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Effect of Copper Addition on Fatigue Strength Al-10Si Alloys Produced by Die Casting

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Abstract. Aluminum Silicon Alloy (Al-Si) is widely used in the industry because it has a good cast ability, good mechanical properties and good corrosion resistance. At its expense, many failures are caused by fatigue fracture. Fatigue fracture is caused by a dynamic load within a certain time or cycle. Nearly 90% of structural components damaged caused by fatigue fracture. To improve the mechanical properties of Al-Si alloys can be added Cu elements. In this study Al-10Si alloys added Cu elements with variations of 1, 3, 5 (wt.%) Through die casting process. The casting results are mechanical characterized by hardness test, tensile test and fatigue test. The microstructure was examined by optical microscope and SEM. The results showed that the addition of Cu elements up to 5 wt. % in Al-10Si increased hardness to 98 HRB and tensile strength to 245.23 MPa but decreased ductility from 3.1% to 2.4%. The results of fatigue test showed a significant increase in the number of cycles at 80MPa can reach 1.5 x 107 without fracture (fatigue endurance limit). The microstructure examination results confirmed the presence of $CuAl_2$. The $CuAl_2$ phase inhibits dislocation movement so that greater force for deformation and improve mechanical properties

Introduction

Aluminum Silicon Alloy (Al-Si) is widely used in the industry because it has a good castability, good mechanical properties and good corrosion resistance. The addition of Cu elements to Al-Si alloys can improve mechanical properties. The addition of copper to the silicon aluminum alloy will make this alloy have a good response to heat treatment [1]. Aluminum alloys containing copper elements above the solubility limit will be united with aluminum forming a hard and brittle $CuAl_2$ precipitate. After this heat treatment the properties will become tough and not brittle, this is because the $CuAl_2$ deposits will dissolve at the heat treatment temperature is reached and will re-establish a more homogeneous and more uniform properties at the time of cooling. However, the presence of impure elements such as Fe, Mn and Zn leads to an increasingly complex coagulation process. As a result, the microstructure of Al-Si-Cu cast products comprises several types of intermetallic and eutectic structures, so that alloying elements have a great influence on the characteristics of Al-Si-Cu cast alloys [2].

Aluminum alloys are developed to obtain strong material, light weight, long service life, low production cost, high failure tolerance, and good corrosion resistance. However, Aluminum alloy has lower fatigue strength. In fact, nearly 90% of structural component damage is caused by fatigue failure, such as a rotating axle, pressure vessel and aircraft component. Fatigue failure is caused by repeated loading (fluctuating) in a certain time or cycle. Factors that cause fatigue failure are working stress, number of cycles, surface roughness and material properties. The applied stress shall not exceed the fatigue limit of the material. Fatigue Limit (fatigue strength, endurance limit) of the material can be determined by fatigue test. A main material defect in high-pressure die-cast components is porosity, which is caused by micro shrinkage and by dissolved gases leading to voids. In cast aluminium alloys, High cycle fatigue investigations of aluminium cast alloy showed that fatigue cracks predominately initiate at porosity [3]. This means that voids have to be considered as a main source of fatigue cracks for components produced by common casting techniques, such as sand casting or die-casting *H. Mayer et al.* show that in 98.5% of specimens the fatigue crack initiated at porosity, at the fatigue limit cracks may initiate at porosity but do not propagate to failure [4].

The tensile properties of Al–Si–Cu alloys have been investigated in previous research.Ceschinia et al.found that the tensile strength of Al-10Si-2Cu alloy increased with the decreasing of the average secondary dendrite arm spacing (SDAS) [5]. In addition, El hadari et al. [6] also reported that the tiny eutectic structures and fine round α-Al phases are favorable for better tensile strength and other microstructural features,such as composition of the Copper-rich phases and Fe-rich intermetallic compounds, can play an important role in tensile behavior. These fundamental studies have proven that the tensile properties of Al–Si–Cu alloys depend on the microstructure feature[7]. However, relationship betwen microstructure feature and fatigue properties still not clear. Ovono et al. [8] observed that fatigue cracks always nucleated from larger pores and intermetallic compounds of cast 333 aluminum alloys.They also found that the fatigue life of Al–Si–Cu alloys was essentially controlled by the volume fraction of pores and the density of intermetallic compounds.

The aim of this study is to investigate experimentally the room temperature mechanical properties of Al-10Si with various wt%.Cu including hardness, tensile and fatigue test related to the microstructure features.

