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The Effect of Sample Placement in the Furnace during the Heat Treatment Process of 7075-T6 Aluminum Alloy on Microstructure, Hardness, and Electrical Conductivity

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Abstract. This paper reports the effects of sample placement during the heat treatment on the microstructural morphology and mechanical properties of 7075 Al alloy such as hardness value and electrical conductivity. The material was in the formed of Al alloy sheets where samples were machined into a square with dimensions of 1.5 x 1.5 inch. The 7075-T0 Al alloy as samples were given heat treatment by precipitation hardening (aging) at temperature 120°C for 24 hours, so it becomes 7075-T6 Al alloy. Samples were subjected to some mechanical tests and the morphology of the resulting microstructures were characterized by optical microscopy. The variable was the placement of samples in the furnace which is based on the differences of the 7075 Al alloy properties, from aging process T0 to T6, in microstructure, hardness value and electrical conductivity even though the tools, materials and treatment given are the same. The study showed that as far as the sample from the furnace door, hardness values were increased while the electrical conductivity decreased and it was proportional to the dispersion of precipitates that occurred.

Keywords: 7075 Aluminum Alloy, Heat Treatment, Age Hardening, Microstructure, Mechanical Properties

INTRODUCTION

Aluminum is widely used in industry nowadays, known as one of the three most abundant metals on earth after iron and copper, so it is easy to obtain and has a cheap price. Aluminum and its alloys are used in a variety of cast and wrought forms and conditions of heat treatment. The demand for aluminum grows rapidly because of its unique combination of properties which makes it becomes one of the most versatile of engineering and construction material. The optimum properties of aluminum are achieved by alloying additions and heat treatments. This promotes the formation of small hard precipitates which interfere with the motion of dislocations and improve its mechanical properties such as strength and hardness [1].

For aircraft industry needs, 7075 Al alloy is commonly used as the structural parts of fuselage because of its attractive comprehensive properties such as low density, high strength, ductility, toughness and resistance to fatigue [2]. It contains Zinc (Zn) and Magnesium (Mg) as the major alloying elements to increase the strength, hardness, and toughness of the materials. Staley [3] has found that three types of particles are present in 7xxx series alloys (fine strengthening precipitate particles, dispersoid particles and constituent particles). The fine precipitates including MgZn2 and Al2Mg3Zn3 are responsible for the high strength of 7xxx series alloys. The dispersoid particles including Al12Mg2Cr and Al18Mg3Cr2 are soluble only in liquid, and could play an important role in grain and sub-grain boundaries pinning to make the alloys difficult to recrystallize. In the T6 temper, MgZn2 precipitates are dominant. They are distributed very homogeneously with a size of 2-5 nm [4]. Du et al. [5] reported that the precipitates spots are mainly from η′ (metastable $MgZn_2$) and a small amount of stable η ($MgZn_2$) by comparing to the diffraction patterns of precipitates in other Al–Zn– Mg(–Cu) alloys.

The effects of samples placement is discussed. Hardness, electrical conductivity, and microstructures are investigated. Garuda Maintenance Facility (GMF AeroAsia) as the biggest aircraft maintenance company in Asia, had a problem that was the differences in hardness value and electrical conductivity in precipitation treatment 7075 Al alloy from T0 to T6, so it becomes a concern that must be investigated. However, this concern is still within acceptance limits according to Boeing Aircraft Company (BAC) Standard. The objectives of the current study are to investigate the differences mechanical properties such as hardness value and electrical conductivity of 7075 Al alloy after the aging process and the microstructural morphology when given the same treatment, tools, and materials.

MATERIALS AND METHODS

Materials. The material used in this study was in the formed of Al alloy sheets with dimensions of 1.5 x 1.5 inch per samples and 0.071 inch of thickness. The samples segmented into five samples per test which is Hardness test, Eddy current test, and Optical metallography. Some samples were also sectioned for metallographic test to meet the requirements. The present investigation was carried out on 7075 Al alloy composition that tested using Field Emission Scanning Electron Microscope (FESEM) shown in TABLE 1.

TABLE 1. Chemical Composition of 7075 Aluminum Alloy

Element	Al	Zn	Mg	Cu	Fe	Si
Wt%	90.34	4.87	3.10	1.24	0.30	0.17

Heat Treatment. Two stages of heat treatments were carried out namely solution treatment and precipitation treatment on the samples using SAKAI furnace. The schematic temperature profile of a T6 heat treatment shown in FIGURE 1. Solution treatment was carried out by heating the already machined samples to 495 °C, soaking them at this temperature for 45 minutes with the placement in the furnace as shown in FIGURE 2 which has five places of samples placement and then followed by rapid quenching in water. These quenched samples were then subjected to a precipitation treatment (age hardening). Precipitation treatment was carried out by tempering the already solution treated samples at a temperature of 120 °C for 24 hours (artificial aging) followed by air cooling to room temperature. These procedures are according to BAC 5602 [6].

