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Investigation of Creep Behaviour of Al-9Zn-4Mg and Al-9Zn-4Mg-5Cu Alloys

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Abstract. Two aluminium alloys, Al-9Zn-4Mg and Al-9Zn-4Mg-5Cu was prepared for candidate material impeller turbine radial inflow system Organic Rankine Cycle (ORC) that works at 130 °C. The temperature is high for aluminium alloys so the creep behaviour of the alloys have to investigated. This study identified creep resistance of the alloys and also investigated the creep mechanism of the alloys. Creep test conduct at 50 MPa and variation temperature 150, 200 and 250 °C. The fracture surface and microstructure of subsurface was examined by SEM. The creep test result showed both of alloys did not failure at 150 °C while Al-9Zn-4Mg-5Cu has a good creep strength compare with Al-9Zn-4Mg at temperature 200 and 250 °C. The fracture surface and microstructure of subsurface indicate the coble creep mechanism or difusional creep. The good creep strength of Al-9Zn-4Mg-5Cu due to $CuAl_2$ phase serves as a pin which inhibit the rate of diffusion at the grain boundaries.

Keywords: Creep, Al-Zn-Mg, Al-Zn-Mg-Cu, Impeller, Turbine ORC

1. Introduction

Al-Zn-Mg-Cu alloys have been widely used due to their low density, high strength to weight ratio high corrosion resistance. This kind of alloy is an ageing-hardening treated alloy and heat treatment processing has a great effect on its microstructures and properties. Over the years, new alloys have been developed with increasing total solute content and varying ratios between the three main alloying elements (Zn, Mg and Cu), in order to reach very high levels of strength [1,2]

Al-9Zn-4Mg and Al-9Zn-4Mg-5Cu was prepared for candidate material impeller turbine radial inflow system Organic Rankine Cycle (ORC) that works at 130 °C . Aluminium alloys have excellent mechanical properties of at temperatures between 25 and 100 °C but tensile strength sharply decreases with increasing at elevated temperatures [3]. However, creep resistance is one of the properties required for use of materials in elevated temperature applications. The rate of creep is a strong function of the applied stress and temperature and the resistance to this form of deformation is obviously of great importance when materials are used at elevated temperatures [4,5].

The mechanism of creep in aluminium and its alloys remains a controversial subject. For precipitation hardened aluminium alloys, the mechanism of creep is believed to consist of glide and diffusion assisted climb with the associated development of a dislocation substructure, the dislocation ± precipitate interactions are of primary importance. The creep rate will be determined by the rate at which dislocations interact with and ultimately overcome obstacles provided by the precipitates [5] . Therefore, creep resistance of precipitate hardenable aluminium alloys can be enhance by fine precipitates that provide obstacle to disclocation movement. In contrast, Rapid precipitate coarsening occurs together with loss creep resistance under high temperature applications [4]. The aim of this research is to investigate creep behaviour of Al-9Zn-4Mg and Al-9Zn-4Mg-5Cu that prepared for for candidate material impeller turbine radial inflow system Organic Rankine Cycle (ORC) that works at 130 °C .

2. Research Methodology

Al-9Zn-4Mg and Al-9Zn-4Mg-5Cu was used in this study. This material was manufactured by gravity die casting according to specimen of tension test. The material was heat treated with homogenization at 440± 5 °C for 24h and solution treatment at 460 ± 5 °C for 1 hour. Then, continue with artificial ageing at temperature 130 °C for 16 hours. Uniaxial tensile test was performed before uniaxial tension creep experiment was conducted. The uniaxial tension creep test was performed acording to standart of ASTME 139-06. Three different temperatures (150, 200, 250 °C) with constant stresses (50 Mpa). Surface and sub surface fracture of creep specimen was identified by Scanning Electron Microscope (SEM).

3. Result and Discussion

Specimen for creep test produced by gravity die casting, the microstructures can be seen at Figure 1a and 1b. The microstructures relatively same with impeller turbine was produced by investment casting (Figure 1.c) that used for impeller turbine radial inflow system Organic Rankine Cycle works at temperature 130 °C. Addition of 5 (wt.%) Cu increase second phase at grain boundary, commonly $MgZn_2$, $CuAl_2$ and $CuMgAl_2$ [2]. It can be seen that the second phase more thick in 5 wt.% Cu Alloys. The second phase of $MgZn_2$ and $CuAl_2$ have a good strength and can increase the properties of alloys. After heat treatment, the second phase play esential rule for precipitation hardening.

