Current-Carrying Wear Characteristics of Cast Al-Cu Alloys

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Abstract: The influence of electric current and Cu content on the wear behavior of cast Al-Cu alloys was studied. The results show that the wear rate of cast Al-Cu alloys decreased with the application of electric current, and showed an increasing trend with increasing current. The wear rate of Al-15Cu is higher than that of Al-5Cu and Al-10Cu. Under the condition of current carrying, the difference between Al-15Cu and Al-5Cu/Al-10Cu increases with increasing current. When the current reaches 180 A, the wear rate of Al-15Cu is about three times that of other Al-Cu alloys. In addition, the current carrying wear mechanism of cast Al-Cu alloys was discussed.

Keywords: Cast Al-Cu alloy; Current-carrying wear; Wear rate; Wear mechanism

1 Introduction

Light-weighting is one of the crucial techniques to meet the requirements of higher speed and lower energy consumption for trains. Current-carrying friction pairs are the vital components of trains for effective power transmission [1-3]. Al-Cu alloys are able to be alternative lightweight materials for current-carrying friction pair due to their excellent properties such as high specific strength, good conductivity, thermal conductivity, high temperature performance, and wear resistance [4-6].

2 Experimental procedure

Al-Cu alloys were prepared using electrical resistance furnace with raw materials of pure Al (99.99 wt.%), pure copper (99.7 wt.%) and formed into bars by squeeze casting under a pressure of 106 MPa. Finally, the bars were machined into disc specimens (Φ60×5 mm) by wire-cutting. Alloys were tested on the self-made pin-disc current-carrying wear tester with Cu/C brush as friction pairs (Fig 1). The test was carried out with a load of 24N for 240min, a sliding speed of 60r/s and a current density varying between 0 and 180 A.

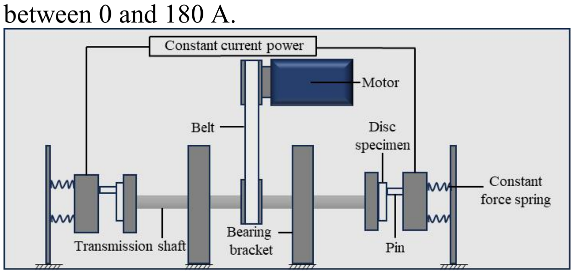

Fig 1 Schematic diagram of the current-carrying wear tester.

Microstructure characterization was carried out by optical microscopy on the samples etched with a Keller reagent. The wear specimens were immersed in alcohol for ultrasonic cleaning, and the mass of each group of wear specimens before and after the test was weighed using the HZK-JA1000 analytical balance to determine wear loss. The micro-morphology of the alloy wear surface and debris were observed using a scanning electron microscope (JSM-IT300).

3 Result and discussion

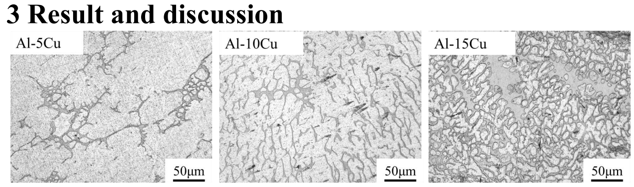

Fig 2 Microstructure of cast Al-Cu alloys

As presented in ***Fig 2***, with the increase of Cu content, the content of eutectic structure increases. The eutectic structure transforms from discontinuous particles and chains into a network-like structure, and even larger block-like eutectic structures emerge in the Al-15Cu alloy.

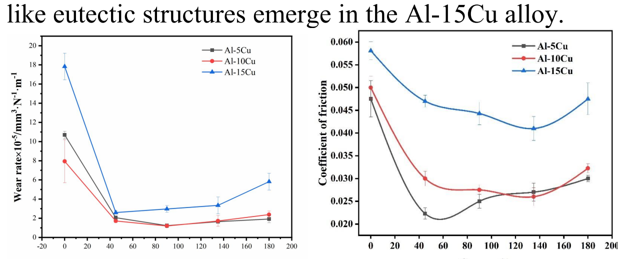

Fig 3 Wear rate and steady-state friction coefficient of cast Al-Cu alloys under different currents

Fig 3 suggests the Cu content has significant effect on the wear rate of Al-Cu alloys. As the current increases from 0 A to 180 A, the wear rate of Al-Cu alloys first decreases and then increases. When the current is 0A, the alloys have the highest wear rate. With the introduction of current, the wear rates decreased sharply, a reduction of approximately 80% with an electric current of 45 A. As the current increases from 45 A to 180 A, the wear rate of the alloys generally shows an increasing trend. The wear rate of Al-15Cu alloy is higher than that of Al-5Cu and Al-10Cu. When no current was applied, the wear rate of Al-15Cu alloy can reach 17.8×10^{-5} $mm^3\cdot N^{-1}\cdot m^{-1}$, which is over twice that of the Al-5Cu alloy. Under the condition of current carrying, the difference in wear rate between Al-5Cu and Al-10Cu is insignificant. However, the difference between Al-15Cu alloy and the two alloys increases with increasing current. When the current reaches 180 A, the wear rate of Al-15Cu is 5.8×10^{-5} $mm^3\cdot N^{-1}\cdot m^{-1}$, which is about three times that of Al-5Cu or Al-10Cu alloy.

