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ScienceDirect
Trans. Nonferrous Met. Soc. China 23(2013) 1898−1904
Transactions of Nonferrous Metals Society of China
www.tnmsc.cn

Effect of heat treatment conditions on microstructure and wear behaviour of Al4Cu2Ni2Mg alloy

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Received 29 August 2012; accepted 5 November 2012

Abstract: Al4Cu2Ni2Mg alloy is an age-hardenable aluminum alloy. The effect of different solution and aging heat treatment conditions on the microstructure, hardness and wear resistance of the alloy was studied. The cast specimens were solution treated and then artificially aged. Optical microscopy and scanning electron microscopy were used to investigate the microstructures of the specimens. The hardness and wear tests were applied to understanding the effects of heat treatment. After aging for 8 h, the hardness of the alloy increases from HV_{10} 96.5 to 151.1. Aging treatment for a longer duration causes a drop in the hardness because of over aging. Increasing the hardness of the alloy increases the wear resistance. As a result of all tests, solution heat treatment at 540 °C for 8 h and aging at 190 °C for 8 h were chosen for optimum heat treatment conditions for this alloy.

Key words: Al−Cu−Ni−Mg alloy; piston alloy; artificial aging; hardness; wear

1 Introduction

Aluminum alloys have a wide diversity of industrial applications because of their high specific strength, low density and corrosion resistance. Therefore, these alloys motivate considerable interest to the transportation and aviation industries [1−7]. Decreasing the mass of the construction in transportation industries improves fuel economy in internal combustion engines as well as reduces the CO_2 emissions to the atmosphere. Because of these facts, grey cast iron has been substituted by aluminum alloys especially in the engines of the automobiles [8−10]. Some parts like engine blocks and cylinders are already being produced using aluminum alloys by most of the automobile producers.

Al−Cu alloys are normally used in making cast elements designed for structural components. Copper addition increases the strength of the alloy [11]. Copper is a potent precipitation agent in aluminum. Cu addition up to about 5% (mass fraction) leads to alloys with high strength and good toughness [12]. The Al_2Cu precipitates which exist after aging process and are named as θ phase provide these superior mechanical properties [13]. The solubility of copper in aluminum increases with increasing temperature. At elevated temperatures Al_2Cu phase dissolves and copper atoms enter into aluminum unit cells to create a solid solution. The dissolution of Al_2Cu precipitates in the alloy leads to a dramatical drop in the strength of the material. To avoid this problem precipitates with different chemical compositions which can withstand elevated temperatures are needed. Most important intermetallic phases which can be stable at high temperatures contain Ni and Mg. The chemical compositions of these intermetallics were reported as Al_6Cu_3Ni, Al_2CuMg, Al_7Cu_4Ni, $Al_{12}Cu_{23}Ni$, Al_3CuNi and Al_3Ni by the previous researchers [13−18].

The control of the microstructural properties like size, chemical compositions and distribution of these precipitates has an important role in the properties of the final product [19]. The difference in the chemical compositions of the intermetallic phases is caused by the chemical composition of the alloy and the thermal history of the material. The production process parameters such as casting conditions and applied heat treatments have major effects on the composition and distribution of the intermetallic phases. Since the presence and properties of the precipitates affect the properties of the final product, the heat treatments have a critical importance to the properties of materials.

The aim of this study is to understand the effect of aging treatment on the microstructure and wear

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DOI: 10.1016/S1003-6326(13)62675-8

behaviour of Al4Cu2Ni2Mg alloy which is a candidate material for parts operating at high temperatures in automotive, marine and aircraft industries due to its excellent properties [20].

2 Experimental

Pure metals were used to produce Al4Cu2Ni2Mg cast alloy. Casting process was carried out using an induction furnace with a graphite crucible. Molten metal was poured in a metal mould. Optical emission spectrometer (OES) was used to obtain the chemical composition of the alloy. The composition of the cast alloy is given in Table 1. To understand the effect of heat treatment duration, different heat treatments were applied to the specimens. The solution treatments were carried out at 540 °C for 4, 6 and 8 h respectively. The specimens were quenched in room temperature water after solution treatments. Following quenching the specimens were aged at 190 °C for durations from 6 to 10 h.

