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Investigation on Wear Characters of Zn-Al Heat Treated Cast Alloy

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Abstract: An attempt is made to find the frictional and wear behavior of Zn-base composite. The heat treated ZA-27 alloys containing 27% Al, about 3% of Copper and about 0.03% Magnesium and as-cast samples were tested using pin-on-disc machine, using the combinations of three different loads and four different linear sliding speeds. The worn surfaces of the specimens were examined by Scanning Electron Microscope (SEM) to determine the wear behavior. It is observed that the reduction in the hardness and tensile strength with increased in the elongation is resulted in specimens by heat-treatment. The tribological behavior of heat treated alloy samples were improved over the as-cast ones, under all the combinations of sliding speeds and loads. The hardness, tensile strength and percentage elongation of the samples increases with addition of copper content and decreases wear rate in the alloy.

Keywords: Heat treatment, Microstructure, Dry sliding, Copper, Hardness, Zinc.

1. INTRODUCTION

Zinc based alloys were used instead of bronze during World War II as journal bearing materials to compensate for copper deficiency in Germany. Zinc based alloys are used due to high strength, high hardness and good friction properties in several engineering applications. Tribological properties of Al and Cu alloys are better than those of pure Zn and Zn–Al alloys. Tribological and mechanical properties of Zn–Al alloys can be improved by heat treatment and by Mn, Si, and Cu addition. These alloys are especially used in automotive and machine element applications as journal bearing materials [1].

Hence in the present study, ZA-alloys as per the ASTM specifications have been used as a base matrix material. Magnesium is added primarily to minimize susceptibility to intergranular corrosion caused by the presence of impurities, which is about 0.015-0.02 % Mg [4]. Copper, like magnesium, minimizes the undesirable effects of impurities which increases the hardness and strength of castings. Range of copper for ZA alloys is 0.5 to 2.5 %. Nickel, chromium, silicon, and manganese are not harmful in amounts up to the solubility limit of 0.02 % Ni, 0.02 % Cr, 0.035 % Si and 0.5 % Mn [5].

2. EXPERIMENTAL PROCEDURE

2.1 Tested materials: For the tests there were prepared four types of Zn-Al (ZA/0, ZA/1, ZA/2 and ZA/3) alloys, cast in ingot mold. ZA/0, ZA/1, ZA/2 and ZA/3 alloys are in accordance with ASTM standards. The chemical compositions of these materials are given in table 2.1.

TABLE 2.1: CHEMICAL COMPOSITION OF ZA-ALLOYS IN WEIGHT PERCENT

Component	Aluminium	Magnesium	Copper	Zinc
ZA/0	27	0.03	0	Balance
ZA/1	27	0.03	1	Balance
ZA/2	27	0.03	2	Balance
ZA/3	27	0.03	3	Balance

In the present investigation the specimens were subjected to T4 (Solution heat treated and naturally aged) heat treatment in electrical muffle furnace , comprising solutionizing at 370°C for three hours, quenching in water and natural ageing at room temperature during more than 30 days for further prediction of hardness microstructural studies and wear behaviors. Tensile tests are simple, relatively inexpensive and fully standardized. Hardness test is a test, which is used to determine resistance to indentation or displacement of metals by pressure, or by resistance to abrasion. The hardness number is determined by the load over the area of the indentation using the digital micro hardness tester.

For metallographic examination, specimens of size 10x10x15 mm are cut from the castings, polished according to standard metallographic procedures and etched suitably. Micro structural examination is conventionally carried out on ground and polished samples of processed alloys using optical microscope. An optical microscope with Clemex Image Analyzer is used for detailed micro structural studies.

Experiments have been conducted in the Pin-on-disc type Friction and Wear monitor (DUCOM; TR-20) with data acquisition system, which was used to evaluate the wear behavior of the composite, against hardened ground steel disc (En-32) having hardness 65 HRC and surface roughness (Ra) 0.5 μm.

3. RESULTS AND DISCUSSIONS

3.1 Tensile test: The tensile strength of alloy ZA-27/3 is found to have maximum with maximum percent elongation. The tensile strength increases with increase in copper content. But strength is reduced by heat treating the ZA-27 alloy. And the heat-treated samples attained increased elongation as compared to that of the as-cast specimens. It is clear that there is an increment in the strength and percent elongation of alloy ZA-27/3. A decrease in strength and increase in elongation of the heat treated elements as compare to as-cast specimens. Similarly the strength of the alloy ZA-27/0 and ZA-27/1 are poor compared to alloy ZA-27/3 as shown in table 3.1(a) and (b).

