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Tribological Investigation of Composite-based ZA-27 Alloy Reinforced by Carbon Fibre in Different Proportions

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Abstract: The study's goal is to see how mechanical, wear, and thermal characteristics of ZA-27 alloy composites are all affected by macroscopic carbon fiber particles. The composites were made using the compo casting process, with carbon fiber particles used to strengthen the ZA-27 alloy. Under unlubricated circumstances, the pin on the disc equipment was subjected to wear testing at varied loads and speeds. With the addition of Carbon Fibre particles, it was discovered that the tribological quality improves. However, based on the results of the other parameters, in order to obtain better performance, the percentage of reinforcing must be tuned depending on the application requirements, and composites may be utilized as structural materials in a number of applications, including bearings and temperature control functions.

Keywords: ZA-27, Carbon Fibre, Reinforcement, Zinc Aluminum, SEM XRD,

1. Introduction

ZA alloys estimated aluminium content is indicated by the designations ZA8, ZA12, and ZA27. These alloys have a good mix of physical, and mechanical features (low melting point, great castability, good strength, machining capabilities, and tribological qualities) and are inexpensive to produce. They are an enticing substitute for aluminum, brass, and bronze when designing buildings and machine components that may be cast. As a result, they are being examined for an increasing number of applications in the industry. These alloys, on the other hand, are only suitable for operating temperatures up to 100°C since their mechanical qualities deteriorate at higher degrees. [1] Being the lightest alloy of ZA27, it has outstanding wear and bearing resistance. It solidifies at a broad range of temperatures and may be processed in the condition of semi-solidity with a non-uniform dendritic microstructure chemical element phase distribution in alloys [2]. Previously, there has been a lot of interest in researching the alloy to see whether it may enhance important qualities like wear and damping while maintaining its mechanical properties. The ZA-27 alloy, in particular, is designated as a high damping material with a strength much greater than standard cast aluminum alloys [3], [4], [13], [14], [5]–[12]. Even though there are several processes for creating composite materials reinforced with particles, stir casting is the most popular method for producing MMCs/MMNCs. The stir casting process has various advantages, including low cost and ease of use. The reinforcement particles can be disseminated in the matrix material using this approach. However, dispersion alone is inadequate in the composite material because nano-sized particles rapidly agglomerate to attain the essential attributes of MMCNs. Zinc-aluminum (ZA) cast alloys are becoming more used in industry in recent years because to their excellent castability, resilience to wear, and mechanical qualities. These alloys have been employed due to their improved wear resistance under higher loads and poor lubrication conditions, bronze and brass are being phased out of the bearing business. These high-aluminum alloys have been shown to be a cost-effective and efficient in terms of energy substitute for a variety of materials [15].

The erosive wear qualities of a material are influenced by a number of factors, considering the angle of particle/fluid collision, the particle/kinetic fluid's energy at impact, the size, shape, amount, and type of particles carried by the fluid, and the eroded material's properties Material features such as microstructure and mechanical properties have been degraded. They have a big impact on a material's erosive wear properties [16]. The impacts of nanoparticle type, number, and structure on the abrasive wear parameters of the MMnCs that were tested were also examined. [17].

2. Taguchi Method

The Taguchi method was created by Dr. Genichi Taguchi. He came up is an approach to develop experiments to investigate how various factors influence the mean and variance of a method evaluation metrics. Taguchi's experimental design involves organizing the parameters impacting the process and levels using orthogonal arrays. The system, parameter, and tolerance design aspects of this procedure are all completed in three steps[18]. System design demonstrates the use of scientific and technical knowledge required for the manufacture of a part. The term "parameter design" refers to the process of identifying the product parameter values and acquire the best levels of process parameters for producing quality features. Tolerance design is used to calculate and assess tolerance for the best combination of parameters recommended by parameter design. The wear properties of a ZA-27 alloy that has been changed is optimized through parameter design in this work.

3. Experimental Details

3.1 Alloy Preparation

The alloy's chemical composition was based on the ZA-27, which had weight percentage as Aluminum – 27%, Copper – 2%, Magnesium – 0.04%, Silicon – 3.5%, Iron-0.007%, Lead- 0.005%, Tin- 0.002%, and balancing Zinc with a 1%. These alloys' main chemical components were weighed and melted in a graphite crucible according specified ratio.