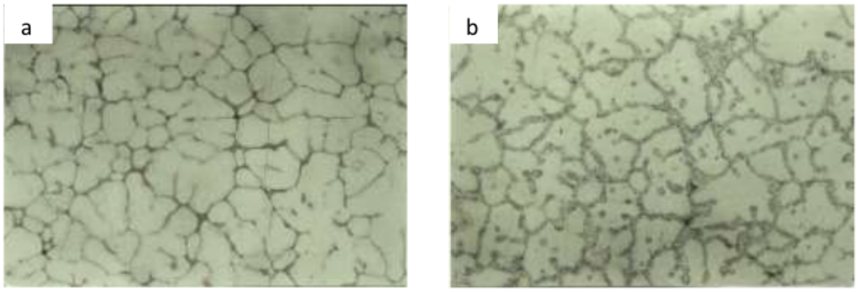


Figure 1. Microstructure of as cast specimen produced by die casting a) Al-9Zn-4Mg b) Al-9Zn-4Mg-5Cu

Figure 2a shows hardness value of alloy after heat treatment. Hardness value of Al-9Zn-4Mg-5Cu alloy achived 91 HRB higher than Al-9Zn-4Mg that only 67 HRB. Addition 5 wt. % Cu significantly increase the hardness of alloys due to $CuAl_2$ precipitate that formed through ageing proces. Figure 2b shows the ultimate strength and elongation of both alloys Al-9Zn-4Mg and Al-9Zn-4Mg-5Cu. It can be seen that ultimate strength of Al-9Zn-4Mg-5Cu at 179.59 MPa higher than Al-9Zn-4Mg that only 152.76 MPa. It also can be seen that the elongasion of Al-9Zn-4Mg-5Cu higher than Al-9Zn-4Mg. It means that $CuAl_2$ precipitate not only increase hardness value but also significantly increase strength, thoughness and ductility.

(a)

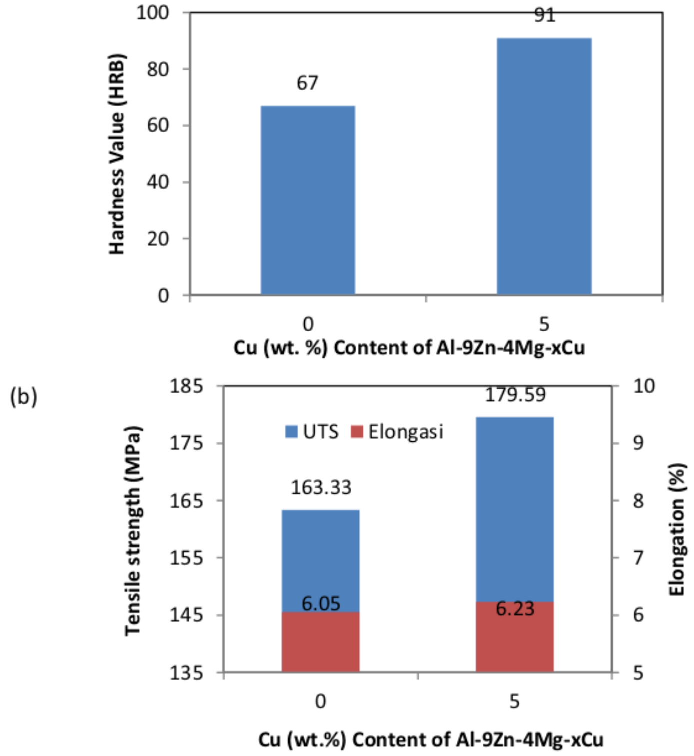
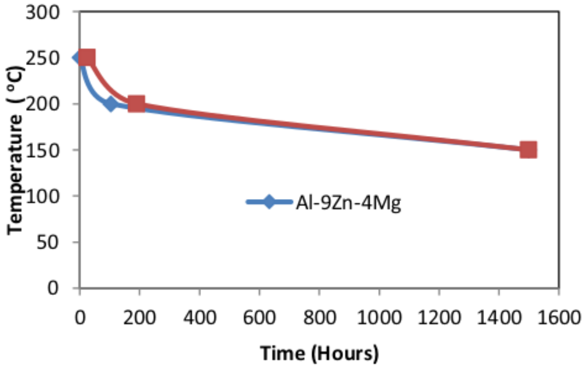


Figure 2. a.) Hardness value b.) Tensile strength and elongation of Al-9Zn-4Mg and Al-9Zn-4Mg-5Cu after heat treatment, homogenization at 440± 5 °C for 24h and solution treatment at 460 ± 5 °C for 1 hour. Then, continue with artificial ageing at temperature 130 °C for 16 hours



