Comparative Study on the High-Stress Abrasive Wear Behaviour of Zinc and Copper Base Alloy

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Abstract - *In this study, an attempt has been made to examine the wear response of Zn-based alloys and a conventional Gunmetal at the sliding speeds of 3 m/s under the applied load range of 5-20 N in the step of 5 N. The test materials alloys have been subjected to a pin-on-disc wear test under the abrasive grit platform of 320μm. The results have shown that the zinc-based alloy revealed higher wear rate when compared with gunmetal. In addition, wear resistance of both the test materials increased with increasing applied load. But it decreased with increasing sliding distance. On the other hand, the frictional heating and friction coefficients of the zinc-based alloy are higher than that of the gunmetal. Microstructural studies showed that the zinc-based alloy exhibits dendritic structure comprising of* α *dendrites surrounded by* $\alpha + \eta$ *eutectoid and metastable* ε *phase in interdendritic regions. The* $\alpha+\eta$ *is a solid solution of zinc and aluminum in aluminum and zinc respectively are soft and ductile while* ε *phase is quite harder and transmits wear resistance to a slight range while gunmetal comprises of primary* α *dendrites, Cu-Al intermetallic compound along with fine particles of iron.*

Key Words: *Abrasive Wear, Gunmetal, Lıquid Metallurgy, Zinc based Alloy*

1. INTRODUCTION

Zinc-based alloys comprising 8–40% aluminum with or without alloying elements have been observed to be cost and energy effective substitute for a number of ferrous and non-ferrous alloys [1–9]. These alloys are gaining wide commercial importance as journal bearing material for high load and low speed applications and found to be an efficient substitute for bronze in bush and bearing applications [1–5,9–11] because of lower coefficient of friction and higher wear resistant, which is attributed to the presence of zinc-rich _ and _ phases, of HCP structures having very high c/a ratio, around the dendrites and/or interdendritic regions in significant amount in the microstructure of these alloys. Abundant availability, good bearing and mechanical properties such as wear resistance, anti-seizure properties, yield and tensile strengths scored in favour of the extensive use of these alloys for bearing applications [12, 13]. Recently, the ZA-27 alloy has been substituted for conventional journal bearing materials in a wide range of industrial applications [14]. The journal bearings produced from these alloys have been used in earthmoving equipment, mining and milling machines, cable winches and compressors [15, 16]. The ZA-27 alloys and the bearings were also used in heavy and dusty environments such as underground machines, mining equipment, ore crushers and rock drills. The hard particles and oxides from these environments such as silicon dioxide, aluminum oxide, and silicon carbide could move into the working surfaces of the bearings and they could lead to abrasive wear on these surfaces. It was also observed that strength, hardness and wear resistance increase with an increase in Al content [6, 8, 11, 17]. It is also expected that the addition of aluminum will lead to improving high-temperature strength as aluminum has a higher melting point than the Zn and favours the formation of intermetallic phases, which are more stable at elevated temperature. In addition, aluminum is lighter than zinc and its cost is comparable to zinc also. But attempts to examine the wear behaviour of Al–Zn alloys containing 30.0–40.0 wt% Zn as compared to conventional Zn–Al alloys are lacking. Furthermore, most of the earlier studies are related to sliding wear behaviour on Zn–Al alloys [1–11, 17] and only a few researchers have attempted to utilize zinc-based alloy for abrasive wear application [12, 18-27]. In the literature, there is not enough information and limited study about abrasive type wear of ZA-37 alloy especially comparative with the copper alloys. The aim of this investigation was to study the fundamental mechanism involved in the high-stress abrasive wear under the effect of various input parameters. Moreover, conventional gunmetal has also been subjected to identical tests to undertake a comparative study. The alloys have been examined at varying applied load and sliding distance.

