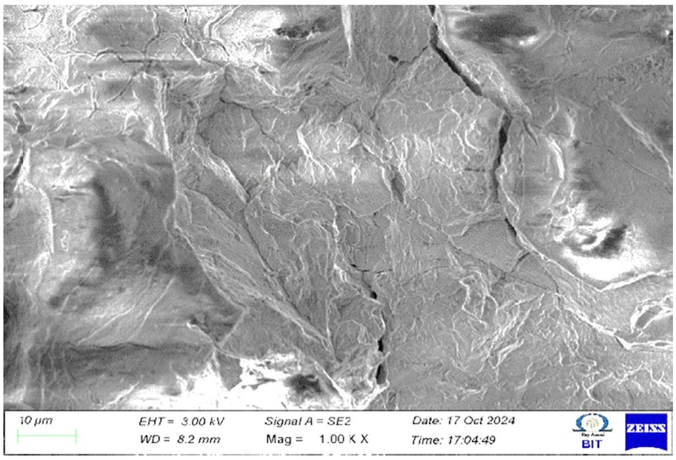


Fig. 1. Microstructure of WE43 MMC with 10% Ceramic Materials

Fig. 2 demonstrates the fracture surface of a WE43 MMC reinforced with ceramic particles like SiC, $B_4C$, and $Al_2O_3$. The fracture surface in the image is rough and uneven, indicates that it has both ductile and brittle properties. The river-like patterns and tiny cracks point to brittle cleavage zones that are common in ceramic particle reinforcements. The dimples and plastic deformation zone between the cracks show that the Mg matrix acts like a ductile material in some part of the specimen [12]. When SiC, $B_4C$, and $Al_2O_3$ are added to the composite, it becomes harder and stronger and causes dislocations because of thermal mismatch. when mechanical stress act on WE43 MMC, it starts creating cracks, which can make the material break sooner and make it less ductile. Adding ceramic particles to Mg matrix composites can make them much more resistant to wear and give them more compressive strength, but this often means they are less tough and less able to stretch. Measurements taken from the cross-sectional micrographs show that the recast layer thickness varies in the range of approximately 6-12 µm, depending on machining conditions. Surface examination revealed micro-pores with sizes of about 1-4 µm and discharge craters with diameters in the range of 5-15 µm, formed due to localized melting, material ejection, and rapid solidification during spark erosion.

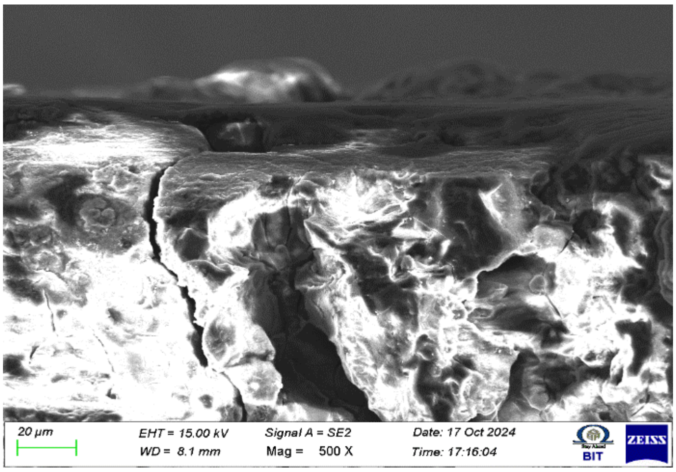


Fig. 2. Microstructure of WE43 MMC with 10% Ceramic Materials – cross section image

Fig. 3 displays sharp trans granular cracks present in SEM image show that brittle fracture occurs due to increase in ceramic particles reinforcement present in WE43 MMC. These hard reinforcements make the composite stronger and harder by making it harder for dislocations to move and increasing its load-bearing capacity. But the place where the ceramic particles and the magnesium matrix meet can become a stress concentration zone. This can make cracks start and spread when the material is under mechanical load The SEM picture shows rough spots and tear ridges that show localised ductile deformation in the matrix.

