Effects of Pouring Temperature Variations on Fatigue Properties of Al-Cu Alloy After Remelting

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Abstract. The aim of this research is to observe the casting temperature variations effects on fatigue properties of Al 2024 with different types of casting temperature. Three different pouring temperatures were carried out 688, 738, 788 °C, and the cast mold was preheated and kept constant at 220°C. The specimen was heat-treated by T6 process in which this method was heat treated in electrical furnace at 500 °C for 2 hours continued by fast quenching into water. Finally, the sample cast was treated by artificial aging method with the temperature at 190 °C. The results show that at 688°C pouring temperature, it has the highest tensile test results than to other variations which is 138.37 MPa, and for the fatigue strength at more than 2x10⁶ cycles is 62.3 MPa. It shows that fatigue life of aluminum alloy 2024 could be improved by T6 heat treatment and artificial aging in which it indicates that the number of the fatigue strength depends on the number of the maximum tensile strength of the material because the increase in the maximum tensile strength will increase the fatigue strength.

Keywords: Al 2024, T6 heat treatment, fatigue properties, pouring temperatures

1. Introduction

Al 2024 is a well-known heat treatable alloy widely applied in aerospace industries and automotive because of its good damage tolerance and low density [1]. This material also can be produced by different casting methods, such as, semi-solid casting, and direct-chill casting. However, casting defects such as microcracks, porosities, hot tearing and macrosegregation have damaging effects on mechanical properties. Therefore, optimizing and detecting are the notable parameters which is able to eliminate defects that would be advantage for the product [2].

Remelting process could reduce the toughness of aluminum alloy caused by porosity due to an increase in hydrogen gas when the metal transforms from solid to liquid then to solid. This identifies that the ability of a material to deform plastically and absorb energy before and after damage is reduced because the material undergoes a process of remelting [3]. The process of remelting in cast aluminum also affects the cracking characteristics of aluminum alloy cracks, for instance, there is a decrease in hardness and fatigue (N) cycles. Fatigue testing results indicate that the remelting process can reduce fatigue life [4]. A518, A713, and A206 are utilized to assist effect on hot tearing and also on the grain size on three different pouring temperatures namely 700, 750, and 780 °C. As a result, it has a significant effect which is would be very useful for other materials [5]. The pouring temperature is a critical parameter for predicting crack susceptibility. The results show a good correlation between grain size, pouring temperature and crack susceptibility, so it is proven that hot tearing significantly decreases with
decreasing pouring temperature[6]. T6 heat treatment and aging temperature will improve the number of failure cycles in which casting metal defects in the form of cracks during the formation of metals such hot tears are one of the sources of crack initiation and could affect the strength of fatigue[7]. In this research, the heat treatment solution included heating the sample in an electric furnace to reach a temperature of 535 °C, for 4 hours and then quickly cooling with room temperature water. It has a purpose to avoid structure diffusion, and to clarify the material structure is still in the α phase. Finally, the process of artificial aging in which the specimens were put and reheated into the furnace at 150 °C for 2 hours until reaching room temperature in the furnace to release heat [8].

The purpose of this work is to analyze the effects of pouring temperature variations on fatigue strength of Al-Cu alloy after remelting.

2. Experimental Methods

2.1 Materials

The base material was aluminum commercial bar wrought alloy 2024. The Table 1 shows chemical composition Al-Cu after remelting process with using Shimadzu EDX-8000. Tensile testing has been carried out by Akhyar [8].

Table 1. Chemical Composition wt/ %.

|   | Al    | Cu    | Mg    | Mn    | Fe    | Si    | Zn    | Cu    | Ta    | Cr    |
|---|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
|   | 94.347| 3.119 | 1.406 | 0.556 | 0.166 | 0.150 | 0.131 | 0.054 | 0.025 | 0.011 |

Table 2. Tensile Properties of Al-Cu Pouring Temperature Variations.

| Casting Temperature (°C) | Ultimate Tensile Strength (MPa) | Elongation (%) |
|--------------------------|---------------------------------|---------------|
| 688                      | 138.37                          | 0.84          |
| 738                      | 83.96                           | 0.88          |
| 788                      | 103.47                          | 1.12          |

2.2 Casting Process

The base material aluminum alloy with a length of 1,500 mm and diameter of 50.8 mm was cut and put into electrical furnace. Casting method used gravity cast. Then, Al 2024 alloy was melted at 688, 738, and 788 °C and poured into carbon steel EMS/17330 with a constant temperature 220 °C for all type casting conditions and the temperature was measured using a K-type thermocouple on the furnace.