2. EXPERIMENTAL DETAILS

2.1 Material Preparation

The alloys were prepared by liquid metallurgy route in a permanent cast iron mould in the form of cylindrical castings (size: 16 mm in diameter, 150 mm long). An electrical furnace was used for melting the Al in a graphite crucible under nitrogen protective atmosphere. After melting Al, the melt temperature was increased to 750 °C and then Al–Cu alloy was introduced to the melt. Subsequently, Zn was added and the melt temperature was decreased to 650 °C. Finally, pure magnesium (99.99 wt.%) was added to the melt at about 620 °C with vigorous stirring under protective gas and melts were then poured into permanent cast iron mould pre-heated to about 200 °C. The raw materials were commercially pure Al (99.8 wt.%), Zn (99.95 wt.%) and Al–Cu master alloy (50 wt.% Cu). The chemical compositions of the alloys were determined by atomic absorption spectroscopy and are presented in Table 1. The chemical composition of the conventional gunmetal, which was procured from the Relume Engineering, Gujarat, India provided in the shape of 20 mm bar, is also shown in Table 1.

Table -1: Chemical composition of the test materials

Element	Wt. %						
	Zn	Al	Cu	Mg	Pb	Sn	Ni
Zinc based alloy	*	37.5	2.5	0.02	-	-	-
Copper based alloy	4	-	*	-	4	5	2

* Remainder

2.2 Metallography

Microstructural examination of the test materials was carried out using a Jeol make, model JSM-6010LA scanning electron microscopy (SEM) on 10 mm diameter and 10 mm thick samples. The samples were polished metallographically as per standard metallographic techniques and etched with a suitable agent to reveal the grain boundaries. Diluted aqua regia was used for etching the samples of the zinc-based alloy while for copper alloy (10 gm $FeCl_3$ + 50 ml HCl + 200 ml distilled water) is used. The presence of phases in microstructure was also confirmed by means of X-ray diffraction (XRD) using a Cu Ka radiation.

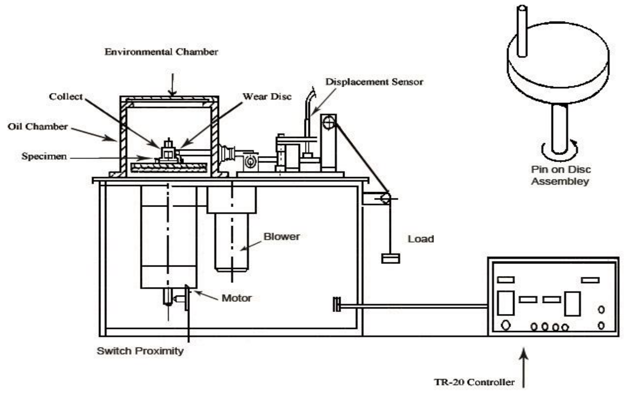

Fig -1: Schematic representations of the test configuration

2.3 Hardness and Density Measurement

The hardness measurements of the test materials were carried out on metallographically polished samples by utilizing a Vickers hardness tester. The measurements were done at an indentation load of 30 kg. The density measurement of the materials was done by using the Archimedean principle at room temperature. Each test was repeated three times, and the average values were accepted as an experimental result.

2.4 Wear Testing

High-stress abrasive wear tests were performed using a pin-on-disc machine. The test materials in the form of pins of 8 mm diameter and 30 mm length were made to slide against a rotating steel disc on which SiC polishing/emery paper (having an average particle size of 29µm) is pasted. Schematic representations of the test configuration are shown in Fig. 1. The sample was held against the rotating abrasive medium with the help of a specimen holder. Load on the sample was applied through a cantilever mechanism with the help of dead weights. The traversal distance was varied over the range of 125-500m in the steps of 125m. The track radius of 50 mm is adopted in this study while sliding speed is fixed as 3m/s. The frictional force was determined using a load cell and the coefficient of friction was calculated by dividing the frictional force by the normal load. The specific wear rate of the pins is defined as the weight loss per unit sliding distance. An electronic balance having an accuracy level of 0.001 mg was used to measure the weight loss. The pins were ultrasonically cleaned and dried prior to each weight measurement. The temperature at a distance of 1.5mm from the contacting surface of the specimen was also monitored during the tests by inserting a chromel–alumel thermocouple in a 1.5mm diameter hole made therein. An average of three observations has been considered in this study.