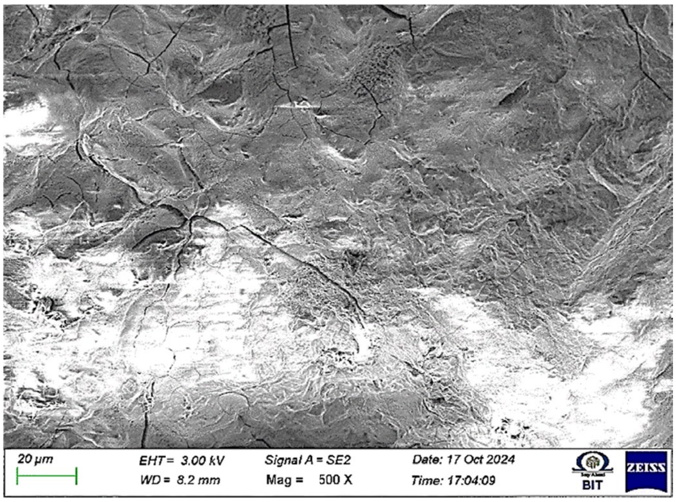


Fig. 3. Microstructure of WE43 MMC with 6% Ceramic Materials

Fig. 4a and 4b show EDS analysis of WE43 MMC. The highest peaks are for oxygen (O), aluminium (Al), and magnesium (Mg) which indicates matrix is mostly made up of magnesium, Silicon, aluminium with a lot of oxide, which is common in magnesium alloys that have been oxidised on the surface or that have been exposed to air during processing. The small peaks like carbon (C), iron (Fe), and copper (Cu) could be due to impurities present in the sample, leftover processing materials, the presence of sulphur (S) and mercury (Hg) signals, even though they are much weaker, could mean that there is some environmental contamination or leftover materials from preparation. Sulphur signals can originate from residual polishing media, etching chemicals, cleaning agents, or atmospheric contamination during sample preparation and handling, as magnesium alloys are highly reactive and prone to surface adsorption. The appearance of mercury is most likely due to detector noise, X-ray peak overlap, or contamination within the SEM chamber, which can produce spurious signals, particularly when analyzing light-element matrices such as magnesium. Since mercury was not involved in any stage of material fabrication or processing, its presence is considered non-physical and unrelated to the composite. As EDS trace peaks at very low intensities do not reflect the bulk composition of the material. Therefore, only the dominant elemental peaks corresponding to Mg, Al, Si, O, and B were considered for compositional interpretation, while the unexpected peaks were excluded from the analysis.

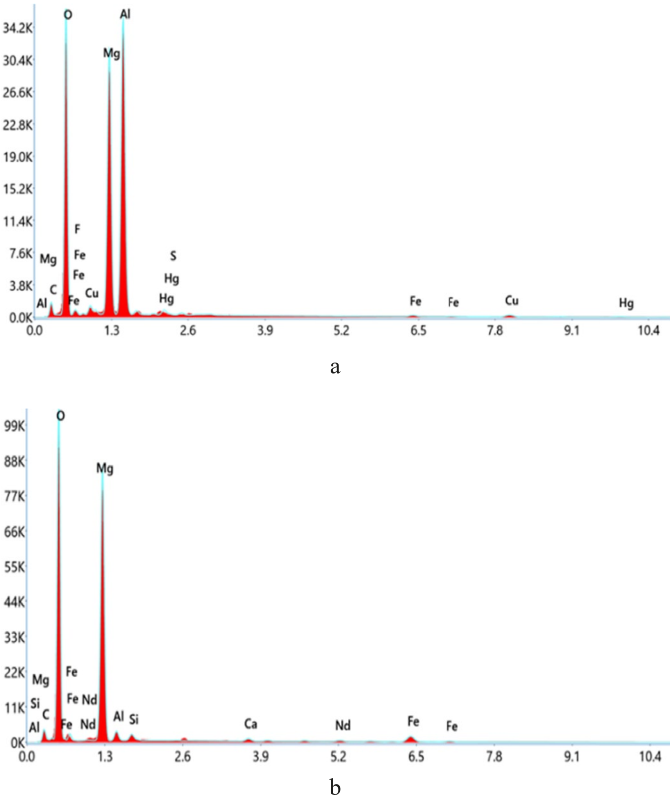


Fig. 4. EDS graph: a – WE43 Mg with 10% ceramic Reinforcement; b – WE43 Mg with 7% ceramic Reinforcement

### 3.2. Mechanical properties of WE43 MMC

WE43 MMC Specimen 1 and 2 show an increase in YS, UTS, UCS, and hardness compared to the base WE43 alloy as shown in Fig. 5. This curve 6 illustrates the trade-off between strength and ductility in metal matrix composites: as the ceramic content increases, the stiffness and strength increase, but the ductility decreases. The decrease in elongation (%) from WE43 to WE43 MMC 2 indicates a reduction in ductility due to these strengthening mechanisms [13]. Fewer active slip systems and more obstacles to dislocation movement make the alloy stronger but less able to stretch before fracture.