Experimental Method

In this study, commercial Al-10Si alloy with Cu addition 1, 3, 5 (wt.%) was employed, The Al-10Si ingot, cut into small pieces was melted in a crucible foundry, and then the liquid Al-10Si was added Ingot Cu . After melt together, the liquid alloy was pouring directly into metal mold. Fig. 1(a) shows casting product of Al10Si-xCu. After solidification, the result of cast alloy was cut to make specimen of hardness, tensile test and fatigue test. Fig. 1(b) shows specimen of tensile test

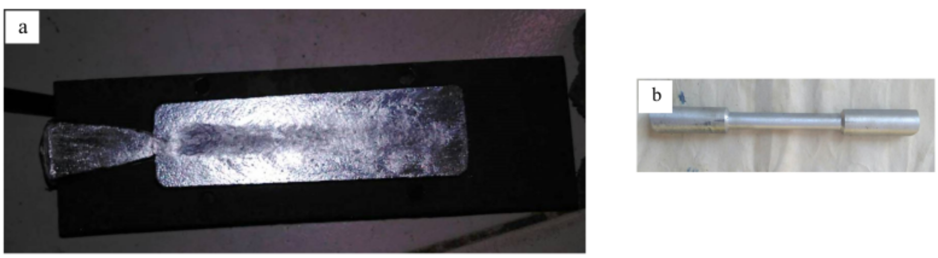

Figure 1.(a) Casting product of Al10Si-xCu (b) Specimen of tensile test after machining

The mechanical properties of the cast samples were investigated experimentally, including hardness, tensile and fatigue test. The hardness was evaluated by a Rockwell hardness tester, tensile properties were examined at room temperature using universal testing machine. The test specimens were designed on the basis of. Fatigue test used rotary bending fatigue test with the specimen standard ASTM - E8. Microstructural characteristics were examined by an optical microscope (MO), a scanning electron micrograph (SEM) and an energy dispersive X-ray spectroscopy (EDX).

Result and Discussion

3.1 Microstructural examination

Fig. 2 showed the microstructure of Al-10Si with variation wt.% of Cu contain. It can be seen that all of specimen indicate dendrite with lamellar Si primer. Contain of Cu relatively not change the size of grain, only 3% Cu showed coarse grain than other. All specimens do not indicate porosity, either shringkage porosity or gas porosity. Fig. 3 representative SEM micrographs of Al10Si1Cu. The light white phases are the intermetallic $CuAl_2$. The dark gray areas correspond to the α-Al matrix and eutectic Si particles that are seen coarse-lamelar. The formed of intermetallic θ-Al_2Cu phase indicate Cu dissolve into matrix α-Al despite contain of Cu lower than sollubility limits of Al.

