Improving Mechanical Properties of Magnesium matrix composite using reutilization of Electronic Waste and Boron Nitride

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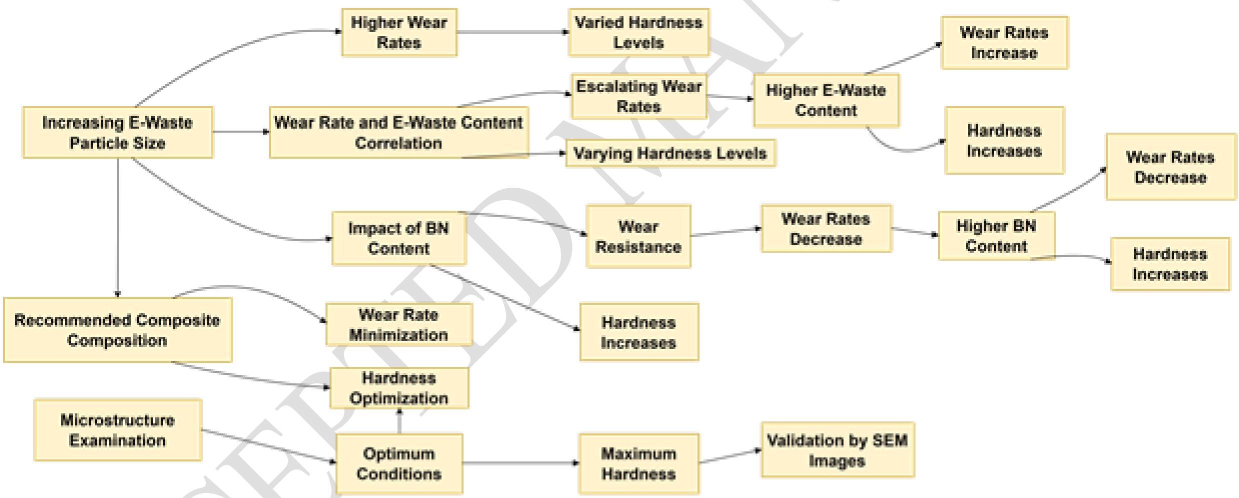
GRAPHICAL ABSTRACT



ABSTRACT

This study examines the properties of Mg (Magnesium)/Electronic Waste/BN (Boron Nitride) composite materials by analyzing their wear rate and hardness using a one-variable-at-a-time approach. It reveals intricate relationships affecting material performance, with increasing E-Waste particle size causing higher wear rates and varying hardness levels. E(Electronic)-Waste particle size increases wear rates, ranging from 0.62 to 1.18 $\times 10^{-2}$ mm^3/m, correlating with size increments. Hardness values range from 32 to 51 HRB, varying with particle size. Wear rate and E-Waste content directly correlate, with higher E-Waste content escalating wear rates from 0.69 to 1.23 $\times 10^{-2}$ mm^3/m

and hardness increasing from 31 to 44 RHB. The weight percentage of BN significantly impacts wear resistance, with wear rates decreasing with higher BN content. Hardness increases from 42 to 47 RHB (Rockwell Hardness Scale B) with higher BN content. A 10 µm size of 5 wt.% of e-waste with 1 wt.% of BN mixed composite is recommended to minimize the wear rate (0.61×10^{-2} mm^3/m) of the composite. The microstructure of the worn-out surfaces under optimum conditions is examined. The maximum hardness (52 RHB) has been obtained by mixing 30 µm of 10 wt.% of e-waste with 3 wt.% of BN particles in a mixed composite. The microstructure of the worn-out surface is validated by Scanning Electron Microscopy (SEM) images.

Keywords: Mg/E-Waste/BN, wear rate, hardness; E-Waste particle size, weight percentage, BN, material properties

1. Introduction

Lightweight materials with high strength-to-weight ratios are required for high-performance products in sectors like automotive and aviation. A difficult and cost-effective composite material comprised of metal and reinforcing components is called Metal Matrix Composite (MMC). Due to production difficulties, particle-reinforced MMC is mostly used as reinforcing ceramic particles, and copper, titanium, magnesium, and aluminium are employed as matrix elements to give specified strength, stiffness, temperature resistance, and wear resistance(Harikaran M. *et al.*2023; Selvakumar *et al.*2023). E-waste, which contains valuable and hazardous elements, is a result of the accessibility of electronic equipment and the quick advancement of technology. E-waste operations have decreased due to high processing costs and rigorous environmental requirements(Hanumanthakari *et al.*2023; Janardhana *et al.*2023). New technology and poor worker protection are two main problems in the processing of e-waste in developing nations like India. A vital component of 55% of televisions and 32% of computer displays are cathode ray tubes, which are constructed of 85% glass and offer cutting-edge display capabilities. They are made up of non-glass components such as a shadow mask and an electron gun, together with a glass panel, funnel, and neck glass.

The difficulty in composites, which depends on the prices of reinforcing and matrix materials, has strengthened the trend of employing waste goods for MMC manufacturing in agriculture and industry (Chaithanyasai et al. 2014). In the construction of MMC, various fly ash wastes made from coal are used as reinforcements. According to studies, some MMCs made with these reinforcements exhibit upright qualities. The following literature explains the waste materials used in making composite materials.