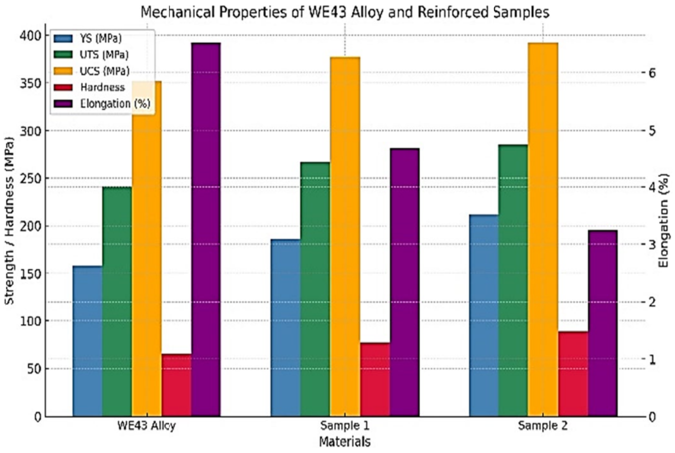


Fig. 5. Mechanical Strength of fabricated Material

The higher hardness values in Specimen 1 and 2 correlates directly with the higher strength value. In WE43 alloy, improved hardness is typically related to a finer and more uniform distribution of ceramic reinforcement during the strengthening phase [4]. The strength and hardness were increased by alloying and processing, elongation and toughness usually decrease. This is due to the nature of the HCP structure and the reliance on limited deformation modes at room temperature [18].

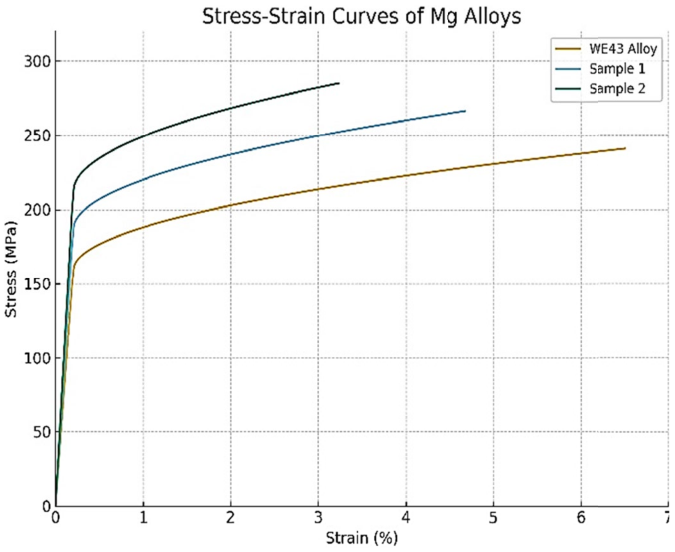


Fig. 6. Stress strain curve

### 3.3. Electrical Discharge Machining (EDM)

EDM is an unconventional machining process that removes material from a workpiece by electrical discharges between an electrode and the workpiece. In the case of hole drilling on magnesium-based MMCs, such as WE43 alloy reinforced with ceramic particles (SiC, $Al_2O_3$, and $B_4C$), EDM presents a significant advantage over conventional drilling methods due to the inherent difficulties in machining hard, brittle, and thermally sensitive materials.