Table -1: Various Properties of the Test Materials

Sample	Vickers Hardness (HV)	Density (g/cm^3)
Zinc based alloy	140	4.43
Copper based alloy	96	9.02

3. RESULTS & DISCUSSIONS

3.1 Microstructure & Phase Analysis

The microstructure of zinc-based alloy and copper alloy are depicted in Fig. 2 & Fig. 3 respectively. The zinc base alloy exhibiting dendrite structure comprising of α-dendrites surrounded by α+ η eutectoid and metastable ε phase in interdendritic regions while microstructure of gunmetal comprises of primary α dendrites, Cu-Al intermetallic compound along with fine particles of iron. The microstructure of zinc aluminum alloys consists of a mixture of α-Al (Al-rich solid solution) and η (zinc-rich solid solution) phases at room temperature distributed in a specific manner depending on the concentration of Al present therein [28]. The ε ($CuZn_4$ intermetallic phase) has been reported to participate out in the interdendritic channels of Zn-Al alloys containing copper beyond 1% [29]. Magnesium (0.01-0.05%) present in the Zn-Al alloys remains dissolved in the solid solution of the alloy [28, 30]. Based on the binary Zn-Al equilibrium diagram [28, 30], ZA37 alloys comprising 37.5% aluminum fall in the hypereutectoid range. Therefore, the microstructure of both the alloys revealed primary α-dendrites surrounded by α + η eutectoid as well as metastable ε-phase. The XRD pattern of the test materials is shown in Fig.4 & Fig.5 respectively. It was observed that there were four phases β, η, α and ε present in the zinc based matrix alloys whereas gunmetal comprises primarily of copper peaks.