Researchers used a twofold stir-casting technique to create composites made of Aluminium-copper- Magnesium (Al-Cu-Mg) alloy and bagasse ash. Hardness and compression strength were both increased by 43.3 and 57.7 percent, respectively, by bagasse ash particles. The reinforced MMC increased yield strength and ultimate tensile strength while lowering density and impact energy(Aigbodion *et al.*2010). Aluminum-fly ash composites increase hardness and wear resistance in MMCs with 10% and 20% fly ash particles, according to electrochemical experiments, suggesting possible industrial uses in covers, casings, brake rotors, and engine blocks (Marin *et al.*2012). In the study, the effect of thermal aging temperature on the performance of an Al-Cu-Mg alloy/bagasse ash composite was investigated. It was discovered that consistent bagasse ash particle distribution in cast and heat-treated samples led to enhanced mechanical characteristics(Aigbodion2014). Fly ash particles can boost tensile strength by up to 15% in aluminium 6061 alloy, but they also reduce performance. Up to 15% fly ash particle loading causes a drop in the specific wear rate and an increase in base alloy hardness. The addition of 20% fly ash reinforcement to aluminium MMC raises the specific wear rate(Kumar *et al.*2014).

The study used triple-layer feeding-stir casting to assess an Al-Cu-Mg alloy/bean pod ash composite. X-ray diffraction analysis verified the creation of nanostructures. While elongation and impact energy somewhat decreased with the addition of BPA nanoparticles from 0 to 4 wt. percent, tensile strength and hardness were enhanced(Atuanya & Aigbodion2014). The study investigated the wear and corrosion behaviour of hybrid Al-Mg-Si (Aluminium-Magnesium- Silicon) alloy matrix composites reinforced with silicon carbide, silicon dioxide, and rice husk ash. The results revealed increased corrosion resistance but variable performance. Comparable to Al-Mg-Si MMC reinforced with SiC(Silicon carbide) were rice husk ash and SiC-reinforced MMC. The study recommends utilising rice husk powder as a reinforcing material for applications requiring excellent wear and corrosion resistance(Alaneme *et al.*2014). The wear resistance of Al MMC in stir casting with rock dust particles at various weight percentages is examined in the study. According to the results, harder materials have bigger particle sizes and reinforcing, and harder materials also have greater wear resistance. According to the Analysis of Variance results, the applied load, particle size, and percentage of rock dust all have a significant impact on wear performance(Prakash *et al.*2016). Granite dust and graphite reinforced aluminum 6061 base metals. In comparison to unreinforced alloys, the mixture of 2 percent Gr (Graphene) and 4 percent granite dust gives better tribological performance, tensile strength, and wear resistance. Granite dust, a cheap and accessible ceramic filler, may eventually take the place of more expensive fillers like B4C and SiC(Pai *et al.*2015). Utilizing modified electromagnetic stir casting and an external argon gas supply, the A356/ SiC/ Fly-ash hybrid MMC was created. Results indicated that A356/15% SiC/ 5% fly ash MMC produced superior performance to other MMCs(Dwivedi *et al.*2015). Utilizing the liquid metallurgical approach, the study strengthened three distinct types of fly ash particles with Al/3.25Cu/8.5Si alloy. According to the findings of abrasive wear tests, fly ash particles' weight % and size increase MMC's resistance to abrasion while decreasing its rate of wear. Fly ash particle size and weight % both rise along with Coefficient of Friction (Kumar & Sreebalaji2015). Utilizing eggshell waste particles decreased the density of aluminium 2014 matrix composites by 5%. According to mechanical investigations, the hardness, toughness, and fatigue strength were enhanced and distributed uniformly (Dwivedi *et al.*2016). By employing stir casting to reinforce bagasse ash and graphite particles with aluminium 7075 alloy, a hybrid composite was produced. The composites' hardness, ultimate tensile strength, and yield strength were all enhanced, with MMC reinforced with 6% bagasse ash and 5% graphite performing best(Imran *et al.*2016).

Tensile strength, hardness, and fatigue strength were all increased when 12.5 weight percent eggshell was added to MMC. Carbonized eggshell particles outperformed uncarbonized particles and Calcium Carbonate reinforcement in terms of their physical and mechanical characteristics. The hardness of the Al6061 alloy increased while density and electrical conductivity decreased in the Al/12.5 percent eggshell composite, which was 3.92 percent and 12.5 percent lower than the basic material(Dwivedi *et al.*2016). Using a powder metallurgy process, rock dust (RD) is added to 50% aluminium to increase microhardness and wear resistance by 10%. Alumina coated Al/RD MMC performs better in wear and hardness tests, whereas higher compaction pressure improves hardness and wear resistance(Prakash *et al.*2016). Aluminum MMC was made using pumice particles and recycled beer cans as the basic material. Si- silicon (20.93%), Al (11.87%), and O- Oxygen (52.66%) elements were found via EDS (Energy Dispersive X-ray Spectroscopy) analysis. The reinforced MMC was ideal for the production of lightweight materials since it enhanced hardness and tensile strength by 11.08 percent and 28.39 percent, respectively, and had a density that was 39.51 percent lower than that of unreinforced beverage can aluminium(Dagwa & Adama2018). The study used stir casting with bagasse ash particle reinforcement to investigate the mechanical and tribological characteristics of MMC based on Al-Si10-Mg. According to EDS research, bagasse ash particle concentration enhanced wear resistance while increasing hardness, tensile, and impact strength(Shankar *et al.*2018). Study investigates microstructure and thermal behaviour of MSA-reinforced alloy MMC. The main substances found were SiO_2 (silicon dioxide) and Al_2O (aluminum oxide)(Abdulwahab *et al.*2017).