To produce specimens for hardness testing, the stir casting process is employed. The crucible was filled with a determined amount of ZA 27 depending on the furnace's crucible size. It was heated in a crucible at a constant temperature of 600°C before the solid ZA27 was transformed into liquid phase. It was then cooled to 490°C mixing temperature, at which point molten metal stirring was carried out using a stirrer with a speed range of 1 to 500 rpm. 3% of Carbon Fibre particles were weighed based on the weight of molten ZA27, and then injected into a swirling liquid at 200 rpm stirrer speed, progressively increasing to a final concentration of 3%. Similarly, I added 6% and 9% Carbon fibre into the ZA27 alloy.

Figure 1: Laboratory Stirrer for homogeneous mixing of ZA27 with Carbon Fibre

Table 1: ZA27 alloys' chemical composition

Material	Al	Mg	Cu	Zn
Weight %	25.5	0.012	2.0	Remain

Figure 2: ZA27 reinforced with Carbon Fibre

Table 2: Melting Points of constituents of ZA27

Material	Al	Mg	Cu	Zn
Melting Point(°C)	660.3	650	1085	419.5

3.2 Experimental Design

The Taguchi approach was used to create the experimental design, which had two parameters (variables) and four levels. The analysis takes into account process characteristics such as sliding speed and normal pressure. In order to make higher or equal degree of freedom of the orthogonal array to the total number of variables, the orthogonal array was chosen. The results were obtained as the tests were carried out using Taguchi model's run order. The rank is also included in this study which analyses the relative value of the impacts. The L16 orthogonal array was used for this study. The S/N ratio is a response that combines the effects of repetitions and noise levels into a single data point. The experimental data was used to determine signal-to-noise ratios (S/N). The signal-to-noise ratio is the ratio of the signal's mean to the standard deviation of the noise. The S/N ratio describes the degree to which a product or process may be anticipated to function reliably in the face of noise.

4. DENSITY OF PRODUCED PALLET:

Mass per unit volume is called as density of that substance. Density is indicated by the letter ρ.

Mathematically, we can say that density is mass upon volume.

$$\rho = \frac{m}{V}$$

Where ρ is known as density, m is known as mass and V is known as volume. Its unit is g/cm^3.

5. HARDNESS OF THE PRODUCED PALLETS:

Hardness is a measure of how resistant solid matter is to various sorts of irreversible form change when a load is exerted. It may also be characterized as resistance to indentation, scratching, or abrasion on the surface.

Hardness is a material property that cannot be accurately specified in accordance with the basic mass, length, or time units. A stated measuring process yields a hardness property value. Resistance to scratching or cutting has undoubtedly long been used to determine the hardness of materials.

I used Brinell Hardness method to find out the hardness of the pallets.

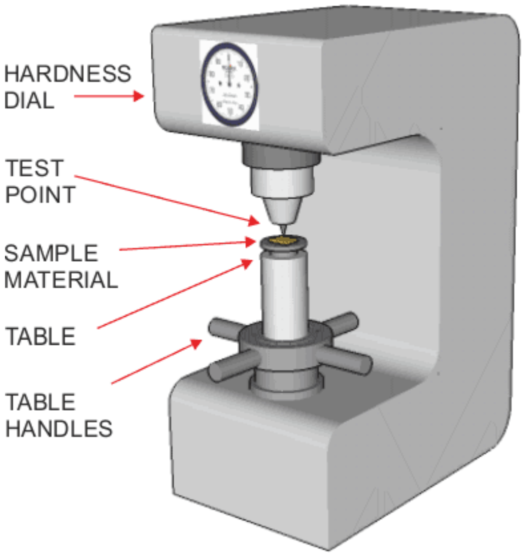

Figure 3: Schematic diagram of Brinell Hardness Testing Machine

5.1 Procedure of Brinell Hardness Testing:

- Position the sample on the anvil such that its floor q is parallel to the path of the applied load.
- Change the position of the anvil using the crank handle until the sample just touches the ball.
- Choose the ball diameter based on the weight and time of usefulness of the weight as specified in the load check table for the object to be inspected.
- Gradually increase the weight and keep it for 15 seconds.
- Sample was removed and remove the weight. The diameter of the indentation left by the ball indenter should be measured.
- Calculate the hardness number after three trials for each sample.