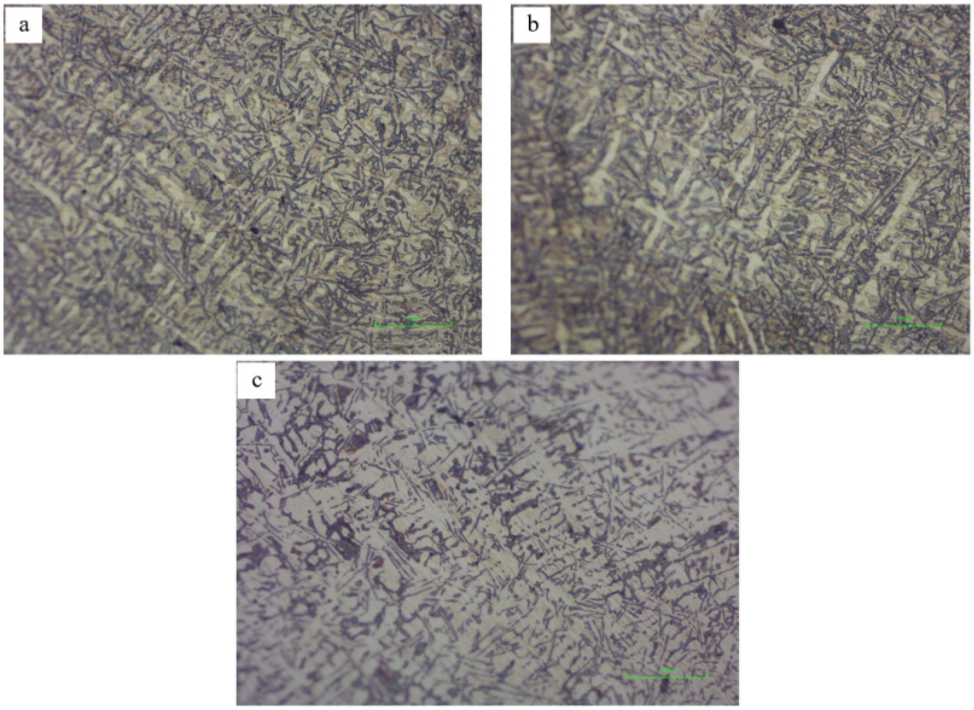

Figure 2 . Microstructure of (a) Al-10Si-1%Cu (b), Al-10Si-3%Cu and (c) Al-10Si-5%Cu

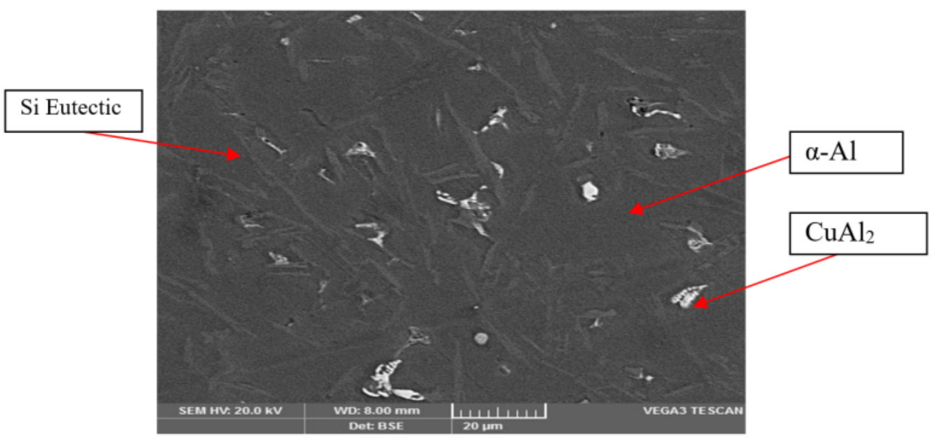

Figure 3. SEM photograph of Al10Si-1Cu

Fig. 4 shows the hardness values of alloys, 1% Cu hardness value of 84.29 HRB, 3% Cu alloys are 91.60 HRB, and 5% Cu alloys are 97.33 HRB, the higher the Cu content the higher the hardness . Cu content less than solubility limit will solve into matrix α-Al and formed intermetalic phase $CuAl_2$ phase. The $CuAl_2$ phase inhibits dislocation movement so that greater force for deformation and improve mechanical properties. the increase of Cu contain will increase Cu contain in matrix α-Al and also $CuAl_2$ is formed also the greater cause of high hardness value [1,2].

Fig. 5 (a) shows the tensile strength of each sample with different Cu Contain. The higher tensile strength of 245 MPa is obtained for 5% Cu. It is higher than 3% Cu (224 MPa) and 1% Cu (203 MPa). The tensile strength value shows the same trend the hardness test. However, the strain value is inversely proportional to the tensile strength that can be seen in figure 5(b). The higher Cu content indicates the smaller strain value. In alloys with 5% Cu having a strain value of 2.4% whereas alloys with 1% Cu have a strain value of 3.1%. The high content of Cu causes the formation of $CuAl_2$ phase that has properties hard but brittle so that the lower value of the strain of the alloy [1,2].

