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Dry sliding wear behavior of rheocast hypereutectic Al−Si alloys with different Fe contents

Chong LIN[1,2], Shu-sen WU[1], Shu-lin LÜ[1], Jin-biao ZENG[1], Ping AN[1]

1. State Key Laboratory of Materials Processing and Die & Mould Technology, Huazhong University of Science and Technology, Wuhan 430074, China;
2. School of Mechanical and Electrical Engineering, Wuhan Institute of Technology, Wuhan 430073, China

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Abstract: The effect of iron content on wear behavior of hypereutectic Al−17Si−2Cu−1Ni alloy produced by rheocasting process was investigated. The dry sliding wear tests were carried out with a pin-on-disk wear tester. The results show that the wear rate of the rheocast alloy is lower than that of the alloy produced by conventional casting process under the same applied load. The fine particle-like δ-$Al_4(Fe,Mn)Si_2$ and polygonal α-$Al_{15}(Fe,Mn)_3Si_2$ phases help to improve the wear resistance of rheocast alloys. As the volume fraction of fine Fe-bearing compounds increases, the wear rate of the rheocast alloy decreases. Moreover, the wear rate of rheocast alloy increases with the increase of applied load from 50 to 200 N. For the rheocast alloy with 3% Fe, oxidation wear is the main mechanism at low applied load (50 N). At higher applied loads, a combination of delamination and oxidation wear is the dominant wear mechanism.

Key words: dry sliding wear; hypereutectic Al−Si alloy; rheocasting; Fe-bearing compound; wear mechanism

1 Introduction

Hypereutectic Al−Si alloys are widely applied in automotive industries due to their excellent wear resistance, low thermal expansion coefficient and high heat resistance [1,2]. Iron is a desirable element that can enhance the elevated temperature properties of the hypereutectic Al−Si alloys [3]. But the equilibrium solid solubility of Fe in aluminum is very low (max. 0.05%) [4], almost all Fe in Al alloys segregates during solidification and tends to form intermetallic compounds. The coarse needle-like or plate-like Fe-bearing compounds are detrimental to the room temperature mechanical properties [5].

The deleterious effects of iron on the mechanical properties can be minimized by various techniques. These include manganese addition [6], rapid solidification [7], melt superheating [8] and rheocasting process assisted with ultrasonic vibration (USV) [9,10]. Among these processes, rheocasting process is an attractive technique due to its uncomplicated process and low cost [11,12]. It has been proved that the Fe-bearing compounds of the hypereutectic Al−Si alloys with high Fe content can be effectively modified by rheocasting process, and the ultimate tensile strengths of the rheocast alloys at room temperature and 350 °C are improved significantly [4,13]. These alloys are often used as piston materials which require excellent wear resistance. It is therefore interesting to find out whether rheocast alloy is more wear resistant than the alloy produced by conventional casting process.

The wear behavior of the Al−Si alloys with Fe has caught the attention of researchers in recent years. TAGHIABADI et al [14] studied the effect of Fe-rich intermetallics on the wear behavior of hypoeutectic Al−Si alloy (SAE F332). The results showed that high cooling rate and Sr modification could be used to refine the needle-like β phase, and these treatments improved the wear resistance of the alloy with 1.2% Fe. ABOUEI et al [15] investigated the effect of Fe-rich intermetallics on the wear behavior of eutectic Al−Si alloy (LM13) with 1.2% Fe. They found that high cooling rate and Mn addition could refine the Fe-rich intermetallics and

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Corresponding author: Shu-lin LÜ; Tel: +86-27-87556262; E-mail: shulin317@hust.edu.cn
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improve the wear resistance of the alloy. NAKATA and USHIO [16] studied the effect of Fe content on wear resistance of thermal-sprayed Al−17Si−*X*Fe (*X*=5, 10, 15, 20, 30, mass fraction, %) alloys coating on A6063 Al alloy substrate. They concluded that the most beneficial coating with good wear resistance and low friction coefficient could be obtained with Al−17Si−(10−15)Fe alloy powders. Recently, ALSHMRI et al [17] have investigated the dry sliding wear of aluminium−high silicon hypereutectic alloys formed by melt spinning and ribbon compaction. They found that the higher amounts of intermetallic-forming elements (Fe, Cu, Ni) were thought to be contributing to the wear resistance. However, reports on the effect of iron content on wear behavior of rheocast hypereutectic alloy are not available.