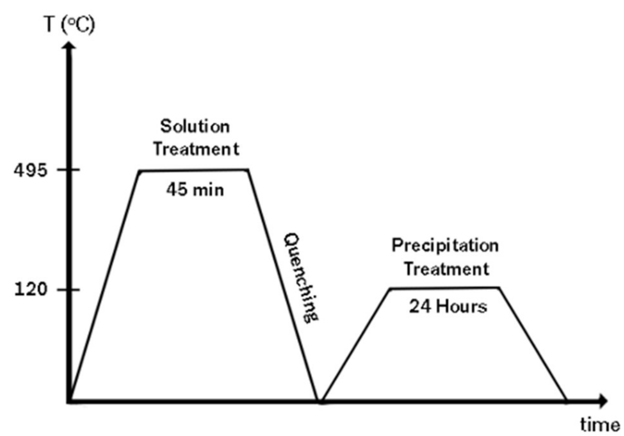

FIGURE 1. Schematic temperature profile of a T6 heat treatment

Hardness Test. The control and the heat-treated samples were subjected to the Rockwell hardness test using Mitutoyo HR-400 and 1/16-inch steel ball as indenter with 100 kgf total test force (Rockwell B) according to ASTM E18. The samples were tested at five spots each samples to have an average hardness values, so the data obtained will be more valid. The average values from five test samples are reported here.

Eddy Current Test. The control and the heat-treated samples were subjected to the Eddy current test using Sigma-test EC.2068 in units of %IACS (International Annealed Copper Standard). Same as the hardness test, this test measure from five spots each samples to find the average values of electrical conductivity, so the data obtained will be more valid. The average values from five test samples are reported here.

Optical Metallography. The heat-treated samples were taken through the process of metallography: sectioning, mounting, grinding, polishing and etching. The morphology of the microstructures were then characterized by using Olympus BX53M optical microscope. After etching in a mixed solution of 1 ml HF, 3 ml HCl, 5 ml HNO3 and 191 ml H2O (Keller's reagent) at ambient temperature for about 5-60 s. And then the amount of precipitates was characterized by using ImageJ Software to see the dispersion of precipitates.

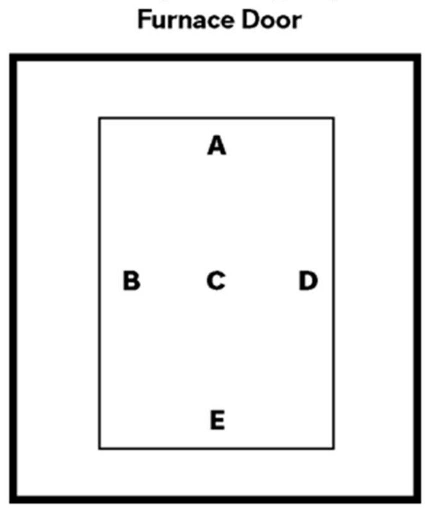

FIGURE 2. Illustration of Sample Placement in the Furnace

RESULTS AND DISCUSSIONS

Samples of 7075-T6 Al alloy which have been etched will be seen in the microstructure using an optical microscopy with 200x magnification. FIGURE 3 show the microstructure of the sample A, sample B, sample C, sample D and sample E respectively. The results of the five microstructure drawings are almost similar, where it shows the finely dispersed precipitate of η′-MgZn2 and η-MgZn2 in aluminum matrix. The presence of dispersed precipitate of MgZn2 correspond with the result of Salamci [7] and Du et al. [5] who discovered that aging heat treatment of Al-Zn-Mg-Cu alloys lead to the formation of MgZn2 intermetallic phase in the structure. In their study on evolution of eutectic structures in Al-Zn-Mg-Cu alloys Fan et al. [8], reported that several coarse intermetallic phases such as MgZn2, Al2Mg3Zn3, Al2CuMg, Al2Cu, Al7Cu2Fe, Al13Fe4 and Mg2Si can be formed below the solidus line during solidification of as-cast 7000 series of aluminum alloys as a result of solute redistribution of metals.

From the results of the optical metallography there are differences in the microstructure, the farther sample from the furnace door, the more precipitates in the Al phase formed. The microstructure consists of elongated and fibroid grains with some dispersed particles, indicating the alloy has not recrystallized even after T6 heat treatment. Fine precipitates were evident in original grain interiors and in subgrain boundaries [16, 17]. It can be seen in FIGURE 3(a) that the number of precipitates

formed is not as much as in FIGURE 3(e). However, sample E was over etched due to the immersion time about 60 s. Over Etching does not really affect the observation, just a little difficult to identify the microstructure. The dispersion of precipitates shown in FIGURE 4 as a percentage. Sample A with 1.987%, sample B with 1.738%, sample C with 1.198%, sample D with 1.938%, and sample E with 2.074%.

