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Short communication

Wear resistance of dilute Zn–Al alloys

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ABSTRACT

The wear resistance of Zn–Al alloys is determined in pin-on-ring wear tests, as a function of type of structure of the as-cast alloys. Three regions were observed; columnar, equiaxed and columnar-to-equiaxed grain transition. The results show that the equiaxed structure is the most resistant. In addition, the relation between wear rate and grain size depends on type of structure and it is more pronounced for the equiaxed structure. The effect is almost negligible for the columnar grain structure.

1. Introduction

During the last three decades, zinc–aluminum alloys (ZA) have gained considerable interest among metallurgists and material scientists in the development of high strength light alloys [1,2].

Zinc cast alloys can be used for general industrial applications where strength, hardness, wear resistance or good pressure tightness is required. Zinc alloys often are employed to replace iron cast because of their similar properties and higher machinability ratings [3]. The good bearing and wear characteristics of zinc alloys permit their use for bearing bushings and flanges. Other applications in which zinc alloys have successfully substituted cast iron or copper alloys include fuel-handling components, pulleys, electrical fittings and hardware components [1–3].

Aluminum imparts fluidity to the alloys. Good engineering properties can be achieved with a wide range of Al concentrations. In addition, small amounts of copper and magnesium are added to achieve the best combination of mechanical properties and castability [4].

The effect of different Al contents on the mechanical and wear properties of Zn-based alloy containing 2.5% Cu and 0.03% Mg has been studied by Prasad et al. [4]. In their experiments, higher strength and elongation properties were obtained with the alloy having 27.5 wt.% Al. Also, as the quantity of Al increased up to 47.5 wt.%, the strength and elongation decreased. Higher strength at elevated temperatures was exhibited as the Al content increased. Wear test results showed that at a speed of 0.42 m s^{-1}, the alloy having 27.5 wt.% Al performed best.

Abou El-Khair et al. [5] have studied the effect of different Al contents on the microstructure, hardness, tensile properties and wear behavior of Zn-based alloys. The tensile tests were carried out at room and elevated temperatures (40, 60 and 100 °C). The wear tests were carried out on pin-on-ring machine at a linear speed of 0.65 m s^{-1} over a load range of 10–100 N. Zn–Al alloys showed a reduction in strength and increase in ductility with increasing temperature. In addition, the wear resistance increased with the increase of Al content and weight loss increased with increasing loads.

In the present work the directional solidification behavior of Zn and Zn–Al alloys (Zn–1 wt.% Al and Zn–2 wt.% Al) and resulting macrostructural features are studied, that is, columnar, equiaxed or columnar-to-equiaxed grain transition (CET). In addition, the mechanical properties of Zn and Zn-based alloys containing different quantities of Al have been determined. The pin-on-ring wear test performed at different loads is used to study the wear rate as a function of type of grain structure (columnar, equiaxial or CET) and aluminum concentration.

2. Materials and methods

2.1. Sample preparations

The zinc–aluminum (ZA) alloys of different compositions were prepared from zinc (99.996 wt.%) and aluminum (99.990 wt.%) directly inside the mold. The molds were made from 23 mm i.d.

Abbreviation: CET, columnar-to-equiaxed grain transition.

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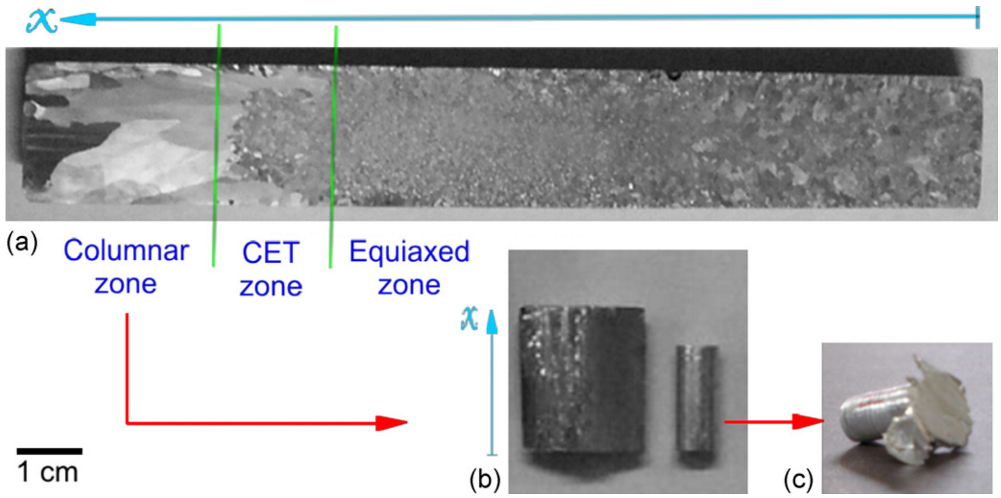

Fig. 1. (a) Directional solidified sample of Zn–1 wt.% Al alloy showing the CET. (b) Pin preparation from columnar zone for wear test. (c) Aspect of the pin after the wear test.

and 25 mm e.d. PYREX tube with a flat bottom and a cylindrical uniform section of 200 mm high.