2.3 Heat Treatment T6

Heat treatment T6 is a heat treatment process in the certain temperature that was done with various pouring temperature, and the temperatures were controlled (+ 2 °C) electrical resistance furnace. Firstly, the temperature is heated (T0) until a temperature of 500 °C and held on the temperature for 2 hours, on this stage, to ascertain the β phase will be solute on the α phase (solutionized). Secondly, the sample is soaked in water (T1=25 + 1 °C) to avert diffusion of the structure, in addition to clarify the structure of the material is still in the α phase. A supersaturated solid solution in the α phase is reheated at a (α+ β) temperature area (T2). Based on previous research [8], T2 was set at 190 °C for artificial aging (T6) for 5 hours and then water quenched in water at room temperature. As a follow methods act as an aging method through temperature release until the samples reach room temperature. The solution treatment leads to three phenomena in the material; firstly, eutectic-Cu fragmentation and spheroidization, secondly, dissolution of precipitate particles, and lastly, chemical homogenization [9].
2.4 Mechanical Properties Test
Fatigue testing of rotary bending is to determine the fatigue of test specimens using the Shimadzu ONO’S type H-6 bending fatigue tester. The shape and size of the test specimens carried out following the JIS Z2274 standard shown in Figure 2. Rotary bending fatigue testing is performed at the ratio R = -1. The maximum cycle is determined at $2 \times 10^6$ under the condition of the non-fractured test specimen. Loading test used a voltage amplitude of 30 to 60% of the maximum tensile strength with an increase of 5% [10]. Hardness testing is to determine effect of pouring temperature after remelting with pouring temperature variations 688, 738, and 788°C. Hardness testing used Brinell method and device

2.5 Microstructure
Microscopic analyzing was carried using an Olympus optical microscope and Optilab device. The samples were set up using standard metallographic procedures be composed of grinding, polishing and etching using Keller’s reagent made of 5 ml HNO₃ (95% concentration), 190 ml H₂O, 3 ml HCl, and 2 ml HF.

3. Results and Discussion

3.1 Hardness Testing
Hardness testing in this study was carried out by the Brinell method. Tests were carried out using a load of 613 kg with an indenter ball-shaped with a diameter of 2.5 mm. Observations were made after doing the indentation. The former indentation was observed using a microscope with a scale 1 mm = 38 strips.

Figure 2 shows the highest hardness value which was obtained at a pouring temperature of 738 °C with a Brinell hardness of 146.675 kgf / mm², whereas the lowest hardness test was 105.324 kgf / mm² with a temperature of 788 °C, and a temperature variation of 688 °C showing a value of 110.886kgf / mm². Based on these data, the decrease in hardness value occurs along with the increase in pouring temperature, due to the larger the grain size and the higher the pouring temperature which could cause easy dislocation.
3.2 Fatigue Properties

Fatigue rotary bending test with aluminum alloy 2024 used a percentage of loading ranging from 40 to 65% of the maximum tensile strength. Tensile testing has been carried out by Akhyar [8]. The highest fatigue life is at the pouring temperature variation 688°C (the test specimen did not break when it reached 2x10^6 cycles) was 55.3 MPa at 40% of the maximum tensile strength. At the pouring temperature variation 738°C obtained the highest voltage amplitude of 37.8 MPa at 45% of the maximum tensile strength which is the smallest amplitude compared to the other pouring temperatures, whereas at the casting temperature variation 788°C the largest amplitude percentage obtained at 40% of the maximum tensile strength with 41.4 MPa working tensile stress. However, the lowest cycle is at a temperature variation of 688 where at a tensile stress of 89.9 MPa or 65% of the maximum tensile stress only obtained 103,100 cycles, whereas other variations at a percentage of 65% of the maximum tensile stress reach above 2,000,000 cycles with all specimens broken condition.

As illustrated in Figure 3 that each variation has a pattern that tends to be the same as the results of the tensile test results where each pouring temperature increases will decrease except at the pouring temperature 788°C which rises slightly. When seen from the percentage of voltage amplitude to the highest variation of the pouring temperature is obtained at a temperature variation of 688°C that is equal to 40% of the maximum tensile strength. Then it can be concluded on the testing of fatigue rotary bending that the fatigue strength depends on the maximum tensile strength value of the material because the percentage of the amplitude of stress that is relatively equal in other words an increase in maximum tensile strength will increase fatigue. Fatigue strength in cast aluminum alloys is affected by defects originating from the casting process such as cracks that are formed due to the greatest defect area and cracks growth propagation that follows the grooves in the smaller defect concentration area [10-12].
3.3 Microstructure

Observation of the structure with an optical microscope was carried out on the surface of the specimen. Microstructure observation results show that the influence of an increase in pouring temperature for casting in the casting process affects the microstructure that results from re-casting.

![Microstructure images](image)

**Figure 4.** Microstructure of Al-Cu after remelting by different pouring temperature (a) 688°C (b) 738°C (c) 788°C.

Figure 4 shows the pouring temperature 688°C having a relatively smaller grain size among other pouring temperature variations, while the 788°C pouring temperature variation has a relatively larger grain size among other variations of the pouring temperature. Grain boundaries are marked with a red line in Fig. with a higher temperature, then a decrease in temperature requires a longer or \((\Delta t)\) longer time. Aluminum cast which has a longer pouring time temperature \((\Delta t)\), the greater it will be to release the stress due to the freezing of liquid metal. this results in larger grain sizes. The higher the pouring temperature, the more porosity will appear, and it will be easy to be contaminated by hydrogen gas which causes the trapping of hydrogen gas in the liquid metal. the presence of porosity defects in the specimen can reduce the mechanical properties of a material.

4. Conclusion

Effect of pouring temperature of Al-Cu of fatigue properties after remelting has been analyzed. result can be concluded: The highest hardness value was obtained at a pouring temperature of 738 °C 146,675 kgf/mm². The highest of fatigue life is at 688°C pouring temperature with 2\times10^6 cycles at working tensile stress 62.3 MPa. Fatigue strength depends on the number of the maximum tensile strength of the material because the increase in the maximum tensile strength will increase the fatigue strength.
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