Table 1(a): Tension test chart for various composition of copper in ZA-27 alloy for as-cast specimens

Composition	Sample Number	UTS(N/mm^2)	Avg. UTS (N/mm^2)	Percent Elongation	Avg. Percent Elongation
ZA-27/0	1	264.17	263.38	0.90	1.01
	2	262.48		1.05	
	3	263.50		1.08	
ZA-27/1	1	318.00	318.60	3.62	3.01
	2	320.56		2.82	
	3	317.26		2.59	
ZA-27/2	1	340.60	346.55	3.26	3.06
	2	350.68		3.51	
	3	348.39		2.41	
ZA-27/3	1	418.72	419.15	3.38	3.18
	2	421.66		3.42	
	3	417.09		2.74	

Table 1(b): Tension test chart for various composition of copper in ZA-27 alloy for heat treated as-cast specimens

Composition	Sample Number	UTS (N/mm^2)	Avg. UTS (N/mm^2)	Percent Elongation	Avg. Percent Elongation
ZA-27/0	1	214.17	212.22	1.90	1.90
	2	222.48		1.78	
	3	199.35		2.04	
ZA-27/1	1	260.00	265.65	2.95	3.34
	2	267.56		3.28	
	3	269.39		3.12	
ZA-27/2	1	301.60	301.26	3.87	3.85
	2	310.68		3.78	
	3	291.50		2.98	
ZA-27/3	1	360.72	363.08	4.03	4.02
	2	365.66		3.89	
	3	362.86		4.09	

3.2 Hardness test : As it is known that hardness of the material plays a vital role during material selection, Hence ZA-27/0, ZA-27/1, ZA-27/2 and ZA-27/3 alloy materials are subjected to digital micro hardness tester and found that hardness of the alloys nearly linearly increases with copper. The hardness of the alloy with 3 wt. % of copper has a maximum hardness and also hardness is decreased after heat treatment as shown in table 3.2(a) and (b). Heat treatment of the alloy caused a moderate reduction in the hardness. Moreover, the heat-treated samples attained increased elongation as compared to that of the as-cast alloy.

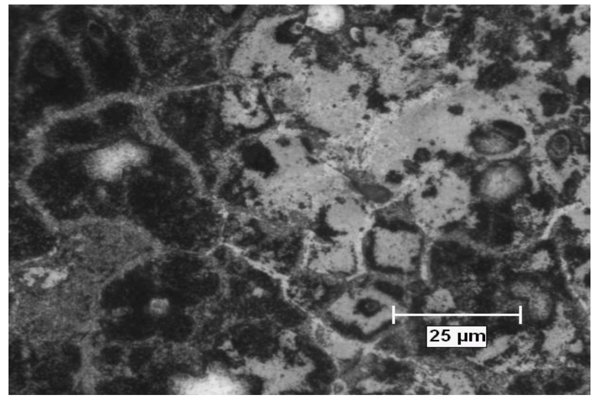
Table 3.2(a): Hardness test chart for various composition of Copper in ZA-27 alloy (as-cast)

Composition	Sample Number	Vickers Hardness	Avg. Hardness value
ZA-27/0	1	123	120
	2	120	
	3	117	
ZA-27/1	1	135	132
	2	130	
	3	131	
ZA-27/2	1	147	140
	2	142	
	3	131	
ZA-27/3	1	157	158
	2	155	
	3	162	

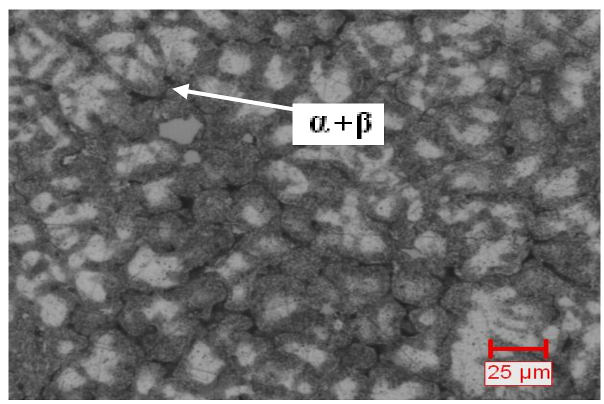
Table 3.2(b): Hardness test chart for various composition of Copper in ZA-27 alloy (heat treated)

