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EXPERIMENTAL INVESTIGATION ON HARDNESS, TENSILE STRENGTH, AND MICROSTRUCTURE OF Al-3,1Cu CAST-ALLOY AFTER T6-TEMPERED

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This research aims to investigate Brinell hardness and tensile strength properties of Al-3,1Cu cast-alloy after T6-tempered treatment and evaluate its microstructural changes. This experiment was first performed by using an electric furnace to melt the metal alloy. The liquid metal was then poured into a rectangular metal mold, and the properties of the cast sample material were improved by using T6 heat treatment. Furthermore, the cast product was processed following acceptable tensile and impact tests standards. The results showed an increase in Brinell hardness and tensile strength after T6-Tempered treatment on the cast product. The observation of the microstructure also showed that the precipitate that grows evenly in α was finely dotted.

Keywords: Al-3,1Cu cast-alloy, T6-tempered, microstructure, hardness, tensile strength

INTRODUCTION

T6-tempered is a heat treatment that increases metals' hardness and tensile strength. It involves two stages, namely solution treatment and artificial aging. The performance of artificial aging is determined by two variables such as temperature and holding time, when this lasts for too long, an over-aged event that causes a decrease in the hardness and tensile strength will occur. Furthermore, the atoms are separated from the coarse particles and diffused through a matrix to form a solid homogeneous solution during solidification. Depending on the atomic dispersion properties and the microstructure roughness, the homogenization of a cast metal has a specific time range [1]. Strength-ductility and strength-index curves were also developed to investigate the effect of Cu. The results showed that the ductility decreases due to a general increase in the strength along with the addition of Cu [2].

The annealed and T6-tempered alloys contain second-phase particles that affect metal's strength [3]. In addition, the effect of varying tensile properties under both artificial over-aging (T7) and natural aging (T4) conditions in the composition of Al-Cu 206 cast alloy was investigated [4]. T6 heat treatment was applied to cast motorcycle wheel products and examined for fatigue crack growth. The result showed that T6-treatment significantly increased tensile strength and decreased the fatigue crack growth rate of the motorcycle wheel product. Meanwhile, the precipitate that appears prevents the occurrence of dislocations associated with the improvement of the mechanical properties [5]. Therefore, this research aims to evaluate hardness and tensile strength of Al-3,1Cu cast-alloy after T6-tempered treatment. The microstructural evolution before and after T6-tempered treatment on cast-product was also analyzed.

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EXPERIMENTAL PROCEDURES

A 2024 aluminum alloy was weighed and smelted in an electric furnace with a casting temperature of 738 °C. Furthermore, the molten metal was poured into a mold at a constant temperature of 220 °C for all conditions. A K-type thermocouple was used to measure the temperature, and a mold was used to print (manufacture) samples from the cast aluminum metal. The mold material was made from EMS/17330 carbon steel because it withstands molten aluminum (i.e., its melting point is higher than aluminum metal). These molds were used to print samples for impact, hardness, tensile and tests, as well as microstructures (the molds are shown in Figure 1). A Spectroscopy test was used to analyze the chemical composition of the cast alloy product.

Heat treatment is a combination of heating and cooling operations on metals or metal alloys in a solid-state over a certain time to achieve specific properties. The aluminum alloy was heated until only a single-phase occurred, after a while, it was continued with rapid cooling until there was no time to switch to another phase. If the material were left for a certain time, aging would occur. Furthermore, changes occurred in the form of second phase precipitations, which began with

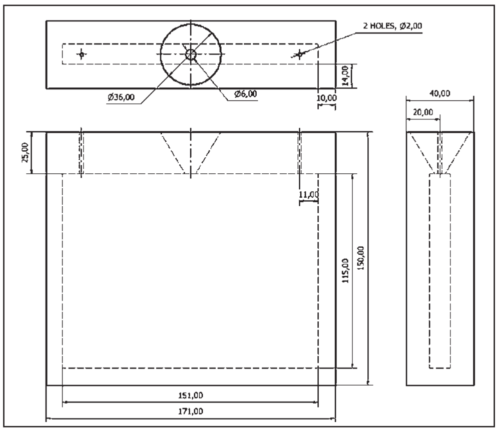

Figure 1 Rectangular mold for printing test samples.

the nucleation and emergence of atomic clusters at the beginning of the precipitation. These precipitates have increased in both strength and hardness. This is an age-hardening process called natural aging. Meanwhile, if it is heated again to a temperature below the solvus line after rapid cooling and held for a long time before being slowly cooled in the air, it is referred to as an artificial aging process. The tempering temperature of 500 °C was held for 2 hours before it was rapidly cooled by quenching in water media and then tempered again at 190 °C which was held for 5 hours before being cooled to room temperature [6], as shown in Figure 2.