Figs. 7,8 and TABLE 2 illustrates the way the MRR, TWR changes over EDM of WE43 magnesium alloys with varying volumes of ceramic introduced and different tool electrodes. The 94% WE43 alloy with 2 wt.% SiC, 2 wt.% $Al_2O_3$, and 2 wt.% $B_4C$ specimen a copper electrode, deionized water as a dielectric fluid gives better result when compare to brass electrode, and highest result is at Trial 14. The higher MRR is because copper conducts electricity and heat better than other metals, which makes sparks and material erosion happen more quickly [2]. Brass electrodes give lower MRR values when compare to copper electrode due to poor conductivity [10]. The 90% WE43 composite with 3.5 wt.% SiC, 3.5 wt.% $Al_2O_3$, and 3 wt.% $B_4C$ have lower MRR values, probably because the higher ceramic

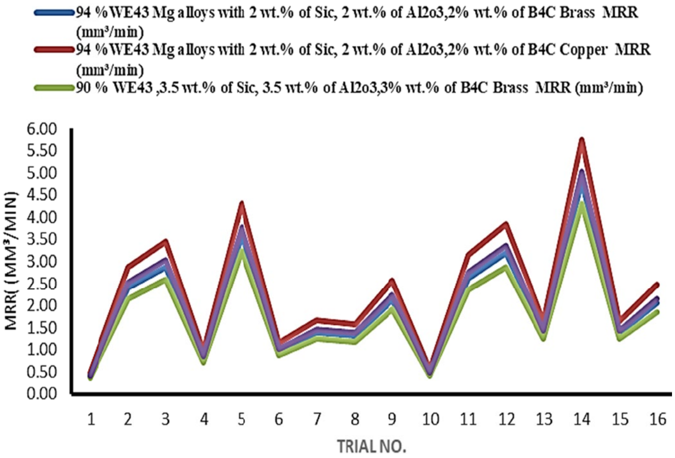


Fig. 7. Material removal rate

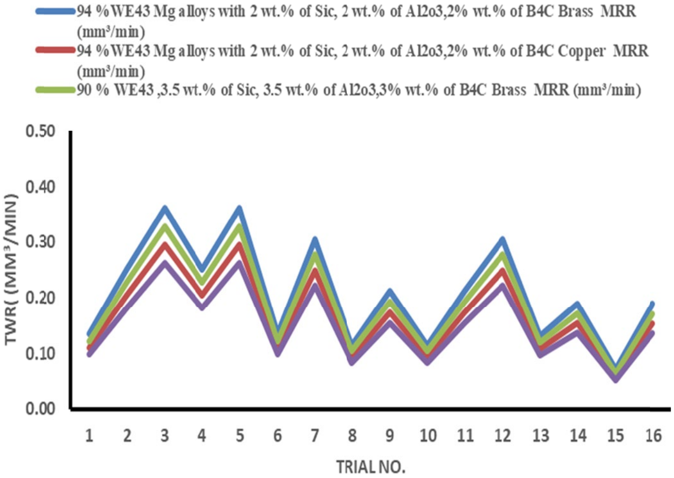


Fig. 8. Tool wear rate

TABLE 2

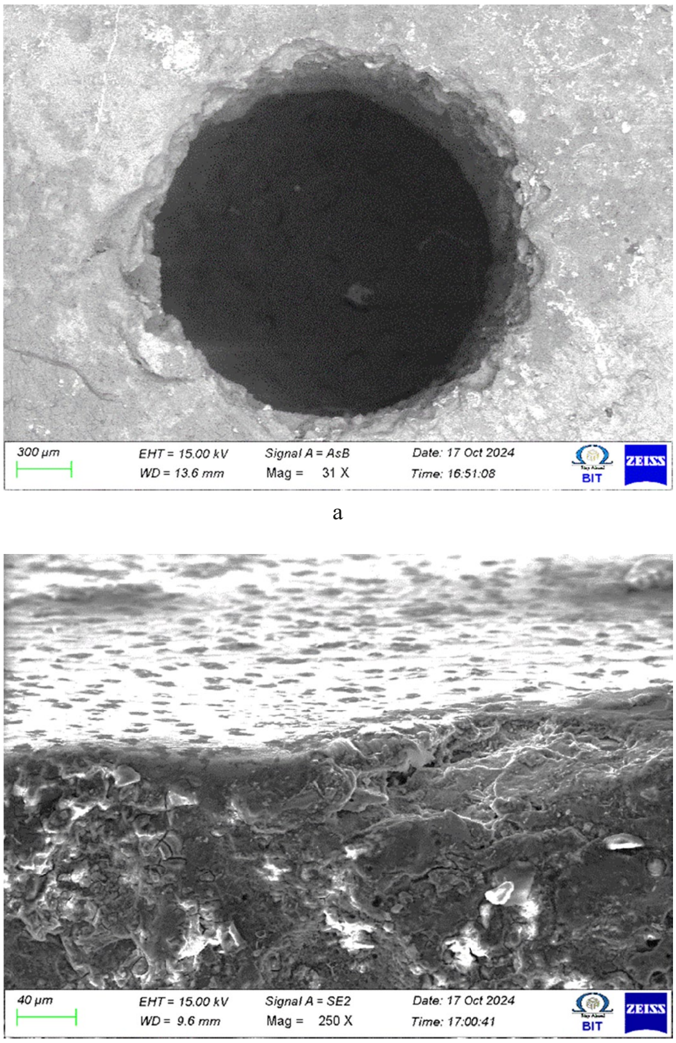
EDM in WE43 MMC

| Trial No. | Pulse On-Time (Ton) (µs) | Pulse Off-Time (Toff) (µs) | Peak Current (Ip) (A) | WE43 MMC 1 | | | | WE43 MMC 2 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Brass | | Copper | | Brass | | Copper | |
| | | | | MRR ($mm^3$/min) | TWR ($mm^3$/min) | MRR ($mm^3$/min) | TWR ($mm^3$/min) | MRR ($mm^3$/min) | TWR ($mm^3$/min) | MRR ($mm^3$/min) | TWR ($mm^3$/min) |
| 1 | 10 | 50 | 3 | 0.40 | 0.13 | 0.48 | 0.11 | 0.36 | 0.12 | 0.42 | 0.10 |