Composition	Sample Number	Vickers Hardness	Avg. Hardness value
ZA-27/0	1	104	102
	2	97	
	3	105	
ZA-27/1	1	109	110
	2	113	
	3	108	
ZA-27/2	1	125	121
	2	122	
	3	116	
ZA-27/3	1	133	135
	2	134	
	3	138	

3.3 Microstructure studies: A study of the Zn–Al phase diagram shows that, as the ZA-27 zinc alloy is cooled from the melt to room temperature, it goes through several phases, namely (L+ α), β, (α+β), and finally (α+η). The introduction of low copper content in the ZA-27 will lead to formation of an inter-metallic compound $CuZn_4$ (ε) at 377 ^{0}C through a ternary eutectic reaction given by L = □α+β+ε . At a lower temperature of 268 ^{0}C a ternary phase known as Al_4Cu_3Zn (T') will result from the reaction ε+α = □ T'+η.



(a)



(b)

Figure 3.1: Micro Structural Features Of Zinc-Aluminum Alloy Without Copper A) Heat Treated B) As-Cast

The microstructure of the ZA-27 as-cast alloy consisted of a cored aluminum-rich matrix (α, Face Centered Cube) and an inter-dendritic zinc-rich phase (η, HCP), $CuZn_4$ (ε) and an Al_4Cu_3Zn (T'). With heat treatment, the micro-composition of ZA-27 alloy became more homogeneous and the microstructure was refined. In the microstructure of ZA-27 alloy, which was solutionized for 3 hours at 370ºC and then quenched, one can distinct the residual dendrite cores and very fine α+η mixture, which occupies the largest portion of the structure. However, by the increase of copper content by 2 % approximately, zinc and copper-rich phases are formed in the interdendritic regions of the Zn–Al–Cu alloys. The intermetallic phases rich in copper formed results in reduction of the copper content of the matrix (aluminum-rich) of the alloys, and hence reduces the strengthening effect of solid solution as shown in figure 3.1. In addition, cracking tendency of the alloys increases by the copper-rich particles because the particles are more brittle and harder than the matrix.

3.4 Wear test: Every material which has to be used as a bearing material should have excellent tribological characteristics such as wear with respect to time and load. In our study dry sliding wear test has been carried out by pin on disc machine to characterize zinc based aluminum alloy having copper and magnesium. The wear loss plotted is a function of copper content for various velocities by an average of three different values .Wear rate before heat treatment decreases with the increase in the copper content and the wear loss is almost constant for 3 wt%. Copper content at different speed.

The results reveal that better wear resistance is observed for alloy with 3 % of Copper. Moreover maximum wear rate is observed for alloy with zero copper even the sliding velocity is minimum. And also with increase in the copper content after heat treatment the wear rate is decreases. The decreased wear rate for the heat treated specimens compare to as-cast specimens as shown in figure 3.2.

Figure 3.2: Variation of wear rate with copper addition

CONCLUSIONS: In the present investigation, development and characterization of Zn based aluminum alloys with the addition in Copper and Magnesium is studied in detail. The results are drawn after carefully studying of the different properties of the developed alloy. The tribological behavior of heat-treated specimens over as-cast ones are improved (wear rate and coefficient of friction are reduced), for all applied loads in dry sliding conditions. The worn surfaces of heat-treated specimens are more in ductile mode of fracture than the as-cast alloy. The copper content influenced significant tribological improvement of ZA-27 matrix material. As the copper percentage increases wear rate decreases. The mechanical properties are affected by the structural changes i.e. in the heat treated specimens large increase in elongation in combination with high strength was achieved compare to as-cast specimens. The wear rate increases with applied load and wear rate of the as-cast specimens is more than heat treated specimens under dry sliding conditions. The wear resistance is displayed as the heat treated specimen was attributed to breaking of dendrite structure, decreasing fraction of interdendrite regions and formation of very fine mixture of phases. The tensile strength, hardness and percentage elongation increases as the copper content increases. The increase in copper content results the decrease in wear rate.

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