The alloy samples were melted and solidified directionally upwards in an experimental setup consisting of a heat unit, a temperature control system, a temperature data acquisition system, a sample moving system and a heat extraction system [6,7]. The experimental procedure was as follows: first, the liquid metal into the mould in the furnace was allowed to reach the selected temperature above the melting point of the alloy. Then, the furnace power was turned off and the melt was allowed to solidify from the bottom.

Heat was extracted through a cooling system, which consisted of a copper disc attached to a copper coil, both cooled by water flow. The crucible was also isolated at the top to reduce heat losses to a minimum. With this experimental setup unidirectional heat flow was achieved and also convection associated with the pouring of the liquid into the mould was eliminated.

After solidification the samples were cut in the longitudinal direction, polished with emery paper and etched to reveal the macrostructure. For zinc and zinc–aluminum alloys, concentrated hydrochloric acid was used for 30 s at room temperature. This was followed by rinsing and wiping off the resulting black deposit. The reagent used to reveal the microstructure was a solution containing 5 g CrO_3, 0.5 g Na_2SO_4 and 100 ml H_2O (Palmerston's reagent). The etching time varied from 15 to 60 s, depending on the alloy solute content. After etching, the samples were rinsed in a solution of 20 g CrO_3 and 100 ml H_2O before optical microscopy examination. Etching was performed at room temperature [8]. A typical resulting macrograph is shown in Fig. 1a for Zn–1 wt.% Al alloy. The position of the transition was located by visual observation and optical microscopy, and the distance from the bottom of the sample was measured with a ruler.

The equiaxed grain size was measured at equally spaced intervals utilizing ASTM E112 standard norm [9]; the counting starts at the position where the transition began. The columnar region was divided in a similar way and the width and length of the grains measured directly. The measured grain sizes in each zone of the samples are presented in Table 1.

Composition analysis of the different alloying elements along the cast samples was done by scanning electron microscopy and energy dispersive X-ray microanalysis.

2.2. Wear tests

The wear tests were performed in a pin-on-ring machine, consisting of a grey cast iron disc of 280 HV in hardness and 170 mm in diameter, which rotates giving a tangential velocity of 2.7 m s^{-1}.

Cylindrical pins of 6.35 mm in diameter and 16 mm in length were used as samples, see Fig. 1b. The pins were obtained from the casting ingots selecting a representative of each part of the sample that contained equiaxed, columnar and CET structures. The pins were cut with a handsaw and then lathed at a slow velocity and low stress. One of the plane surfaces of the pin is used as the contact surface, which was ground and polished using SiC abrasive paper from #220 up to #1500 in grid size, then finished with 0.25 μm alumina suspension.

According to the pin-on-ring configuration the disc axis is horizontally orientated and the pin is mounted vertically on top of the disc, on the curved edge. A load of 32.4 N is applied on the pin axis. The total distance and amount of wear were registered during the test. The wear was measured by the change in length of the pin every 100–200 m of test up to a final distance of 2000 m. The final distance assured that the steady state of wear was achieved in all tests [10]. All the experiments were performed at room temperature and the ambient humidity ranged from 60 to 75% RH. The temperature of the samples was measured with a thermocouple inserted perpendicularly to the pin axis at 6 mm of the contact surface.

3. Results and discussion

One ingot of each composition; pure Zn, Zn–1% Al and Zn–2% Al was solidified, each one having three regions; columnar, transition and equiaxed structures. Table 1 lists the grain size and the solidification structures as a function of the aluminum concentration. It is observed in the columnar and equiaxial structures that the mean grain size decreases with the aluminum concentration; in the CET region the mean grain size on the pure Zn is the largest, however in the alloys the size increases with the aluminum concentration.

Table 1
Grain size of the ZA alloys.