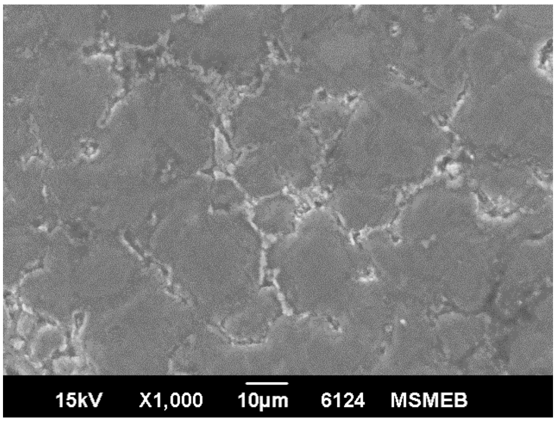

Fig -2: Microstructure of zinc-based alloy

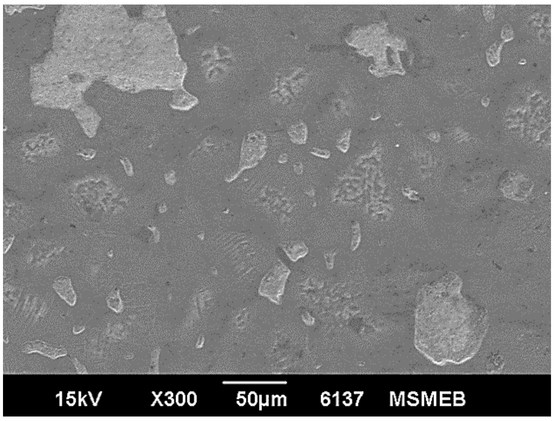

Fig -3: Microstructure of copper-based alloy

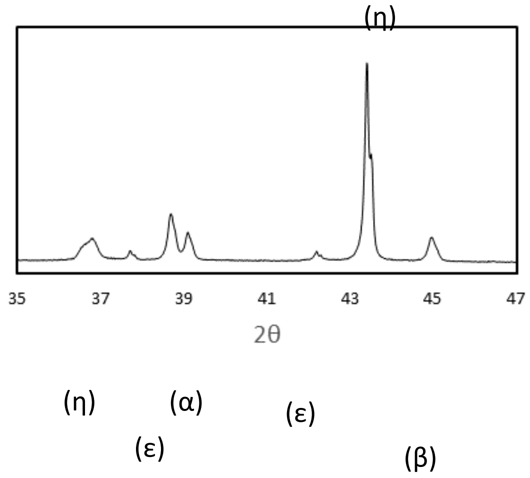

Fig -4: XRD pattern for the zinc-based alloy

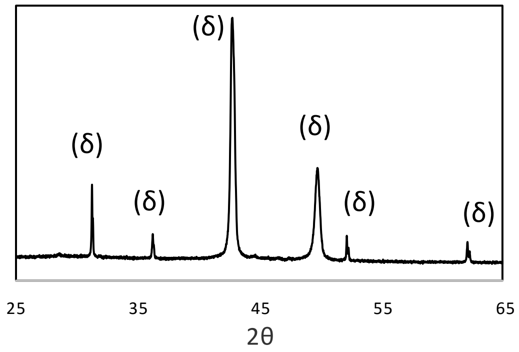

Fig -5: XRD pattern for the copper-based alloy

3.2 Density & Hardness

Table 2 represents various properties of the specimens. The zinc-based alloy attained somewhat higher hardness than the copper based alloy. So far as the density is concerned, it was highest for the copper based alloy.

3.2 Wear Behaviour

Wear rate of the samples has been plotted as a function of abrading distance at an applied load of 5N and 20N are shown in Fig.7 & Fig.8 respectively while Fig.9 depicted the effect of applied load at the sliding distance of 5oo meters. The wear rate decreases with the increase in abrading distance for both the test materials and at all the loading conditions. It was also observed that the wear rate is more in the case of the zinc-based alloy at lower applied load while at higher load copper based alloy delineates more rate of wear. Moreover, it may also be noted that at higher load (20N) and at a larger sliding distance (375 & 500 meters), wear rate was not obtained due to the excessive wear loss and abrading of the pin samples up to the hole made for the insertion of the thermocouple.