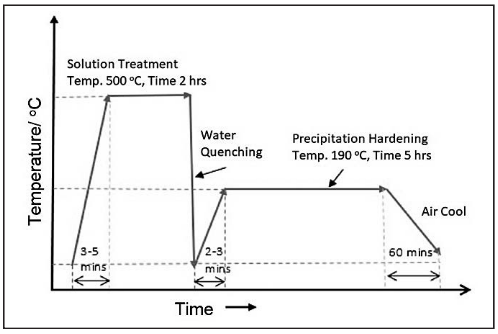

Figure 2 Design of T6-Tempered

A Brinell test was used to perform a hardness test to observe the difference in hardness value of aluminum cast products. A total of 10 repetition points were taken for each sample to obtain the average Brinell Hardness Number (BHN). Additionally, the impact test was used to measure hardness of aluminum cast products. The sample followed the ASTM standard: E23 with a V-notch and was tested using the Charpy method with a pendulum load of 1 kg. In this research, tensile test determines the ultimate tensile strength of the metal casting samples with and without T6-tempered treatment. The test was carried out with a Servopulser machine that produces the sample in accordance with the ASTM E8 standard. Optical microscopy and grain size analysis was also performed after etching with 1 ml HF, 1,5 ml HCl, 2,5 ml HNO_3, and 9,5 ml Aquades which were ground and polished. The Olympus optical microscope (OM) was used to observe the microstructure after etching.

RESULTS AND DISCUSSION

The Shimadzu EDX8000 Energy Dispersive X-EDX is the tool that was used in the chemical composition test carried out and the results are shown in Table 1.

Table 1 **Chemical composition/wt.%**

Cu	3,119	Zn	0,131
Mg	1,406	Ca	0,054
Mn	0,556	Ta	0,025
Fe	0,166	Cr	0,011
Si	0,150	Al	Bal.

The chemical composition results showed that, besides aluminum, copper (Cu) was most dominant in the alloy material. Therefore, an impact test was performed to determine the amount of energy the material absorb when subjected to a shock load. The Charpy method used is a test in which the sample was placed on the pedestal in a horizontal position, and the direction of loading was opposite the notch. The energy absorbed by Al-3,1Cu cast-alloy was 0,049 J/mm^2. This differed slightly from the impact hardness in Al-Si-Cu recycled metal experiment tested using the Charpy method that resulted in the energy of 1,7 J/mm^2 [7]. This was because Si was greatly affected by the impact toughness.

For Brinell hardness, a load of 613 kg with a spherical indenter of diameter 2,5 mm was used, and the diameter of the indenter stamp was observed using an optical microscope. The hardness values with and without T6-tempered are shown in Figure 3a. The non-treated Brinell hardness was 99,92 BHN, while Brinell hardness value increased to 129,61 BHN after T6-tempered treatment. The tensile strength of Al-3,1 cast-alloy was obtained at 73,53 MPa untreated conditions and increased to 83,96 MPa after T6-tempered treatment (Figure 3b).

The microstructure was observed on the sample's surface with an optical microscope. The results showed that T6-tempered affected Al-3,1Cu cast-alloy product and microstructure, as shown in Figure 4 at two magnifications. The heating of Al-3,1Cu metal alloy in an oven above the solvus line at 500 °C for 2 hours dissolved all Cu elements in α. During rapid cooling (quenching), Cu does not escape from α.