Alloy	Average grain size (mm)		
	Columnar	CET	Equiaxed[a]
Zn	3.4 ± 0.5	2.6 ± 0.4	2.9 ± 0.4
Zn–1% Al	2.8 ± 0.4	1.7 ± 0.2	1 ± 0.2
Zn–2% Al	2.6 ± 0.4	2.05 ± 0.4	0.8 ± 0.1

[a] Near to the CET.

Table 2
Composition and microhardness by regions of the ZA alloys.

Alloy	Al composition, wt.%			Microhardness, 0.5 HV		
	Columnar	CET	Equiaxed[a]	Columnar	CET	Equiaxed[a]
Zn	–	–	–	34.1	37.7	40.3
Zn–1% Al	0.812	0.847	0.891	39.0	44.5	45.6
Zn–2% Al	1.783	1.862	1.905	37.7	41.1	48.8

[a] Near to the CET.

The variations of the composition among the three regions of the ingots are indicated in Table 2. In all the cases the concentration is less than the nominal composition. In addition, the Al concentration slightly increases from the bottom to the top of the samples showing some degree of macrosegregation. The corresponding microhardness in the three regions is shown in the same table and they are the results of a mean of 10 lectures. It is observed that the microhardness increases from columnar-to-equiaxed region which may not be related to segregation.

In Fig. 2, the grain size versus microhardness of the alloys is compared. It is observed that there is a linear relation between them, independently of the type of structure and composition. This is indicating that grain size is an important mechanism of hardening in these.

One sample of each region was taken for the wear test. All of them had the axis parallel to the solidification direction and nine samples were tested twice to obtain two points per sample. The wear rate is calculated as the ratio between the change of the pin length and the sliding distance, which minimizes the error related to plastic deformation and burr generation [11]. The initial running-in transient distance to the steady state was not considered in the calculation.

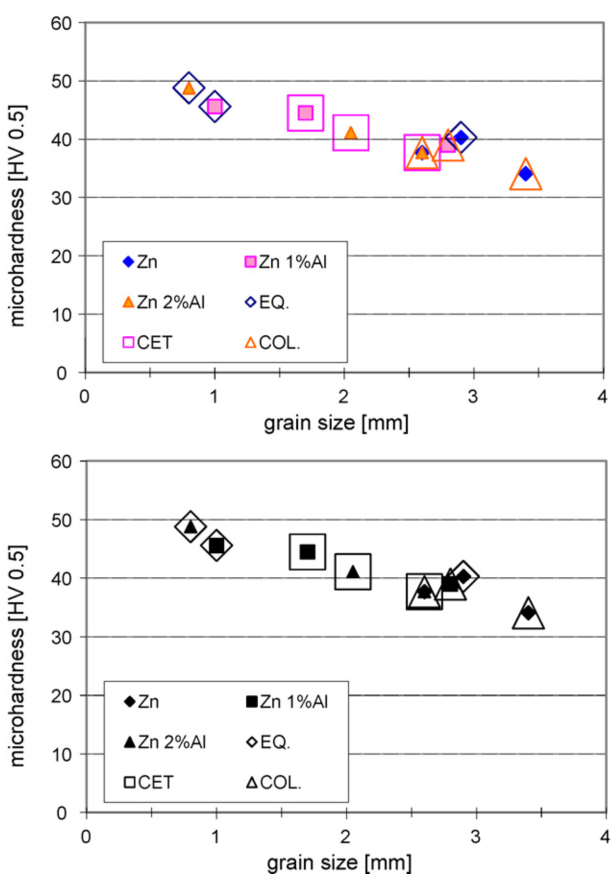

Fig. 2. Relation between grain size and microhardness grouped by composition and structure.

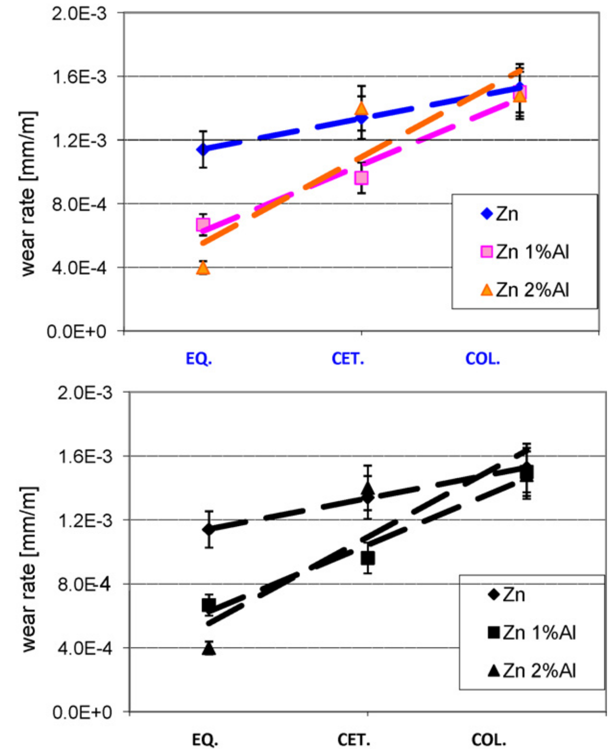

Fig. 3. Wear rate of dilute Zn–Al alloys and pure Zn.