Based on the above considerations, this study was conducted to investigate the dry sliding wear properties of rheocast hypereutectic Al−17Si−2Cu−1Ni alloys with different Fe contents. The sliding wear mechanisms were also discussed based on observations of the worn surface, worn subsurface and wear debris.

2 Experimental

The alloys investigated had the compositions shown in Table 1 and were prepared with raw materials of Al−25.8%Si (mass fraction, the same in the following) and Al−10%Mn master alloys, commercial pure Al (99.8%), pure Fe (99.9%), pure Cu (99.99%), pure Ni (99.99%) and pure Mg (99.9%). The materials were melted in a resistance furnace, and then the tensile samples of these alloys with diameter of 8 mm were produced using rheocasting process assisted with USV [4,18]. The applied ultrasonic power was 1.6 kW, and the frequency of USV was 20 kHz. The USV treatment time was 1.5 min. For comparison, conventional gravity casting samples were also made using the same permanent mold without USV treatment under a pouring temperature of 750 °C. The samples were then heat-treated with T6 process (solution treatment at 510 °C for 7 h, followed by water quenching, then artificial aged at 190 °C for 10 h).

Table 1 Chemical compositions of hypereutectic Al−Si alloys (mass fraction, %)

Allloy	Si	Fe	Cu	Ni	Mg	Mn	Al
A0	17	0.23	2	1	0.4	0.4	Bal.
A1	17	2	2	1	0.4	0.8	Bal.
A2	17	3	2	1	0.4	0.8	Bal.

The dry sliding wear tests were carried out on a pin-on-disk wear tester to evaluate room temperature (i.e., 25 °C) wear behavior of Al−17Si−2Cu−1Ni alloys with different Fe contents. The pins, 6 mm in diameter and 12 mm in length, were machined from the rheocast or conventional casting samples. The disc, with a diameter of 70 mm and a thickness of 10 mm, was made of AISI 52100 steel. The hardness of the disk was approximately HRC 58. Before the wear test, the surfaces of the Al−Si alloys pins and the counterface of the disc were polished to a surface roughness (R_a) of 0.8 μm.

The pins in horizontal orientation were loaded against the rotating steel disk through a dead weight loading system. The radius of the work formed on the disk by the pins was 28 mm. The tests were conducted at four different loads of 50, 100, 150 and 200 N. Sliding speed and distance were kept constant at 0.75 m/s and 1000 m, respectively.

The mass loss during wear test was measured using an electronic balance with a resolution of 0.1 mg. The pins were thoroughly cleaned with acetone in ultrasonic cleaner before and after the wear test. The wear rates were determined from the measured mass loss and expressed in terms of volume loss per unit sliding distance (m^3/m). Each wear rate was averaged from the data obtained on at least three wearing pins.

After each test, the wear debris was collected and stored for further analysis. The worn surfaces and wear debris after sliding at different loads were examined using a Quanta 200 environmental scanning electron microscope (SEM) fitted with an energy dispersive X-ray spectroscopy (EDX). Subsurface microstructures were also investigated at the cross-sections perpendicular to the worn surface. In order to highlight the differences in phase hardness, nano-indentation measurements (TI750, Hysitron) of different phases were also carried out. Indentations with a Berkovich type indenter were performed normally on the polished cross-sections by using a maximum load of 8 mN. An average of 5 indentations on one particle of different phases was analyzed.

3 Results and discussion

3.1 Microstructures of alloys with and without USV treatment

Figures 1 and 2 present the as-cast microstructures of the alloys produced by different processes. As can be seen from Fig. 1, the addition of Fe to the hypereutectic Al−Si alloy leads to the precipitation of long needle-like β-Al_5(Fe,Mn)Si and coarse plate-like δ-Al_4(Fe,Mn)Si_2 phases in the matrix [4,18]. The average length of long needle-like β and coarse plate-like δ phases are about 100 μm and 150 μm, respectively. The average grain size of primary Si in Fig. 1(a) is about 47 μm. After USV treatment, the coarse plate-like δ and the coarse primary