Optical microscopy and scanning electron microscopy (SEM) were used to investigate the microstructures of the specimens. The specimens were metallographically prepared with usual manner with a final polishing with 3 μm diamond. Keller's reagent was used for etching to reveal the microstructure of the specimens.

Table 1 Chemical composition of Al4Cu2Ni2Mg alloy used in experiments (mass fraction, %)

Cu	Ni	Mg	Si	Ti	Al
4.21	1.98	1.55	0.6	0.01	Bal.

Future-Tech Vickers hardness tester was used to understand the effect of heat treatments on the hardness of the alloy. All given hardness values are the average of 5 measurements. All sepecimens were metallographically prepared before wear tests. Wear tests were conducted on a Nanovea pin-on-disc type tribometer at room temperature, using 10 N normal load and AISI 52100 steel ball of 5 mm in diameter was used as a counter surface. Sliding distance was kept constant at 1 km for all tests. The specimens were cleaned with alcohol and then dried with a hot air blower before and after tests. The wear loss data of the cleaned samples were obtained using a microbalance with 0.1 mg resolution.

3 Results

3.1 Microstructure

Micrographs of as-cast Al4Cu2Ni2Mg alloy are given in Fig. 1. Figure 1 shows that the Al−Cu eutectic phase surrounds the *α*(Al) dendrites. When Al_2Cu precipitates are coarse and placed along grain boundaries, the effect of copper on the hardness and strength of the alloy is very limited. Also the fragility of hard Al−Cu precipitates in grain boundaries affects the toughness of the alloy negatively. Besides Al_2Cu, some other intermetallic phases were reported in the microstructure of the alloy. These intermetallic phases were formed by other alloying elements (Mg, Ni) during solidification. It was expected to dissolve these phases in *α*(Al) solid solution during solution treatment.

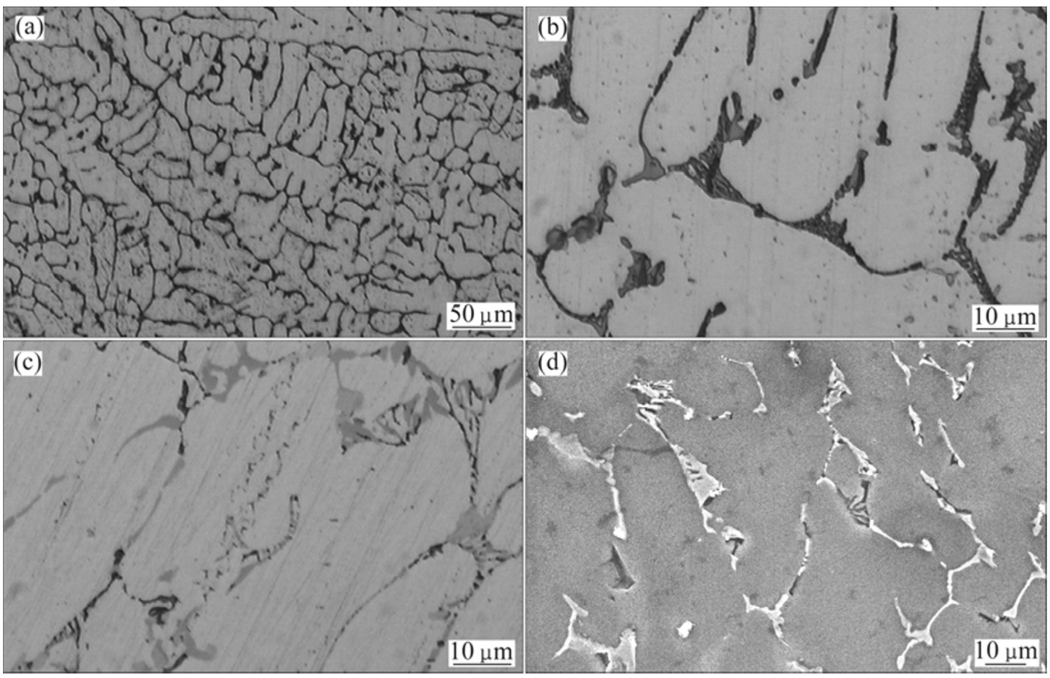

Fig. 1 OM (a, b, c) and SEM (d) images of as-cast Al4Cu2Ni2Mg alloy