A review of the literature identifies research holes in MMC, with the expense as a key hindrance. Compared to MMC made from aluminium, magnesium MMC made from waste particles is significantly less expensive. The time for recycling Cathode Ray Tube panel glass is quickly running out, hence efficient reuse techniques are required. There is few research on how the machining of magnesium-based materials is impacted by the reinforcing particle size, emphasising the significance of machinability. The hot-pressing approach has effectively created hybrid composites including titanium and nickel components, resulting in yield and compressive strength gains of 33% and 83%, respectively, while preserving magnesium ductility when compared to ceramic materials (Kelen2023a). The hot-pressing process has effectively created hybrid composites including titanium and nickel components, resulting in yield and compressive strength enhancements of 33% and 83%, respectively, while preserving magnesium ductility when compared to ceramic materials (Kelen2023b).

The novelty of the present research is the fabrication of a new (Mg/Electronic Waste/BN) composite material that, while increasing E-Waste particle size, increases wear rates and hardness, while higher BN content improves wear resistance and hardness. The study identifies an optimal composite mix to minimize wear rate, and SEM validation provides insights into particle interactions and material performance. By altering the E-Waste particle size, weight % of E-Waste, and weight percentage of BN, this research study systematically examines the characteristics of Mg/E-Waste/BN composite materials. The impacts of these factors on wear rate and hardness are examined using a one variable at a time method.

2. Materials and methods

2.1. Experimental Setup

Pure magnesium, which has density of 1,74 g/cm^3, a melting temperature of 655° C, and a boiling point of 1090°C, is chosen as the basic material to create the lightweight MMC. E-waste computer and electric components milled waste powder and boron nitride are used in the study as primary and secondary reinforcement, respectively. E-waste is created from computer, mobile phone, and laptop panels, printed circuit board components, which weigh a lot, have a lot of silica, and a tiny quantity of other elements(Haribalaji *et al.*2022).

The study used two types of boron nitride, cubic boron nitride (CBN) and hexagonal boron nitride, as supplementary reinforcements for magnesium hybrid MMC construction (BN). While the current study combines soft hexagonal boron nitride and CRT panel glass, soft BN is a solid lubricant comprised of graphite and molybdenum disulphide. Since BN has chemical, thermal, and electrical characteristics, it may be used in a variety of applications(Koshariya *et al.*2023a, 2023b). Due to its solid lubricant properties, thermal stability, and electrical resistivity, it may be used in vacuum and oxidizing atmospheres, especially in space applications. Powder metallurgy is used to create the Mg/E-Waste/BN hybrid composite, with milled electronics component powder serving as the main reinforcement. Ball milling produces electronic components with different particle sizes (10, 20, 30, 40, and 50 µm), which are used as the main reinforcement. While secondary BN solid lubricant reinforcement weighs between 1 and 2%, primary E-waste reinforcement weighs between 5 and 15%. Property decrement occurs after further BN addition, with an interval of 0.25 percent. Utilizing size, weight, and pure magnesium, five magnesium composites were created(Boopathi *et al.*2022).

A ball mill container with a 3:1 stainless steel ball-to-powder ratio is used for the mechanical mixing of base magnesium and reinforcements. The mixture is mixed for 3 hours, then compacted in a 40-mm-diameter split-type die with a compression testing machine at 600 MPa. The dwell time is 10 minutes. Green compacts (ø40 × 40mm) are sintered at 570 °C in a muffle furnace before being cooled to ambient temperature. Due to the strong air reactivity of the magnesium material, sintering under an argon environment is necessary. Sintered specimens are taken out and cleaned for examination, and an ongoing supply of argon gas is supplied. The study used a Rockwell hardness setup to assess the hardness of produced specimens using a 1/16" ball intender and a 100 kgf load for 15 seconds (Krystal Industries).

The Rockwell hardness technique compares the indenter's penetration depth under light and heavy loads to determine the hardness of a material. It is appropriate for examining a variety of materials since it is basic and straightforward to use. There are scales from A through G, with B and C being the most popular. Hard materials employ diamond intenders, whereas soft materials use steel spherical intenders(Jeyakymar *et al.*2022; Kavitha *et al.*2022).

According to ASTM (American Society for Testing and Materials) G99 standards, dry sliding wear analysis evaluates CRT panel glass using a pin-on-disc test device (Figure 1(a)). The pin-on-disc technique entails swiftly moving a stationary pin across a revolving disc. The research makes use of

8x8x30mm pins made of hardened EN31 steel with a hardness of 65 HRC (Rockwell Hardness Scale C). Before each run, samples are sliced, polished, and cleaned with acetone.

Figure 1. (a) Pin-disc **(b)** Mg/E-Waste/BN Composite Specimens

A one-variable-at-a time approach is used to conduct all the experiments. While varying E-waste particle size, the weight percentages of E-waste (wt%) and BN (wt%) are constantly maintained at their mean levels. The wear rate and hardness of each experiment are recorded at the end of the testing. The specimens made by experiments are shown in Figure 1(b).

3. Results and Discussion

3.1. Effect of E-Waste Particle size on the wear rate and hardness

The testing findings for the wear rate and hardness of Mg/BN/E-Waste composite materials as the E-Waste particle size fluctuates are shown in Table 1 below. E-waste weight percentage is set at 10% for this inquiry, while BN weight percentage is set at 2%(Haribalaji *et al.*2022).