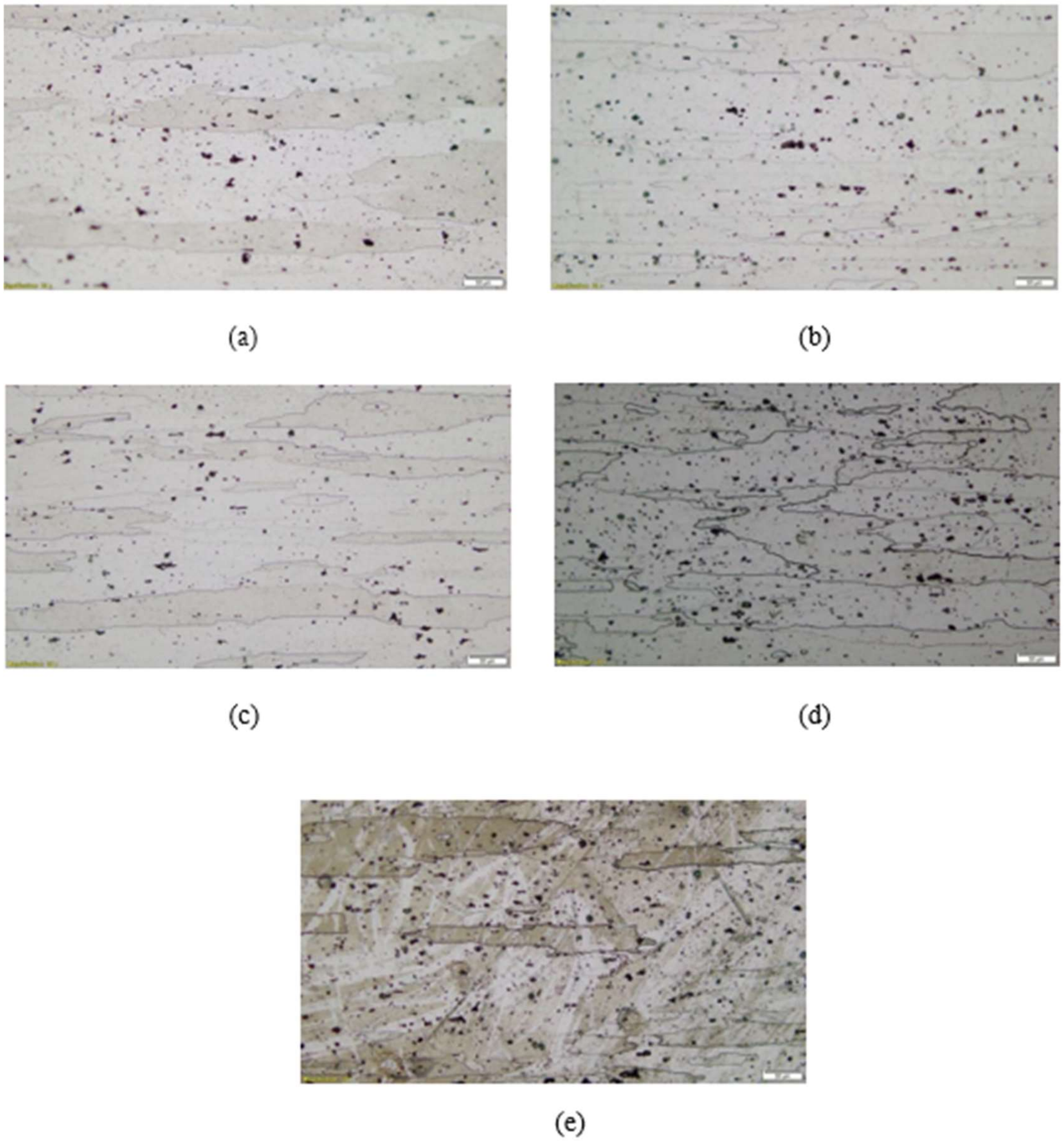

FIGURE 3. Microstructure of 7075-T6 Al alloy with variation of sample placement in the furnace: (a) sample A; (b) sample B; (c) sample C; (d) sample D and (e) sample E.