The wear rate versus type of structure is shown in Fig. 3, for three alloy compositions. It is observed that the wear rate increases from the equiaxed to CET and columnar structure. In the tests the contact surface is perpendicular to the columnar and the transition structure. With respect to the effect of the concentration on the

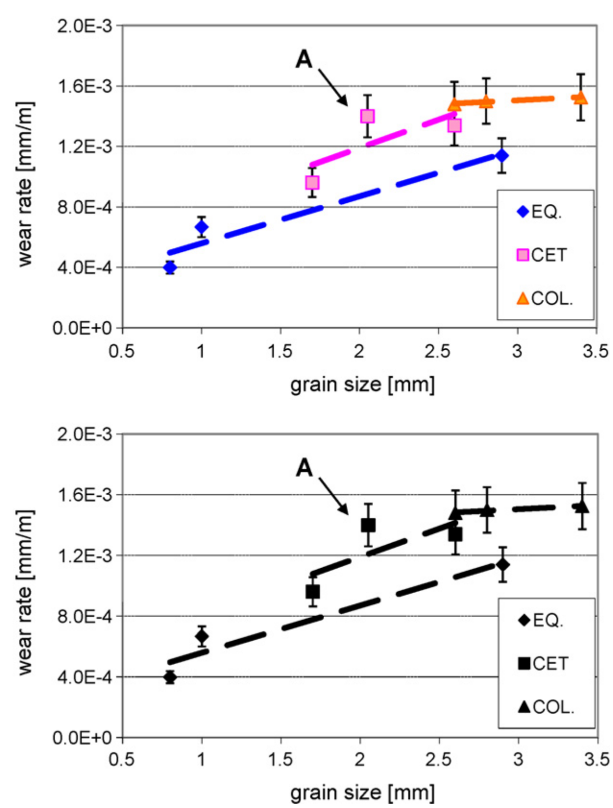

Fig. 4. Wear rate versus grain size for three types of structure.

wear rate, it is observed that the influence is larger on the equiaxial structures than on the columnar structures. For example; for the equiaxed structure the wear rate for pure Zn is 1.13×10^{-3} mm/m, and decreases to 3.10×10^{-4} mm/m for the Zn–2% Al alloy. The wear rate of the columnar structure is almost independent of the aluminum concentration with an average value of 1.50×10^{-3} mm/m. The samples of CET structure show intermediate wear rate values; higher than for the equiaxial and lower than for the columnar structures. In all the samples the temperature at 6 mm of the surface was of 70 °C in average.

In Fig. 4, the wear rate versus grain size for the three types of structure (columnar, transition and equiaxed) are compared. It is observed that the wear rate increases when the grain size increases. This effect is strong for the equiaxial and CET structures; however in the columnar structure the effect is negligible for the three points considered.

For the case of the samples with transition structure, it is observed that there is a higher dispersion in the behavior as shown by point A in Fig. 4. This behavior in regard to grain size is attributed to the presence of columnar and equiaxed grains coexisting in the region in a composition that varies from experiment to experiment.

In the present report no analysis of the wear mechanisms is made. However, it is mentioned that in the samples some transfer material was observed on the contact surface of the pin. This material is an indication of the formation of a tribolayer in the contact surface [12] as previously reported for this alloys [5,10].

4. Conclusions

The conclusions obtained from the experiments on wear of Zn and dilute Zn–Al alloys, are as follows:

1. For the same wear conditions the equiaxed structure has a wear rate lower than the columnar and transition structures.
2. For the equiaxed structure the wear rate decreases when the aluminum concentration increases.
3. For the columnar structure the wear rate is independent of the aluminum concentration.
4. The results indicate a direct relation between the grain size and the wear resistance.
5. For similar grain size the equiaxed grains are more wear resistant than the columnar grains.
6. The transition zone has an intermediate resistance between the columnar and the equiaxed structure for similar grain size.

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