Table 1. Wear rate and hardiness of Mg/E-Waste/BN composite versus E-Waste particle size (E-Waste (wt.%) = 10%; BN (Wt.%) = 2%)

Source	**Experiment number**				
	1	**2**	**3**	**4**	**5**
E-Waste particle size (µm)	10	20	30	40	50
Wear Rate (10^{-2} mm^3/m)	0.62	0.67	0.83	0.98	1.18
Hardness (RHB)	32	40	51	45	43

Wear Rate Analysis: The wear rate is a measurement of how much material is lost over a predetermined distance or period of time as a result of friction and wear. It is stated in this instance in units of 10^{-2} mm^3/m. Due to bigger E-waste particles possibly causing faster wear rates in the composite material, the wear rate normally increases as the E-waste particle size increases. Because bigger particles could be more abrasive and have greater contact with the counter surface, which would speed up material loss(Jeyakymar *et al.*2022).

Hardness Analysis: The wear rate is a measurement of the amount of material lost over a certain distance or period of time as a result of wear and friction. In this instance, it is stated in terms of 10^{-2} mm^3/m. Larger E-Waste particles may cause greater wear rates in the composite material, which is why the wear rate normally increases as the size of the E-Waste particle size does. Due to the possibility that bigger particles may exert greater abrasive force and come into contact with the counter-surface, material loss may increase (Jeyakymar *et al.*2022; Kavitha *et al.*2023a).

Table 1 demonstrates that when the size of the E-waste particles grows, the wear rate rises while hardness first rises and subsequently falls. While the hardness ranges from 32 for 10 µm to 51 for 30 µm, the wear rates range from 0.62 for 10 µm to 1.18 for 50 µm. Due to their greater hardness, larger particles may boost wear resistance, but they also run the risk of causing more abrasive wear.

Figure 2 illustrates that wear rate increases as E-waste particle size increases, whereas hardness first rises and later falls. In comparison to the hardness, the wear rates vary from 32 for 10 µm to 51 for 30 µm, while the hardness ranges from 0.62 for 10 µm to 1.18 for 50 µm. Larger particles may have more wear resistance because they are harder, but they also run the risk of increasing abrasive wear.

These outcomes are based on a one-variable-at-a-time methodology. As a result, even though the impacts of E-waste particle size have been examined while holding all other factors constant, real-world situations can sometimes be significantly more complicated.

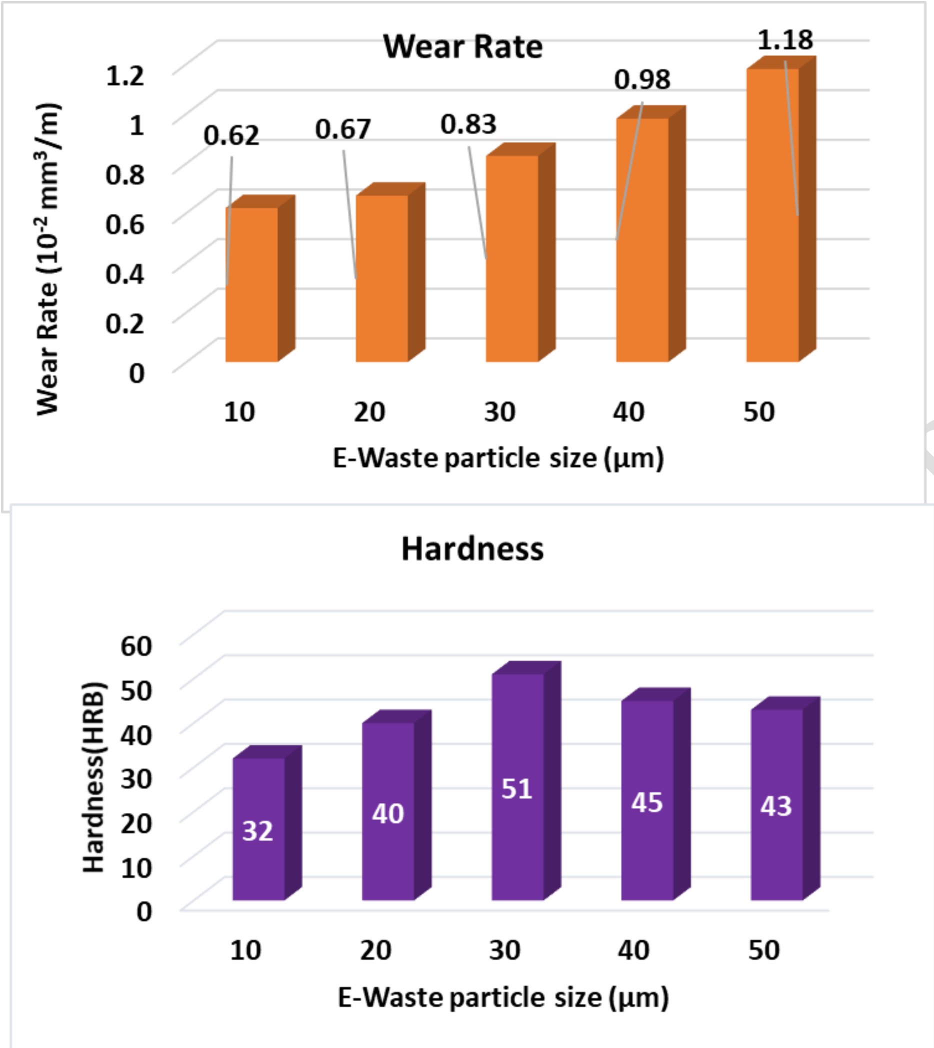


Figure 2. Variation of hardness and wear rate composite by increasing E-Waste particle size

Table 2. Wear rate and hardiness of Mg/E-Waste/BN composite versus weight percentage of E-Waste (E-Waste particle size = 30 µm BN (Wt.%) = 2%)

Source	**Experiment**				
	1	**2**	**3**	**4**	**5**
E-Waste (wt. %)	5	7.5	10	12.5	15
Wear Rate (10^{-2} mm^3/m)	0.69	0.72	0.87	1.07	1.23
Hardness (RHB)	31	38	44	46	44

3.2. Effect of Percentage of E-Waste on the wear rate and hardness

As the weight percentage of E-waste changes, Table 2 shows experimental results pertaining to the wear rate and hardness of Mg/E-waste/BN composite materials. E-waste particle size at 30 m and BN weight percentage at 2 percent serve as the study's constants.