Brinell Hardness number can be calculated by:

$$BHN = \frac{2P}{\pi D(D - \sqrt{D^2 - d^2})}$$

Where BHN = Brinell Hardness Number

P = Pressure in kgf

D = diameter of the ball in mm

d = diameter of the indentation in mm

Table 3: Unreinforced and reinforced ZA27 Brinell hardness results /Carbon Fibre composite

S.No.	Composition	BHN
1	ZA27/CF 0%	115
2	ZA27/CF 3%	116
3	ZA27/CF 6%	117
4	ZA27/CF 9%	118

6. WEAR TEST:

One of the most frequent and straightforward techniques for determining rate of the wear was to employ the usage of a pin-on-disc wear tester. The wear test setup on solid particles employed in this is able to produce repeatable erosive circumstances to evaluate the composite sample's erosion wear resistance. The loss in weight is kept track of so that the erosion rate may be calculated later. The method is continued until the rate of erosion reaches a value of steady state, which is referred to as steady state erosion rate [18].

The corresponding disc was constructed of EN- 32 steel that had been quenched and tempered. All of the as cast samples were specimens fabricated with a diameter of 10.33 cm. The 80mm track diameter allowed for linear sliding rates of 1.0, 1.25, 1.5, and 2.0m/s at rotating speeds of 120, 150, 180, and 210 rpm. The specimen's load was decided as 20N, 40N, 60N, and 80N. In order to obtain efficient contact of the fresh surface with the hardened steel, new specimens were examined to rolling on abrasive paper of 240grit thickness connected to the hardened steel. The force is applied to the samples using a cantilevered arrangement as it slides, and the specimens are brought into close proximity to the spinning disc via an 80mm track radius. To eliminate impurities, before every experiment, the disc was cleaned using chemical solvents.

An electronic microbalance with a 0.01mg precision was used to record the wear losses of sample pins. After cleaning and weighing the wear test specimens, they were weighed again. Using a weight-loss approach, the wear rate was estimated.

Figure 4: Produced pallets for Pin-on-Disc Testing

6.1 SPECIFICATION OF WEAR AND FRICTION TESTER

Model: IWFT-DD
Disk Rotating Range: 120-210 RPM
Maximum Normal Load: 80 N
Size of the Pin: 1cm
Size of the Disk: 80 mm radius × 8 mm thickness
Voltage supply: 230 Volts AC current at 50 HZ

Figure 5: Control Panel of Wear Testing Machine

Figure 6: Rotating Disc

Figure 7: Wear Testing Machine

6.2 The Levels of Process Variables:

Table 4 lists the process conditions and their ranges in the current investigation.

Parameters	L 1	L 2	L 3	L 4
Reinforcement (CF % by weight)	0	3	6	9
Applied Force (Kg)	2	4	6	8
Rolling Distance (Km)	0.5	1	1.5	2
Rolling Speed (m/sec)	1	1.25	1.5	2

6.3 INITIALIZATION OF PIN-ON DISK TESTER:

There are some initializations steps consider before starting the experiment which are given below:

1. After all the connections the friction and wear tester is installed, the instrument can be turned ON.
2. Ensure the rotating disk is not rotating.
3. The following displays are initialized as below:
   a. **Axial load:**
      i. Connect the axial load sensor
      ii. Without any load applied the display should read "00.0"
      iii. If it is not showing the "00.0" value then set the display to read "00.0" using the tare button.
      iv. The display is now ready to measure the axial load.
   b. **Frictional force:**
      i. Connect the frictional force sensor
      ii. Without any load applied and the instrument not running the display should read "00.0"
      iii. If it is not showing the "00.0" value then set the display to read "00.0" using the tare button
      iv. The display is now ready to measure the frictional force.
   c. **Displacement:**
      i. Disconnect the displacement LVDT sensor
      ii. Press tare button if the display is not showing "00.0"
      iii. Connect the LVDT displacement sensor
      iv. Set the mechanical zero of the sensors by moving the shaft of the sensor
      v. Display is now ready to measure the displacement.
   d. **Speed:**
      i. Connect the speed sensor
      ii. The display is ready to display the speed.
   e. **Revolutions:**
      i. Press the reset button to reset the revolution counter to zero
      ii. The display is ready to count revolutions.
4. The speed of the motor should be kept minimum at "F 3.4", this can be done by pressing the down arrow button on the motor controller.
5. If the environmental chamber is used then set the temperature in controller using INC and DEC arrow.
6. If the temperature is below the temperature limit, then the LED will glow and the temperature starts to rise.
7. Once it crosses the temperature limit the LED will be OFF and temperature will keep on reducing after some time till it falls below the temperature limit.
8. The instrument is initialized and ready to operate now.
9. Do not connect the coolant while using the environmental chamber.