| 2 | 10 | 10 | 6 | 2.40 | 0.25 | 2.88 | 0.21 | 2.16 | 0.23 | 2.52 | 0.18 |
| 3 | 10 | 15 | 9 | 2.88 | 0.36 | 3.46 | 0.30 | 2.59 | 0.33 | 3.02 | 0.26 |
| 4 | 10 | 50 | 6 | 0.80 | 0.25 | 0.96 | 0.21 | 0.72 | 0.23 | 0.84 | 0.18 |
| 5 | 10 | 10 | 9 | 3.60 | 0.36 | 4.32 | 0.30 | 3.24 | 0.33 | 3.78 | 0.26 |
| 6 | 10 | 15 | 3 | 0.96 | 0.13 | 1.15 | 0.11 | 0.86 | 0.12 | 1.01 | 0.10 |
| 7 | 12 | 50 | 9 | 1.39 | 0.31 | 1.67 | 0.25 | 1.25 | 0.28 | 1.46 | 0.22 |
| 8 | 12 | 10 | 3 | 1.31 | 0.11 | 1.57 | 0.09 | 1.18 | 0.10 | 1.37 | 0.08 |
| 9 | 12 | 15 | 6 | 2.13 | 0.21 | 2.56 | 0.17 | 1.92 | 0.19 | 2.24 | 0.15 |
| 10 | 12 | 50 | 3 | 0.46 | 0.11 | 0.56 | 0.09 | 0.42 | 0.10 | 0.49 | 0.08 |
| 11 | 12 | 10 | 6 | 2.62 | 0.21 | 3.14 | 0.17 | 2.36 | 0.19 | 2.75 | 0.15 |
| 12 | 12 | 15 | 9 | 3.20 | 0.31 | 3.84 | 0.25 | 2.88 | 0.28 | 3.36 | 0.22 |
| 13 | 20 | 50 | 6 | 1.37 | 0.13 | 1.65 | 0.11 | 1.23 | 0.12 | 1.44 | 0.10 |
| 14 | 20 | 10 | 9 | 4.80 | 0.19 | 5.76 | 0.15 | 4.32 | 0.17 | 5.04 | 0.14 |
| 15 | 20 | 15 | 3 | 1.37 | 0.07 | 1.65 | 0.06 | 1.23 | 0.06 | 1.44 | 0.05 |
| 16 | 20 | 50 | 9 | 2.06 | 0.19 | 2.47 | 0.15 | 1.85 | 0.17 | 2.16 | 0.14 |

content made the composite harder and more resistant to heat, which made it less effective at eroding materials. The results show that both the type of electrode material and the amount of reinforcement have a big impact on EDM performance. This is in line with what other research have found when looking at magnesium composite [2,10].