As the weight percentage of E-waste increases, there is a general trend of increasing wear rates in the composite material.

This hints that more E-Waste might make things wear out faster. It could be because there's more stuff that rubs against things when there's more E-Waste in the mix. As you put in more e-waste, the material gets harder. This pattern shows that the e-waste has an impact on how hard it gets. Maybe it's because the bits of E-Waste work like a support making the whole thing stronger overall.

Wear rates go from 0.69 to 1.23 for 5% and 31 to 44 for 12.5% hinting that more E-Waste might make stuff tougher and harder to wear down. Figure 3 shows a link between how much E-waste is in there and how fast the mix wears out and how hard it is. This could mean that having more E-Waste bits in the mix helps it resist wear and tear better and makes it harder. The findings point to the idea that putting in more E-Waste by weight could make these mixed materials tougher and harder to wear out. It's key to balance these good points with how much it costs how easy it is to make, and what the material is like overall.

This suggests that higher concentrations of E-Waste might lead to higher wear rates. This could be due to the increased presence of abrasive particles in the composite as the E-Waste content rises. As the weight proportion of e-waste grows, the composite material's hardness tends to rise. This pattern suggests that more E-Waste is responsible for the hardness trend. This could be because the E-Waste particles act as reinforcement, improving the composite material's overall mechanical qualities.

Wear rates range from 0.69 to 1.23 for 5% and 31 to 44 for 12.5%, suggesting that higher E-Waste content may enhance wear resistance and hardness. According to Figure 3, there appears to be a connection between the weight percentage of E-waste and the composite's wear rate and hardness. This may suggest that a larger concentration of E-Waste particles contributes to the composite material's enhanced wear resistance and hardness. The results suggest that increasing E-Waste weight percentage could enhance wear resistance and hardness in composite materials. Balancing these properties with cost, ease of fabrication, and material characteristics is crucial.

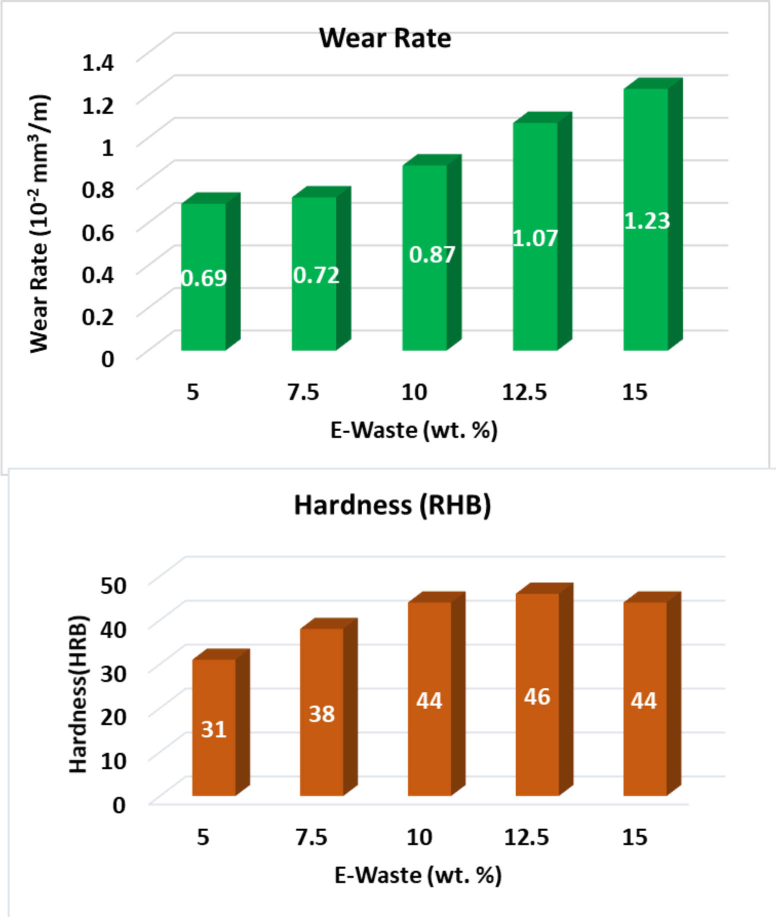


Figure 3. Variation of hardness and wear rate composite by increasing E-Waste weight percentage

Table 2 shows that increasing E-Waste weight percentage leads to higher wear rates and hardness.

3.3.Effect of Percentage of BN particles on the wear rate and hardness

As the weight % of BN fluctuates, Table 3 shows experimental findings on the wear rate and hardness of Mg/E-Waste/BN composite materials. E-Waste weight percentage of 10% and E-Waste particle size of 30 µm serve as study's constants.