6.4 PIN ON DISC TESTING PROCEDURE:

- To check the material's wear properties using a Pin of samples sliding on a disc rotating on a predefined set of RPM of the disc and different forces exerted in the pin using different weights.
- Test is performed at Tribology Lab of MJP Rohilkhand University, Bareilly, Uttar Pradesh.
- Sample size of the pin is 1 cm in diameter and 1 inch in length and this pin is cut from the samples using a Lathe machine in a shop in Bareilly, Uttar Pradesh.
- Taguchi method is used in this process and L16 orthogonal arrays are used to find out 16 different experiments which are performed to find out the wear properties of different samples.

- Weighing machine which can measure in milligrams is used in weighting the weight of samples before and after the test.
-

6.5 FORMULAS FOR CALCULATING WEAR:

Variations in rolling speeds, rolling lengths, and resultant force are used to conduct wear experiments on the specimens. The effects of these parameters have been studied and calculated by given relations.

$$\text{sliding speed } \left({}^{m}/_{s}\right) = \pi DN/60$$

$$\text{sliding distance (m)} = \pi D \times \text{number of rotations}$$

Where D = wear diameter of the route in m, N = rpm (revolutions per minute) of the disc

$$\text{volumetric loss in wear (mm3)} = \frac{\text{wear weight loss}}{\text{density of specimen material}}$$

$$\text{wear height loss } (\mu m) = \frac{\text{Volumetric wear loss}}{\text{cross sectional area of specimen}}$$

$$\text{time (s)} = \frac{\text{sliding distance}}{\text{sliding speed}}$$

Wear Weight Loss (gram) = initial Weight – Final Weight

7. DENSITY OF THE SAMPLES:

Table 6 in this study shows the measured vacuum densities of all Carbon Fiber/ZA-27 metallic materials.

Sample	Composition	Density (gm/cc)
1	ZA27/CF 0%	3.8063
2	ZA27/CF 3%	3.9538
3	ZA27/CF 6%	4.0497
4	ZA27/CF 9%	4.0934

8. XRD TESTING:

Data from XRD is quantified and graphed. Petrology, metallurgy, and engineering all use it.

The analysis requires an X-ray diffractometer, which is a specialized piece of equipment. However, there are other alternatives to the XRD test that might produce identical findings. A diffraction pattern, for example, can be captured by photographing the sample from various angles using a camera or by using an electron microscope.

XRD is a type of microscopy that compares the wavelengths of X-ray beams with the known frequencies and wavelengths released when they interact with, or pass through, mineral crystals to discover crystal structures in an item. This is the most typical sort of examination for jewelry and gemstones.

Mining, metallurgy, and metrology all employ X-Ray Diffraction technologies. XRD is frequently used in conjunction.

This test gives you instant feedback on the quality of your design.

I have performed the XRD test on my specimen and reinforced ZA27 alloys. The test results are shown in the figures below:

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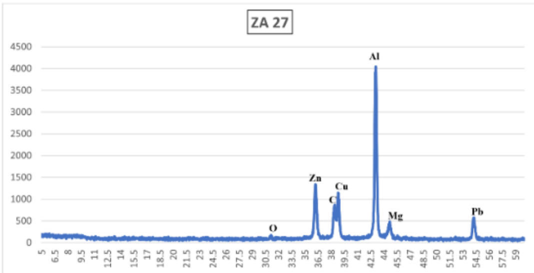
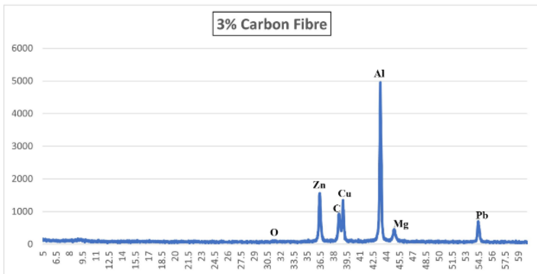


(a)