Note : Under temperature 150 °C, the alloy did not failure until 1500 hours

Figure 3. Temperature vs time result of creep test Al-9Zn-4Mg dan Al-9Zn-4Mg-5Cu alloys with stressed 50 MPa

Figure 3 shows result of creep test of Al-9Zn-4Mg and Al-9Zn-4Mg-5Cu with stressed 50 MPa and variation temperature at 150, 200 and 250 °C. It can be seen that both of alloys failure when aplied temperature test at 250 °C and 200 °C. But both of alloys did not failure when temperature test at 150 °C until 1500 hours. It means that both of alloys can works under temperature 150 °C, save from creep failure. From Figure 3 also can be seen that addition 5 wt.% Cu increase creep resistance of alloys. Creep test at temperature 200 °C, Al-9Zn-4Mg failure at 104 hours and Al-9Zn-4Mg-5Cu failure at 190 hours. When temperature of creep test conducted at 250 °C, Al-9Zn-4Mg failure only at 1,5 hours and Al-9Zn-4Mg-5Cu failure at 25 hours. The increasing of temperature decrease creep resistance of alloy significantly. Increasing temperature decrease the ductility of alloys and became more brittle.

It can be seen at figure 4 the surface and sub surface facture of specimen after creep test. The surface fracture of Al-9Zn-4Mg-5Cu shows more dimple that indicate ductile fracture than Al-9Zn-4Mg. Sub surface fracture shows void at grain boundary. It is indicate the coble creep mechanism, where failure due to difusion of atom at grain boundary [4]. Void at grain boundary in Al-9Zn-4Mg more large than Al-9Zn-4Mg-5Cu, in Al-9Zn-4Mg-5Cu there are second phase at grain boundary that works as pin or obstacle and avoid the crack. The second phase was identified as $CuAl_2$. $CuAl_2$ not only play as precipitate that increase the strength and thoughness, but $CuAl_2$ which is not solute in the matrix and stay at grain boundary play as pin or provide effective obstacles to dislocation movement[5].

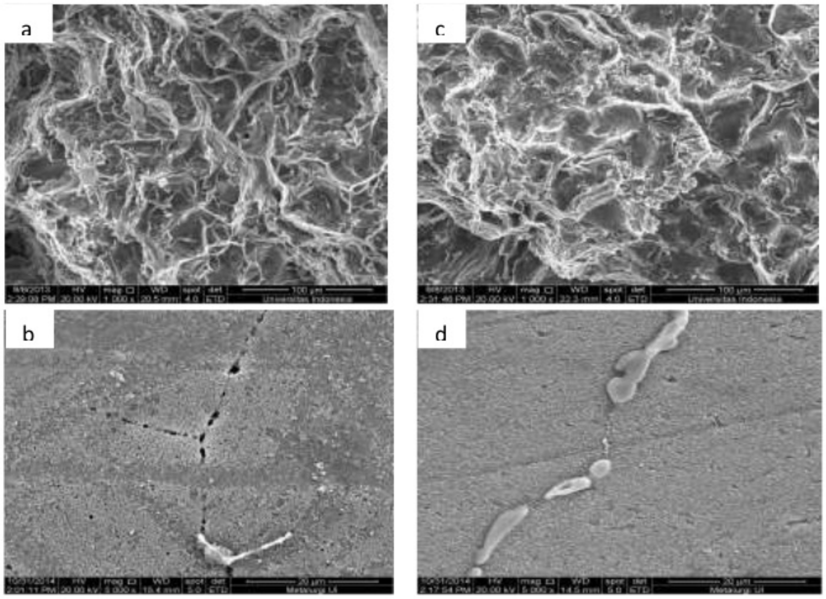


Figure 4. Surface fracture and sub surface fracture specimen after creep test, conducted at temperature 250 °C and stress 50 Mpa (a,b) Al-9Zn-4Mg and (c,d) Al-9Zn-4Mg-5Cu

4. Conclusion

The effects of Cu on the and creep resistance of the Al –ZnMg--Cu alloy were investigated. But both of alloys did not failure when temperature test at 150 °C until 1500 hours. It means that both of alloys can works under temperature 150 °C without creep failure. Creep resistance of Al-9Zn-4Mg-5Cu higher than Al-9Zn-4Mg due to $CuAl_2$ phase. $CuAl_2$ not only play as precipitate that increase the strength and thoughness, but $CuAl_2$ which is not solute in the matrix and stay at grain boundary play as pin or obstacle and works to avoid crack at the grain boundary in high temperature.

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