Table 3. Wear rate and hardness of Mg/E-Waste/BN composite versus weight percentage of BN (E-Waste (wt.%) = 10%; E-Waste particle size = 30 µm)

Source	**Experiment**				
	1	**2**	**3**	**4**	**5**
BN (wt. %)	1	1.5	2	2.5	3
Wear Rate (10^{-2} mm^3/m)	0.90	0.83	0.81	0.76	0.72
Hardness (RHB)	33	38	42	47	46

As the weight percentage of BN increases, there appears to be a general trend of decreasing wear rates in the composite material. This indicates that higher concentrations of BN might lead to reduced wear rates due to the lubricating or reinforcing effect of BN, which could help reduce friction and wear between the composite's components(Boopathi2023).

The hardness of the composite material tends to increase as the weight percentage of BN increases. This suggests that a higher proportion of BN contributes to higher hardness. BN's presence could enhance the material's structural integrity and mechanical properties, leading to increased hardness.

Figure 4 shows that increasing BN content leads to decreased wear rates and increased hardness. Wear rates range from 0.72 to 0.90%, while hardness ranges from 22% to 25%. A higher BN content may result in reduced wear rates and improved hardness.

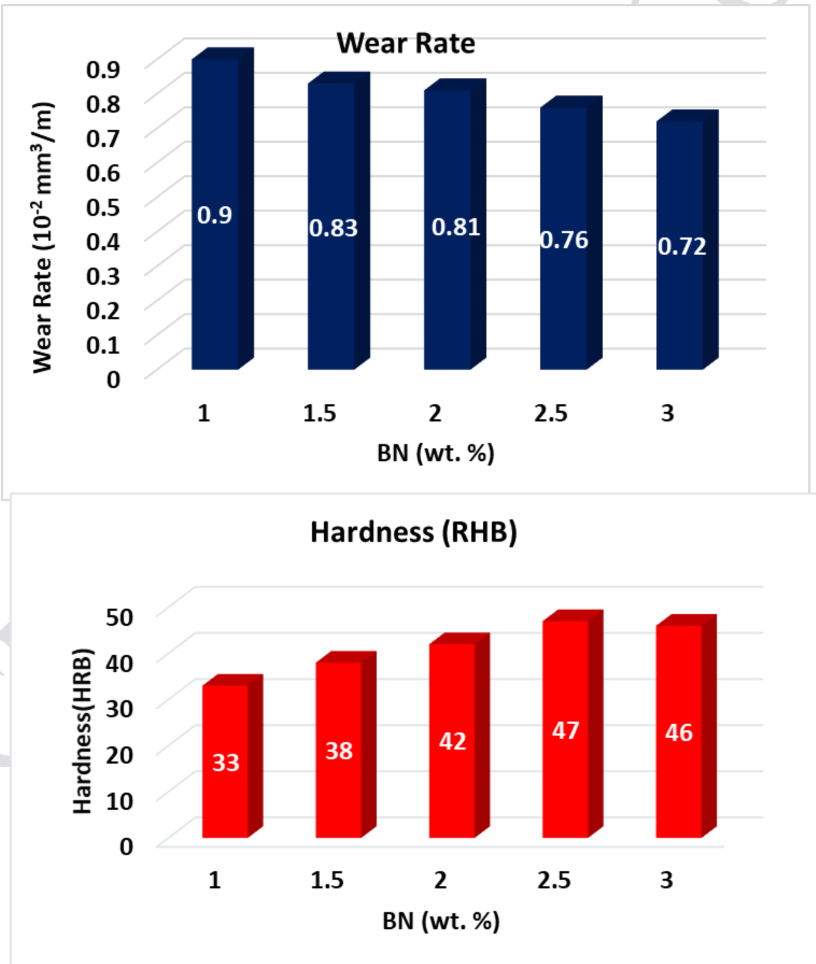


Figure 4. Variation of hardness and wear rate composite by increasing BN weight percentage

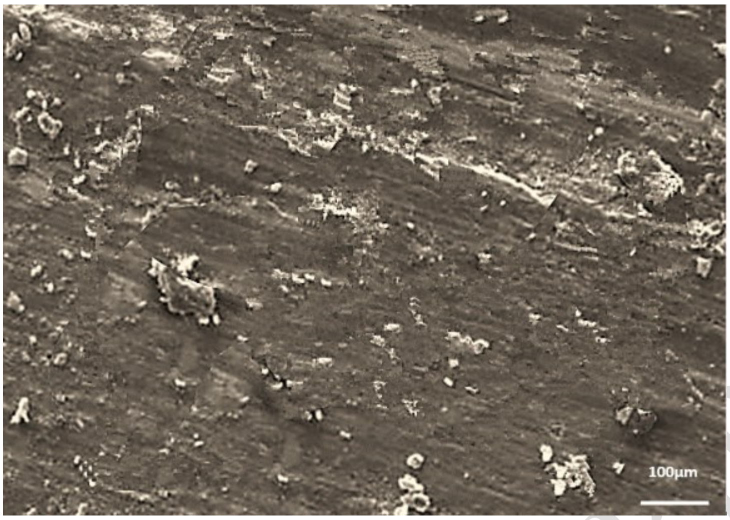


Figure 5. Optimum Worn-out surface using (10 µm size of 5% of E-Waste with 1% of BN mixed Composite)

The results show that there may be an inverse link between the wear rate in the composite and the weight % of BN. Additionally, BN concentration and hardness appear to be positively correlated. This would imply that materials with a greater BN concentration might balance enhanced hardness and better wear resistance(Siddaraju *et al.*2015; Kavitha *et al.*2023b). Consider potential interactions between variables, such as BN content, E-Waste particle size, and weight percentage, to understand complex behaviours and potential interactions. The findings could impact composite material design for specific applications, such as increased wear resistance and hardness with an increased BN weight percentage. However, practical considerations, cost factors, and material properties must be considered during the design process. Figure 5 shows a 10 µm E-Waste mixed composite with BN to minimize wear rate, examined using SEM images.