As for the steady-state friction coefficient, the friction coefficient of Al-Cu alloys generally exhibits a trend of first decreasing and then increasing as the current increases from 0 to 180 A. Initially, all studied Al-Cu alloys have the maximum friction coefficient at 0 A. After the introduction of current, the friction coefficient decreases significantly. The friction coefficient of Al-15Cu alloy increases significantly from 0.041 to 0.048 when the current is between 135 A and 180 A, representing an increase of approximately 15%. For Al-10Cu and Al-5Cu alloys, the friction coefficient generally shows an upward trend but with a small increase. Comparing the differences in friction coefficients between Al-Cu alloys with different Cu contents, it can be found that the friction coefficient of Al-15Cu alloy is much higher than that of Al-10Cu and Al-5Cu. The change curve of the friction coefficient basically shows a trend of increasing with the increase in Cu content. It is also noted that under current-carrying conditions, as the current increases from 45 A to 180 A, the steady-state wear temperatures of the three alloys show a roughly linear upward trend. Among them, the temperature of the Al-15Cu alloy has the maximum rise, increasing from 47.9°C to 81.9°C, an increase of approximately 120%.

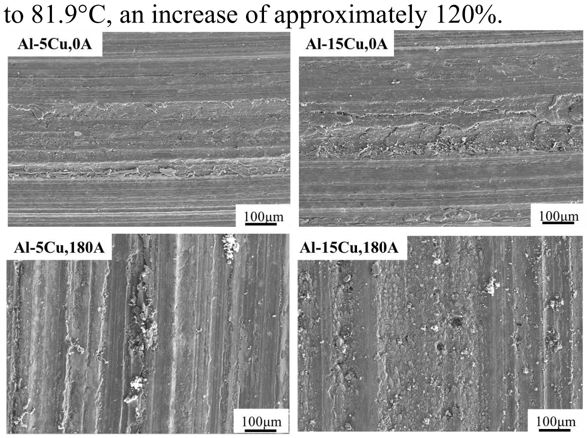

Fig 4 Microscopic wear morphology of cast Al-Cu alloys under different currents

As indicated in Fig 4, when the current is 0 A, the matrix was torn and peeled severely. In the torn and peeled areas of the Al-15Cu wear surface, more large-scale flaky wear debris and peeling can be observed, indicating a poor surface condition. Both alloys have distinct furrow-like groove traces on the wear surface, indicating an abrasive wear mechanism.

The intervention of current promoted graphite transfer and the formation of an oxide mixed layer on the worn surface, which played a lubricating and protective role in reducing the wear rate. When the current is 180 A, for the Al-5Cu alloy, a large amount of adhesion can be observed on the surface, with graphite and Cu adhesion transferred along the wear sliding direction distributed on the wear surface. The surface along the sliding direction is relatively smooth, but furrow-like morphology can also be found. Aggregated spherical granular substances are found in some areas of the wear surface. In contrast, the Al-15Cu alloy exhibits severer tearing and peeling of the matrix, caused by the hard, brittle and low conductivity network eutectic structure. Furthermore, a large amount of flaky wear debris adhesion can be seen on the surface, which is from material transfer under the high-temperature effect of the arc during wear. In addition, after wear with 180 A current, the Al-15Cu alloy exhibits more obvious arc erosion pits on the surface, resulting in a severe degradation of the surface condition and high wear rate.

4 Conclusion

The wear rate of cast Al-Cu alloys decreased with the application of electric current, and showed an increasing trend with increasing current. The wear rate of Al-15Cu is higher than that of Al-5Cu and Al-10Cu. Under the condition of current carrying, the difference between Al-15Cu and Al-5Cu/Al-10Cu increases with increasing current. When the current reaches 180 A, the wear rate of Al-15Cu is about three times that of Al-5Cu or Al-10Cu alloy. The intervention of current promoted graphite transfer and the formation of an oxide mixed layer on the worn surface, leading to a reduction of wear. The increasing current promotes adhesive wear and arc erosion, resulting in high wear rate. The high wear of Al-15Cu alloy can be attributed to the action of eutectic structure during current carrying wear.

Acknowledgments

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