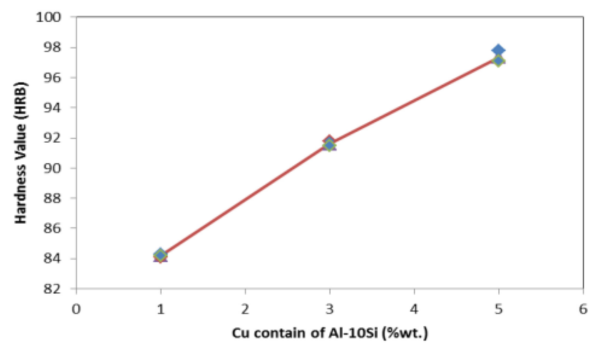

Figure 4. Effect of Cu content of Al-10Si on hardness value

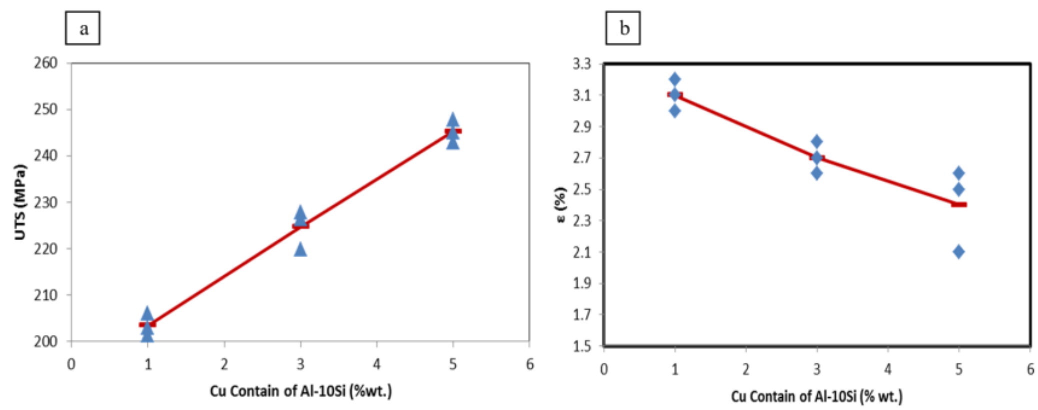

Figure 5. (a) Tensile strength of Al-10Si-xCu (b) Strain of Al-10Si-xCu

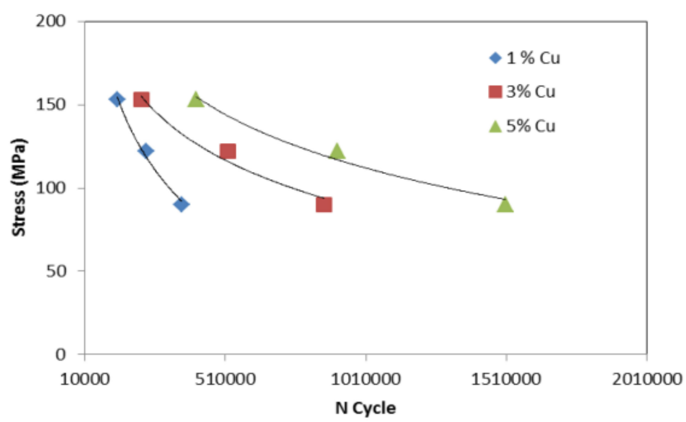

Figure 6. S-N Curve of Al-10Si-xCu

Graph S-N fatigue test results can be seen in Fig. 6. The higher Cu content indicates higher number of cycles. This is consistent with the results of tensile strength and hardness values. Although the addition of Cu reduces the value of strain, this does not affect the fatigue strength of Al10Si alloys. Working stress on fatigue test is taken Based on the value of tensile strength on Al10Si1Cu alloy that is by taking 75%, 60% and 45% of tensile strength. Graph S-N result of fatigue test can be seen in figure 6.The working stress of 153 MPa (75% of UTS value of Al10Si1Cu) for alloys with 5% Cu obtained 405880 cycle, while at a working stress of 90MPa (45% of UTS Value Al10Si1Cu) obtained 1506720 cycle. This value is still lower than the endurance limit of aluminium alloy ie 10^7 cycles. To improve the fatigue strength of this alloy it is necessary to improve the casting process so as to produce finer grain size, more rounded grain shape and finer particle particles [5,6]. This can be obtained by the addition of grain refiner, by stir casting or semisolid casting method

Conclusion

The mechanical properties of cast Al-10Si-xCu alloys ogy has been studied, and the obtained results can be summerized as follows:

1. Microstructural characterization showed that Cu addition did not influence grain size, all specimens were dendritic with coarse lamellar Si eutectic. The addition of Cu is not all soluble in the α-Al matrix and partly forms the $CuAl_2$ phase
2. The higher the Cu content the higher the hardness, the increase of Cu contain will increase Cu contain in matrix α-Al and also $CuAl_2$ phase which is the greater cause of high hardness value. The $CuAl_2$ phase inhibits dislocation movement so that greater force for deformation and improve hardness value. The tensile strength value shows the same trend as the hardness test. However, the strain value is inversely proportional to the tensile strength, the higher Cu content indicates the smaller strain value
3. The higher Cu content indicates higher number of cycles. This is consistent with the results of tensile strength and hardness values. Although the addition of Cu reduces the value of strain, this does not affect the fatigue strength. To improve the fatigue strength of this alloy it is necessary to improve the casting process so as to produce finer grain size, more rounded grain shape and finer particle particles

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