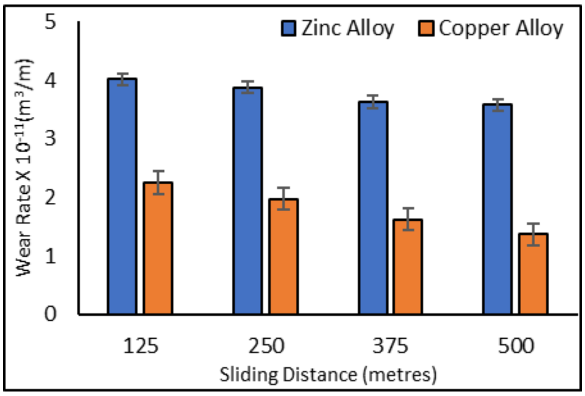

Fig -6: Wear rate versus sliding distance at 5N load

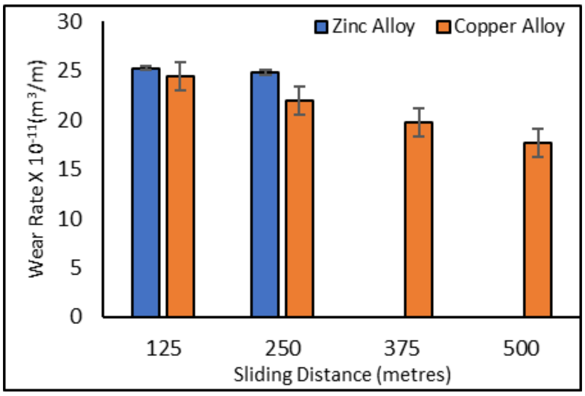

Fig -7: Wear rate versus sliding distance at 20N load

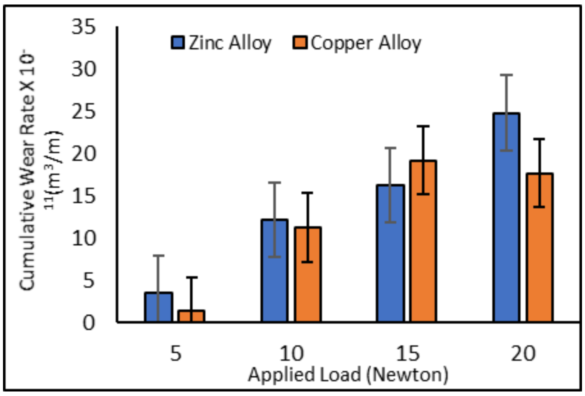

Fig -8: Wear rate versus applied load for 500m

Temperature near the contact surface of the test materials at an applied load of 5N and 20N plotted as a function of abrading distance are shown in Fig.9 & Fig.10 respectively. The temperature rises linearly with the test duration and the maximum frictional heating is attained by zinc-based alloy. As far as the effect of load on the frictional heating is concerned, the temperature increases with the increase in applied load irrespective of the test material, however, the severity of increase is the maximum for zinc-based alloy at lower load while at higher load opposite trend of variation was obtained (Fig.11).