Furthermore, at room temperature, the structure was still in the form of an α single-phase solid solution and

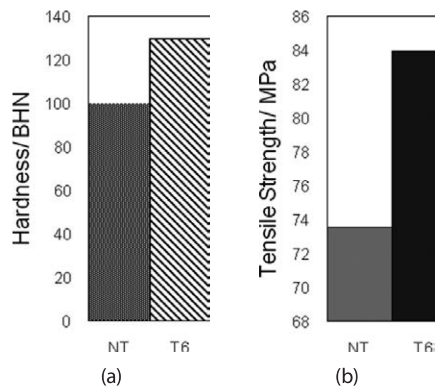

Figure 3 (a) Brinell hardness and(b) tensile strength in non-treated (NT) samples vs. T6.

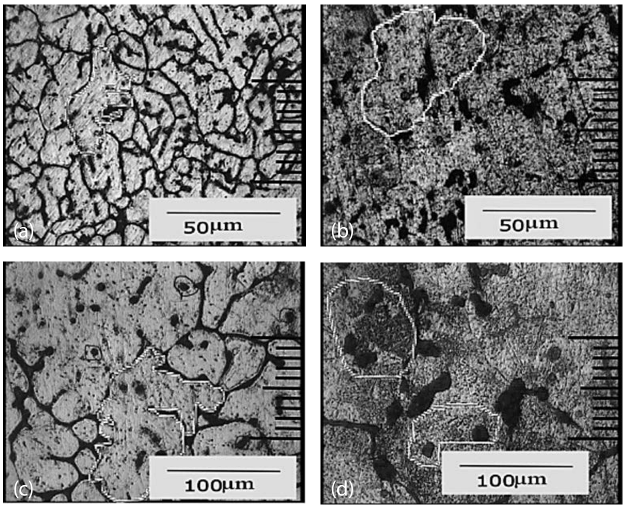

Figure 4 Microstructure with two magnifications: (a) 50x NT magnification, (b) 50x T6 magnification, (c) 100x NT magnification, and (d) 100x T6 magnification.

the properties including still soft and slightly ductile did not change. In this situation, the solution was supersaturated because it contained a solute that exceeded its specific limit for that temperature. In addition, artificial aging treatment changed hardness and tensile strength and became harder and stronger. This strengthening was brought about by the emergence of $CuAl_2$ particles (θ phase) which precipitated in α crystal. This precipitate caused stress on the crystal lattice as the precipitates were evenly distributed in the crystal lattice (Figures 4b and 4d). Therefore, the entire lattice became tense, increasing hardness and strength. The phase of θ-Al_2Cu was readily soluble in the matrix since not all particles were easily soluble during solidification [1]. Natural aging (T4) and artificial aging (T6) generally increased the tensile strength due to the appearance of Al_2Cu particles dispersed in the granules for T4-treatment conditions, which accumulated at the grain edges for T6 [8]. The increase in mechanical properties was consistent with modifying the microstructure for the interrupted aged material. The precipitate formed in the microstructure looked finer, denser, more densely distributed, and was present in greater numbers [9]. The evolution of the microstructure during T6-treatment led to the dissolution of the atoms at the treatment temperature. Also, the solid solution was supersaturated at room temperature leading to the formation of a precipitate due to artificial aging [10].

The illustrations of microstructure above show that the untreated samples had relatively smaller grain sizes, with grain boundaries marked with red lines. Based on Figure 4, each sample exhibits porosity defects. The defective porosity is visible in the figure and marked with a blue circle. Porosity defects caused by melting aluminum metal at high temperatures are easily contaminated with hydrogen gas. The higher the temperature of molten aluminum, the more hydrogen gas is trapped in the molten metal. This increasingly causes porosity defects in cast products. Additionally, in T6-tempered sample, the precipitation is indicated by the appearance of fine black dots scattered in α.

CONCLUSIONS

The effect of T6-tempered on hardness and tensile strength as well as observations of microstructural changes, were evaluated on Al-3,1Cu cast-alloy metal. Furthermore, the amount of energy absorbed by Al-3,1Cu cast-alloy was 0,049 J/mm^2. After T6-tempered treatment on Al-3,1Cu cast-alloy, hardness increased by about 77 %, while the tensile strength was increased by about 84 %. In general, T6-tempered increased hardness and tensile strength, which is indicated by the appearance of precipitates in the form of fine dots evenly distributed in α matrix.

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