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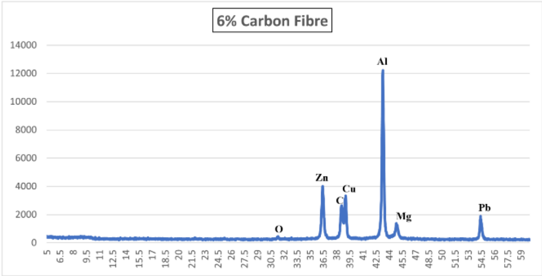
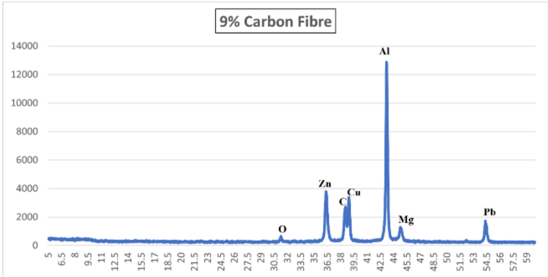


(c)



(d)

Figure 8: Carbon Fiber reinforced ZA-27 X-ray diffractogram

9. Conclusions:

The following precise results have been reached as a result of this numerical and simulation examination on particulate-filled ZA-27:

1. The stir casting process may be used to successfully fabricate particle-reinforced blends ZA-27 with typical ceramic infill addition such as carbon fibre.
2. These composites have a reduced porosity content, as well as increased micro-hardness and impact strength. They do; however, compressive and impact characteristics are somewhat lower than the native ZA-27 material.
3. The Taguchi experimental design approach may also be used to investigate the properties of erode of these components. For the optimization of control parameters, the Taguchi approach provides a straightforward approach that is both methodical and effective. The successful deployment of a signal-to-noise response technique identifies significant elements impacting the degradation rate of composites. Influence velocity and filler content were discovered to have the greatest impact.
4. In this study, a machine learning model-based prediction model was utilized to successfully anticipate and recreate the wearing behaviour of materials in a wide range of experimental situations within and without the research station.

Author Contributions: For this research, Himanshu Singh is the main author. Himanshu Singh is the final year student of BTech + MTech Integrated course of Mechanical Engineering Department of Invertis University, Bareilly, Uttar Pradesh. The other author is Mr. Anuj Kumar, Asst. Prof. of Mechanical Engineering Department of Invertis University Bareilly, Uttar Pradesh who helped in Brinell's Hardness Test and its Density calculation through Archimedes' Principle. The third and last author is Arsum Javaid, who is also a student of BTech + MTech Integrated course of Mechanical Engineering Department of Invertis University, Bareilly, Uttar Pradesh, helped in finding the materials and helps in finding the foundry shop where I can melt and mix the components of ZA27. Also, he helped me in several ways like finding of stirrer machine which I used for homogeneous mixture of ZA27 material.

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Data Availability Statement: I have read and gone through various articles available on the internet and I have added many of them as reference to this paper which I used.

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Conflicts of Interest: I, Himanshu Singh, as a main author of this paper declares no conflict of interest.

S. No.	Reinforcement (C.F.)	Load (N)	Distance (m)	Speed (m/s)	Speed (rpm)	Time (s)	Weight$_1$ (in Gram)	Weight$_2$ (in Gram)	Weight$_1$ – Weight$_2$ (in Gram)
1	0	20	500	1	120	500	10.54	10.38	0.16
2	0	40	1000	1.25	150	800	10.38	10.02	0.36
3	0	60	1500	1.5	180	1000	10.02	9.74	0.28
4	0	80	2000	1.75	210	1140	9.74	9.48	0.26
5	3	20	1000	1.5	180	670	9.57	9.13	0.44
6	3	40	500	1.75	210	285	9.13	8.88	0.25
7	3	60	2000	1	120	2000	8.88	8.69	0.19
8	3	80	1500	1.25	150	1200	8.69	8.36	0.33
9	6	20	1500	1.75	210	860	9.06	8.76	0.3
10	6	40	2000	1.5	180	1330	8.76	8.47	0.29
11	6	60	500	1.25	150	400	8.47	8.21	0.26
12	6	80	1000	1	120	1000	8.21	8.04	0.17
13	9	20	2000	1.25	150	1600	9.08	8.89	0.19
14	9	40	1500	1	120	1500	8.89	8.63	0.26
15	9	60	1000	1.75	210	570	8.63	8.37	0.26
16	9	80	500	1.5	180	330	8.37	8.03	0.34

Table 5: Variable pairing in a (L16) Orthogonal Array

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