3. Future Work

The one-variable-at-a-time method has its limits when studying how E-waste weight percentage affects properties. Other factors like particle size and BN content can change how the composite behaves. Looking at Mg/BN/E-Waste composites shows tricky links between E-Waste particle size, wear rate, and hardness. Bigger E-waste particles tend to cause more wear and a U-shaped hardness trend. Using more E-Waste and BN seems to make the material tougher and harder to wear down. But it's not that simple - these things all work together in ways we don't get yet. To understand how E-Waste particle size, weight percentage, and BN content interact, we need to do more thorough tests. This could show us if these things work together or against each other in ways we can't see when we look at one thing at a time. In this research, the best mixing percentages of BN and E-waste particles were used to obtain the maximum hardness and minimum wear rate of the eco-friendly composite materials. Hence, the XRD analysis has not been performed. However, the XRD analysis of the newly made composite specimen will be performed in our future work. Future studies should look at multiple variables at once to make composites work better in real life. The main goal is to figure out how all these factors work together so we can make composites with just the right properties. Nanomaterials and electronic materials will also be added to composites to enhance their mechanical, electrical, and electronic properties.

4. Conclusions

This research looks at how Mg/E-Waste/BN composite materials behave when you change the E-Waste particle size how much of it you use, and how much BN you add. It checks out how these changes affect how the material wears down and how hard it is showing there's a lot going on that impacts how well it works.

- When you mess with the E-Waste particle size, the wear rate goes from 0.62 to 1.18×10^{-2} mm^3/m, and it tends to get bigger as the particles get bigger. The hardness is between 32 and 51 RHB first going up but then dropping as the particles get larger.
- E-Waste Weight Percentage Changes: Wear Rate Range: 0.69 to 1.18×10^{-2} mm^3/m, which goes up as E-Waste content gets higher. Hardness Range: 31 to RHB showing that it gets harder when there's more E-Waste.
- BN Weight Percentage Changes: Wear Rate Range: 0.72 to 0.90×10^{-2} mm^3/m, which goes down as BN content increases. Hardness Range: 42 to 47 RHB showing that it gets harder when there's more BN.
- The mixing 5% of E-Waste (10 μm size) with 1% of BN in the composite is the best way to reduce wear rate (0.61×10^{-2} mm^3/m). We looked at the structure of worn-out surfaces under these ideal conditions.
- The composite with 10% of E-Waste (30 μm size) and 3% of BN particles mixed in gave the highest hardness (52 RHB).

References

Abdulwahab M.Umaru O.B.Bawa M.A.and Jibo H.A. (2017), Microstructural and thermal study of Al-Si-Mg/melon shell ash particulate composite, . *Results in physics*, **7**, 947–954

Aigbodion V.S. (2014), Thermal ageing on the microstructure and mechanical properties of Al–Cu–Mg alloy/bagasse ash particulate composites, . *Journal of King Saud University-Engineering Sciences*, **26**, 144–151

Aigbodion V.S.Hassan S.B.and Oghenevweta J.E. (2010), Microstructural analysis and properties of Al–Cu–Mg/bagasse ash particulate composites, . *Journal of Alloys and Compounds*, **497**, 188–194

Alaneme K.K.Adewale T.M.and Olubambi P.A. (2014), Corrosion and wear behaviour of Al–Mg–Si alloy matrix hybrid composites reinforced with rice husk ash and silicon carbide, . *Journal of Materials Research and Technology*, **3**, 9–16

Atuanya C.U. and Aigbodion V.S. (2014), Evaluation of Al–Cu–Mg alloy/bean pod ash nanoparticles synthesis by double layer feeding–stir casting method, . *Journal of alloys and compounds*, **601**, 251–259

Boopathi S. (2023), An Investigation on Friction Stir Processing of Aluminum Alloy-Boron Carbide Surface Composite, . In *Materials Horizons: From Nature to Nanomaterials* . Springer Nature, 249–257

Boopathi S.Jeyakumar M.Singh G.R.King F.L.Pandian M.Subbiah R.and Haribalaji V. (2022), An experimental study on friction stir processing of aluminium alloy (AA-2024) and boron nitride (BNp) surface composite, . *Materials Today: Proceedings*, **59**, 1094–1099

Dagwa I.M. and Adama K.K. (2018), Property evaluation of pumice particulate-reinforcement in recycled beverage cans for Al-MMCs manufacture, . *Journal of King Saud University-Engineering Sciences*, **30**, 61–67

Dwivedi S.P.Sharma S.and Mishra R.K. (2015), RETRACTED ARTICLE: Microstructure and mechanical behavior of A356/SiC/Fly-ash hybrid composites produced by electromagnetic stir casting, . *Journal of the Brazilian Society of Mechanical Sciences and Engineering*, **37**, 57–67

Dwivedi S.P.Sharma S.and Mishra R.K. (2016), Mechanical and metallurgical characterizations of AA2014/eggshells waste particulate metal matrix composite, . *International Journal of Precision Engineering and Manufacturing-Green Technology*, **3**, 281–288

Hanumanthakari S.Gift M.D.M.Kanimozhi K. V.Bhavani M.D.Bamane K.D.and Boopathi S. (2023), Biomining Method to Extract Metal Components Using Computer-Printed Circuit Board E-Waste, . 123–141