The Fig. 8 shows the TWR for WE43 magnesium alloy composites with varied ceramic reinforcements using brass and copper electrodes as an electrode material and deionized water as a dielectric fluid under different EDM trials. From experiments it observed that the 94% WE43 composite with 2 wt.% each of SiC, $Al_2O_3$, and $B_4C$ produces lower TWR when machined with a copper electrode compared to brass, indicating copper's superior wear resistance due to its higher thermal conductivity and melting point [2]. But TWR for the 90% WE43 composite reinforced with 3.5 wt.% SiC, 3.5 wt.% $Al_2O_3$, and 3 wt.% $B_4C$, is more due to increased abrasive interaction from the higher ceramic content, which accelerates tool degradation. These trends confirm that tool material selection and reinforcement proportion significantly impact TWR in EDM, aligning with prior findings where copper tools exhibited better durability and stability during machining of hard particle-reinforced metal matrix composites

Fig. 9 shows SEM analysis on WE43 magnesium alloy reinforced with SiC, $Al_2O_3$, and $B_4C$ after EDM reveals characteristic features of thermal erosion and recast layer formation. The Fig. 9(a) show a EDM machined micro-hole with a relatively uniform circular geometry, surrounded by a heat-affected zone (HAZ) indicating localized melting and resolidification due to intense spark discharges [12]. The SEM image illustrates micro-cracks and irregular edges along the periphery may be due rapid quenching and thermal stresses, commonly observed in EDM-processed MMCs. The Fig. 9(b),



a

b

Fig. 9. SEM images after EDM in WE43 MMC 2: a – 300 µm around Hole; b – SEM image in Hole Cross section 40 µm

a cross-sectional SEM micrograph, displays a dense recast layer with evidence of molten material resolidification and globule structures within the surface. Measurements obtained from the cross-sectional micrographs show that the recast layer thickness is approximately 8-15 μm, depending on the machining conditions. The machined surface exhibits discharge craters with diameters in the range of 10-25 μm and micro-pores of about 2-6 μm, which are formed due to localized melting and rapid resolidification during spark erosion. The recast layer exhibits voids and micro-pores due to entrapped gases and vaporized binder material during machining. The uneven morphology, shallow crater formation were typical results of the high-energy spark erosion of hard ceramic particles, indicating irregular MRR [2]. These features are consistent with prior reports on EDM of metal matrix composites, highlighting the challenge of controlling surface integrity and subsurface damage in ceramic-reinforced Mg alloys.

### 3.4. WEAR TEST

Fig. 10 illustrates the WE43 magnesium alloy and its ceramic-reinforced composites wear under different loads (5-20 N). The base alloy has the highest wear rate because it is not very hard and does not resist adhesive and abrasive mechanisms very well. Addition of ceramic reinforcement SiC, $Al_2O_3$, and $B_4C$ into WE43 MMC greatly increases wear resistance by making the surface harder and making it harder to remove material when the load increases [14]. The Specimen 1 with 94% WE43 magnesium alloy and 2 wt.% of each ceramic phase wears less than the base alloy. The specimen 2 with 90% WE43 magnesium alloy and 3.5 wt.% SiC, 3.5 wt.% $Al_2O_3$, and 3 wt.% $B_4C$ show even more improvement, at higher loads. The increase in the volume fraction of hard particles, which act as load-bearing elements and reduce direct metal-to-metal contact, is what makes this improvement possible. This limits plastic deformation and damage below the surface. [14,16] both found that adding $B_4C$ and $Al_2O_3$ to magnesium alloys improved their tribological behavior by making the particles bond better to the matrix and making it easier to remove material.

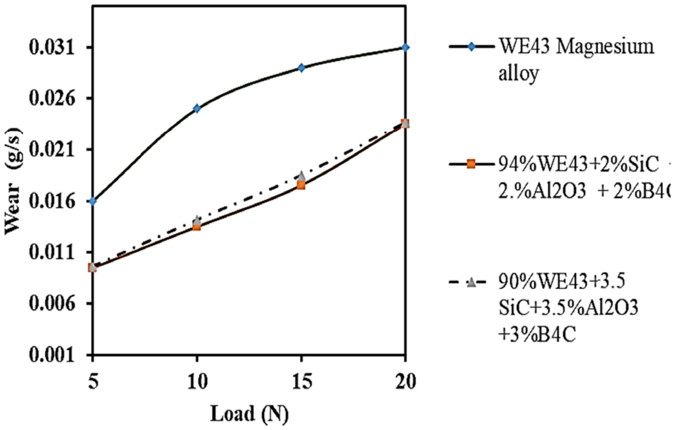


Fig. 10. Wear analysis with respect to different load conditions

### 4. Conclusions

The current study shows the performance of multi-ceramic reinforcement affects the mechanical, tribological, and EDM behavior of WE43 magnesium alloy. The experimental result show that addition of ceramic reinforcement to the WE43 alloy makes it perform better than the unreinforced version.