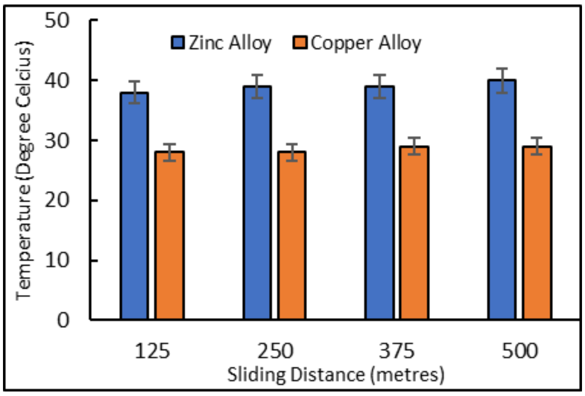

Fig -9: Temp. rise versus sliding distance at 5N load

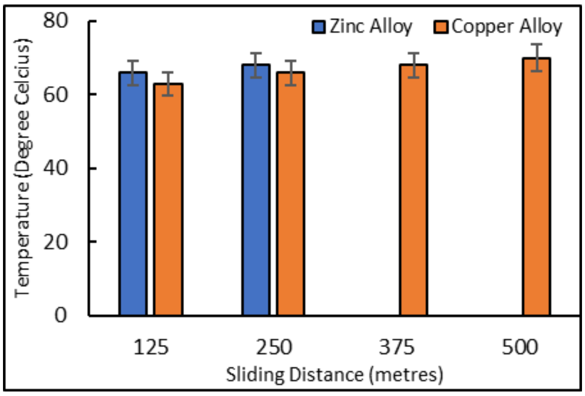

Fig -10: Temp. rise versus sliding distance at 20N load

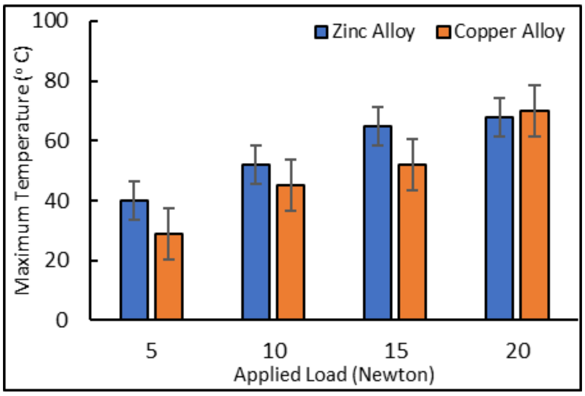

Fig -11: Maximum temperature versus applied load

Fig.12 & Fig.13 represents the friction coefficient of the test materials as a function of abrading distance at an applied load of 5N and 20N respectively. The friction coefficient decreases with the increase in test duration for both the test material and it is observed that the friction coefficient is more in the case of the zinc-based alloy. Moreover, an increase in load increases the friction coefficient of the test materials in a linear manner (Fig.14). It is also worth noting that in the case of 20N load no friction coefficient was obtained at 375 & 500 m sliding distance due to termination of experiments because of the abrading of the pin samples up to the hole made for thermocouple insertion.

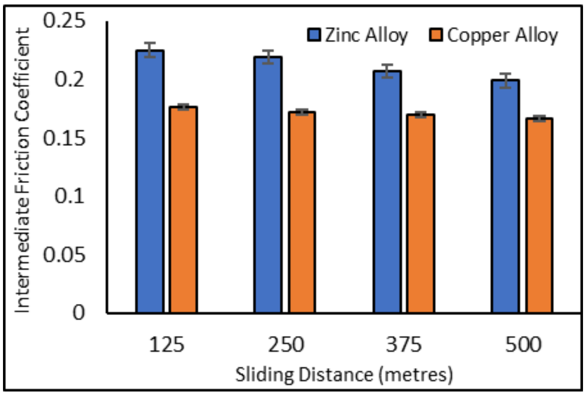

Fig -12: Friction coeff. versus sliding distance at 5N load

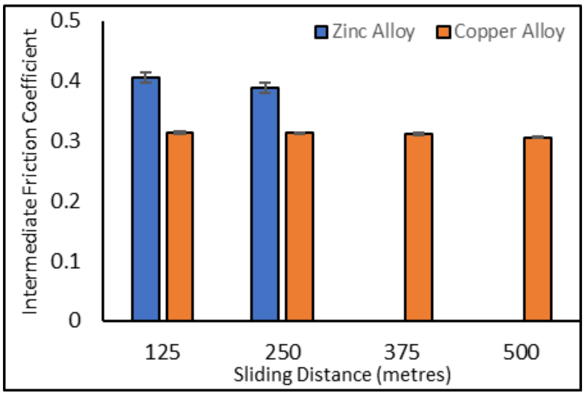

Fig -13: Friction coeff. versus sliding distance at 20N load

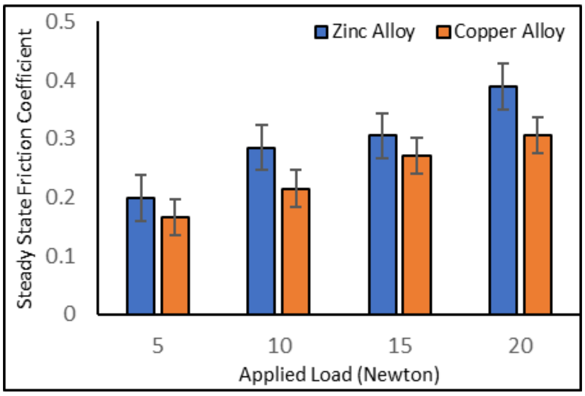

Fig -14: Steady State Friction coeff. versus applied load

4. CONCLUSIONS

Based on the observations made in this study, it may be concluded that the zinc base alloy exhibiting dendrite structure comprising of α- dendrites surrounded by α+ η eutectoid and metastable ε phase in interdendritic regions while microstructure of gunmetal comprises of primary α dendrites, Cu-Al intermetallic compound along with fine particles of iron. The copper based alloy exhibited maximum density while hardness was maximum for the zinc-based alloy. Wear Rate increased with load but decreases with sliding distance. The copper alloy delineates lower wear rate than the zinc-based alloy. Frictional heating increased with load and test duration while friction coefficient increased with load but decreases with test duration. Moreover, zinc-based alloy attains higher frictional heating and friction coefficients than the gunmetal.

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