Haribalaji V.Boopathi S.Mohammed Asif M.Yuvaraj T.Velmurugan D.Anton Savio Lewise K.Sudhagar S.and Suresh P. (2022), Influences of Mg-Cr filler materials in Friction Stir Process of Aluminium-based dissimilar alloys, . *Materials Today: Proceedings*, **66**, 948–954

Harikaran M.Boopathi S.Gokulakannan S.and Poonguzhali M. (2023), Study on the Source of E-Waste Management and Disposal Methods, . In *Sustainable Approaches and Strategies for E-Waste Management and Utilization* . IGI Global, 39–60

Imran M.Khan A.R.A.Megeri S.and Sadik S. (2016), Study of hardness and tensile strength of Aluminium-7075 percentage varying reinforced with graphite and bagasse-ash composites, . *Resource-Efficient Technologies*, **2**, 81–88

Janardhana K.Singh V.Singh S.N.Babu T.S.R.Bano S.and Boopathi S. (2023), Utilization process for electronic waste in eco-friendly concrete: Experimental study, . In *Sustainable Approaches and Strategies for E-Waste Management and Utilization* . IGI Global, 204–223

Jeyakymar M.Munusami V.Shanmugam P.Boopalan N.Boopathi S.and Sureshkumar M. (2022), An investigation on wear loss and hardness of nitro-carburizing coated stainless-steel grade-316, . *Materials Today: Proceedings*, **66**, 1398–1404

Kavitha C.Geetha Malini P.S.Charan Kantumuchu V.Manoj Kumar N.Verma A.and Boopathi S. (2023a), An experimental study on the hardness and wear rate of carbonitride coated stainless steel, . *Materials Today: Proceedings*, **74**, 595–601

Kavitha C.Geetha Malini P.S.Charan Kantumuchu V.Manoj Kumar N.Verma A.and Boopathi S. (2023b), An experimental study on the hardness and wear rate of carbonitride coated stainless steel, . *Materials Today: Proceedings*, **74**, 595–601

Kavitha C.Malini P.S.G.Charan V.Manoj N.Verma A.and Boopathi S. (2022), An experimental study on the hardness and wear rate of carbonitride coated stainless steel, . *Materials Today: Proceedings*,

Kelen F. (2023a), Fabrication, microstructure and mechanical properties of novel titanium and nickel micro-particulates reinforced AZ91D magnesium alloy metal matrix hybrid composites, . *Journal of Alloys and Compounds*, **968**, 171999

Kelen F. (2023b), Novel magnesium matrix hybrid composites manufactured through powder metallurgy technique, . *Materials Today Communications*, **35**, 106348

Koshariya A.K.Khatoon S.Marathe A.M.Suba G.M.Baral D.and Boopathi S. (2023a), Agricultural Waste Management Systems Using Artificial Intelligence Techniques, . 236–258

Koshariya A.K.Khatoon S.Marathe A.M.Suba G.M.Baral D.and Boopathi S. (2023b), Agricultural Waste Management Systems Using Artificial Intelligence Techniques, . In *AI-Enabled Social Robotics in Human Care Services* . IGI Global, 236–258

Kumar K.R. and Sreebalaji V.S. (2015), Desirability based multiobjective optimisation of abrasive wear and frictional behaviour of aluminium (Al/3.25 Cu/8.5 Si)/fly ash composites, . *Tribology-Materials, Surfaces & Interfaces*, **9**, 128–136

Kumar V.Gupta R.D.and Batra N.K. (2014), Comparison of Mechanical Properties and effect of sliding velocity on wear properties of Al 6061, Mg 4%, Fly ash and Al 6061, Mg 4%, Graphite 4%, Fly ash Hybrid Metal matrix composite., . *Procedia Materials Science*, **6**, 1365–1375

Marin E.Lekka M.Andreatta F.Fedrizzi L.Itskos G.Moutsatsou A.Koukouzas N.and Kouloumbi N. (2012), Electrochemical study of Aluminum-Fly Ash composites obtained by powder metallurgy, . *Materials Characterization*, **69**, 16–30

Pai A.Sharma S.S.D'Silva R.E.and Nikhil R.G. (2015), Effect of graphite and granite dust particulates as micro-fillers on tribological performance of Al 6061-T6 hybrid composites, . *Tribology International*, **92**, 462–471

Prakash K.S.Balasundar P.Nagaraja S.Gopal P.M.and Kavimani V. (2016), Mechanical and wear behaviour of Mg–SiC–Gr hybrid composites, . *Journal of magnesium and alloys*, **4**, 197–206

Selvakumar S.Shankar R.Ranjit P.S.Bhattacharya S.Gupta A.S.G.and Boopathi S. (2023), E-Waste Recovery and Utilization Processes for Mobile Phone Waste, . In *Handbook of Research on Safe Disposal Methods of Municipal Solid Wastes for a Sustainable Environment* . IGI Global, 222–240

Shankar S.Balaji A.and Kawin N. (2018), Investigations on mechanical and tribological properties of Al-Si10-Mg alloy/sugarcane bagasse ash particulate composites, . *Particulate Science and Technology*, **36**, 762–770

Siddaraju N.Satish N.Chandrashekar A.Reddappa H.N.Ajaykumar B.S.Satish N.Reddappa H.N.Ajaykumar B.S.and Siddaraju N. (2015), Assessment of Tensile and Hardness Property of AA5083/Nano-Al2O3 Metal Matrix Composites, . *International Journal of Composite Materials and Matrices*, **1**, 28–34