1. The MMC with 3.5 wt.% SiC, 3.5 wt.% $Al_2O_3$, and 3 wt.% $B_4C$ (WE43 MMC 2) had the best mechanical properties. The yield strength went up by about 18-22% compared to the lower-reinforced composite (WE43 MMC 1), and the ultimate tensile strength went up by about 20-25%. The hardness went up by about 15-18% and the compressive strength went up by almost 25%. The main reasons for these improvements are that the grains have become finer, the load is transferred more effectively to the hard-ceramic particles, and the dislocation motion is limited because of the thermal mismatch between the matrix and the reinforcements. The elongation, on the other hand, dropped by almost 30-35%, which means that the material became less ductile because it became more brittle and stress concentrated at the particle-matrix interfaces.
2. The wear test showed that the reinforced composites had a much lower wear rate. WE43 MMC 1 gives 30-35% lower than that of the base WE43 alloy. WE43 MMC 2 gives 45-50% lower, especially when higher loads were applied. The enhanced wear resistance is due to the presence of hard ceramic particles that serve as load-bearing phases and reduce direct metal-to-metal contact during sliding.
3. When using a copper electrode instead of a brass electrode, MRR increased up to 15-20% under the same machining conditions. Copper electrodes gives lower TWR by about 20-25% because they conduct heat better and make sparks more consistently. The composites showed stable machining behavior with acceptable tool wear, even though they had a higher ceramic content, which caused the MRR to drop by about 10-12% because the thermal resistance was higher.

### REFERENCES

[1] L. Prawin Babu, R. Radha, Canadian Metallurgical Quarterly, Advancements in Magnesium-Based Alloys for Orthopedic Implants: Balancing Corrosion, Mechanical Properties, and Biological Effects (Part 1) – a Review. Canadian Metallurgical Quarterly **63**, 1-26 (2024). DOI: https://doi.org/10.1080/00084433.2024.2427455

[2] S. Karthik, P. Karunakaran, G. Velmurugan, International Journal of Electrochemical Science, Experimental Investigation of WE43(T6) magnesium MMCs to enhance mechanical properties and EDM process parameters. **19** (5), 100553 (2024). DOI: https://doi.org/10.1016/j.ijoes.2024.100553

[3] S.M. Banijamali, S. Najafi, A. Sheikhani, Y. Palizdar, Wear, Dry tribological behavior of hot-rolled WE43 magnesium matrix composites reinforced by B4C particles. p. 508-509 (2022). DOI: https://doi.org/10.1016/j.wear.2022.204487

[4] L. Nisar, A. Maqbool, N.Z. Khan, A. Gull, A.N. Siddiquee, Materials Chemistry and Physics, Enhancing ductility, strength, and hardness of WE43 Mg alloy-based metal matrix composite fabricated via friction stir processing: Effect of hybrid reinforcement and Volume percentage. **323**, 129620 (2024). DOI: https://doi.org/10.1016/j.matchemphys.2024.129620

[5] P. Lovašiová, T. Lovaši, J. Kubásek, E. Jablonská, Š. Msallamová, A. Michalcová, D. Vojtěch, J. Suchý, D. Koutný, E.G.H. Alzubi, Metals, Biodegradable WE43 Magnesium Alloy Produced by Selective Laser Melting: Mechanical Properties, Corrosion Behavior, and In-Vitro Cytotoxicity. **12**, 3, 469 (2022). DOI: https://doi.org/10.3390/met12030469

[6] T. Rzychoń, M. Dyzia, I. Pikos, Solid State Phenomena, Microstructure of WE43 Magnesium Matrix Composite Reinforced Ceramic Particles. **211**, 101-108 (2013). DOI: https://doi.org/10.4028/www.scientific.net/SSP.211.101

[7] E. Karthick, J. Mathai, J.M. Tony, K. Marikkannan, Materials Today Proceedings, Processing, Microstructure and Mechanical Properties of Al2O3 and SiC Reinforced Magnesium Metal Matrix Hybrid Composites. **4**, 6, 6750-6756 (2017). DOI: https://doi.org/10.1016/j.matpr.2017.06.451

[8] N. Ananthi, U. Elaiyarasan, V. Satheeshkumar, C. Senthilkumar, S. Sathiyamurthy, K. Nallathambi, Metallurgical Research & Technology, Parametric Effect on Material Removal Rate and Surface Roughness of Electrical Discharge Machined Magnesium Alloy. **118**, 6, 615 (2021). DOI: https://doi.org/10.1051/metal/2021089

[9] T. Sankar, V. Mohanavel, Matéria (Rio de Janeiro), Investigations on Electrical Discharge Machining Parameters of Silicon Nitride Particles Reinforced Magnesium Composites. **29**, 4, (2024). DOI: https://doi.org/10.1590/1517-7076-rmat-2024-0615

[10] R. Mohan, R. Manivannan, V. Kaviarasan, S. Sangeetha, S. Prabakar, Materials Today Proceedings, Experimental Investigation in EDM by Using Brass Electrode with Inconel 690 Materials in Mixed Dielectric Medium. **37**, 3747-3754 (2020). DOI: https://doi.org/10.1016/j.matpr.2020.10.367

[11] A. Nirala, S. Soren, N. Kumar, R. Garg, S.K. Sharma, A. Shrivastava, D.B. Singh, D. Yadav, J. Yadav, Materials Today Proceedings, Comprehensive Study of Magnesium-Based Metal Matrix Composite. **46**, 6587-6591 (2021). DOI: https://doi.org/10.1016/j.matpr.2021.04.062

[12] S. Wu, S. Wang, D. Wen, G. Wang, Y. Wang, Applied Sciences, Microstructure and Mechanical Properties of Magnesium Matrix Composites Interpenetrated by Different Reinforcement. **8**, 11, 2012 (2018). DOI: https://doi.org/10.3390/app8112012

[13] B. Tang, J. Li, Y. Wang, H. Luo, J. Ye, X. Chen, X. Chen, K. Zheng, F. Pan, Vacuum, Mechanical Properties and Microstructural Characteristics of Ti/WE43 Composites. **206**, 111534 (2022). DOI: https://doi.org/10.1016/j.vacuum.2022.111534

[14] K. Rahmani, G. Majzoobi, G. Ebrahim-Zadeh, M. Kashfi, Transactions of Nonferrous Metals Society of China, Comprehensive Study on Quasi-Static and Dynamic Mechanical Properties and Wear Behavior of Mg – B4C Composite Compacted at Several Loading Rates through Powder Metallurgy. **31**, 2, 371-381 (2021). DOI: https://doi.org/10.1016/s1003-6326(21)65502-4

[15] A.K. Khanra, H.C. Jung, S.H. Yu, K.S. Hong, K.S. Shin, Bulletin of Materials Science, Microstructure and Mechanical Properties of Mg-HAP Composites. 33, 1, 43-47 (2010). DOI: https://doi.org/10.1007/s12034-010-0006-z

[16] A. Abbas, V. Rajagopal, S. Huang, Intech Open eBooks, Magnesium Metal Matrix Composites and Their Applications. (2021). DOI: https://doi.org/10.5772/intechopen.96241

[17] S. Abazari, A. Shamsipur, H.R. Bakhsheshi-Rad, A.F. Ismail, S. Sharif, M. Razzaghi, S. Ramakrishna, F. Berto, Materials, Carbon Nanotubes (CNTs)-Reinforced Magnesium-Based Matrix Composites: A Comprehensive Review. **13**, 19, 4421 (2020). DOI: https://doi.org/10.3390/ma13194421

[18] T.S. Ashokan, S. Swamynathan, S. Selvarangan, Materials Science, Investigation of Mechanical Properties of Biodegradable AZ31 Magnesium Alloys with Calcium Addition. **32**, 2, 177-183 (2025). DOI: https://doi.org/10.5755/j02.ms.38398