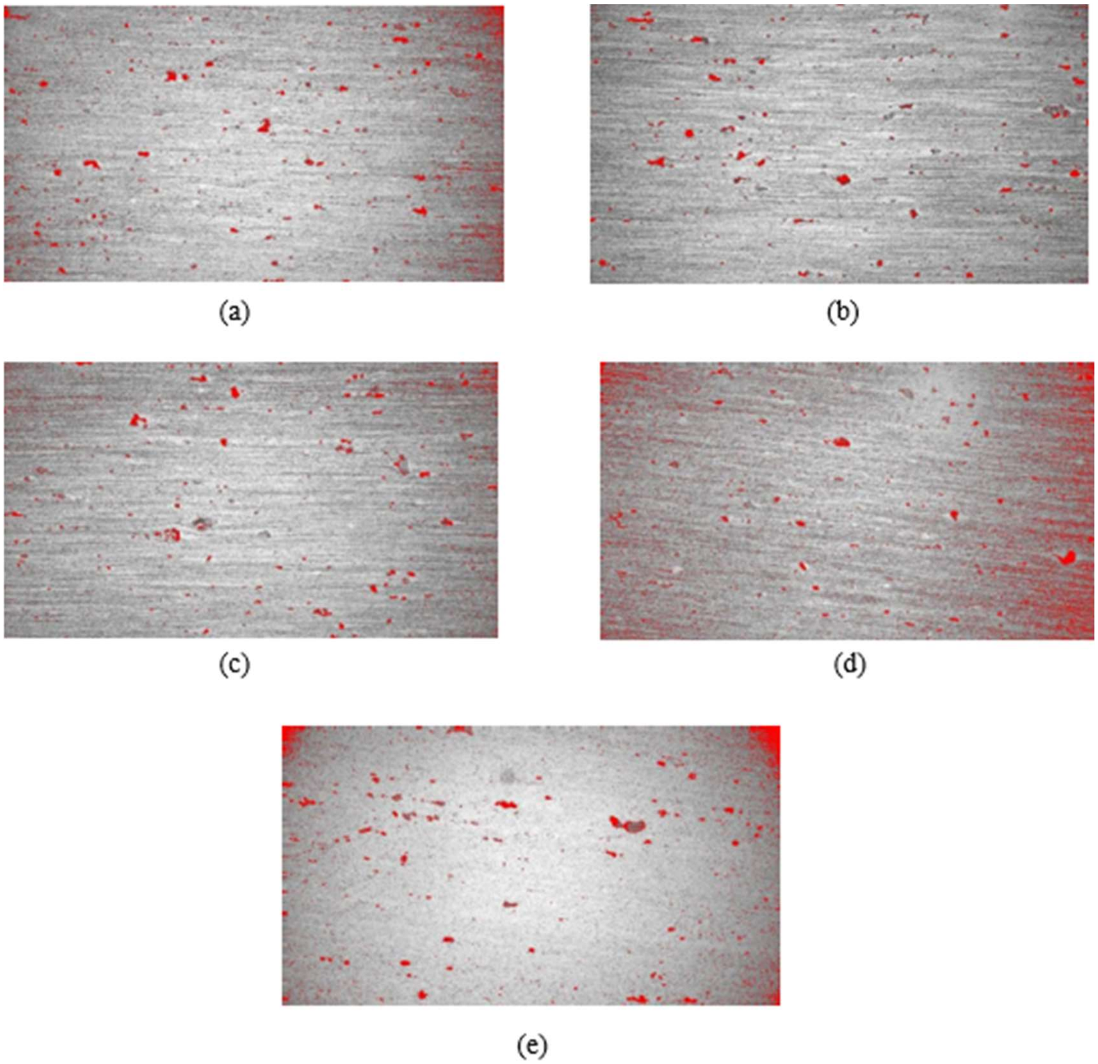

FIGURE 4. The Dispersion of Precipitates: (a) sample A; (b) sample B; (c) sample C; (d) sample D and (e) sample E.

The control and the heat-treated samples were subjected to the Rockwell hardness test using Rockwell B hardness scale (HRB) and the result shown in TABLE 2. From the results of hardness test, sample E has the highest average hardness value followed by sample D, sample A, sample B and sample C. The results of the hardness test were proportional to the microstructure morphology. The growing precipitate due to aging will affect the hardness value of aluminum [9]. The results are still in the range of acceptance limits according to BAC 5946 [10].

The phenomenon of increasing mechanical properties, in this case the hardness of aluminum alloy which have been done an aging process, occurs because the formation of precipitates often leads to the formation of dislocations in the crystal lattice of the solvent atom. Dislocations can be formed if the atomic size of the precipitate is different from the size of the atom of the solvent, if the size of the precipitate is smaller, it will cause tensile stress, and if the size is greater, the precipitate particles will cause compressive stress, the dislocation will also cause a force field. Dislocation will be like being drawn towards the precipitate [11]. Whereas on the other hand, the dislocation will be impeded by precipitate particles, so that the more precipitate is formed, the mechanical properties such as hardness and strength of the specimen will increase. [12, 13].

TABLE 2. Results of Hardness Test

Spot	**Hardness Rockwell B (HRB)**				
	A	**B**	**C**	**D**	**E**
1	80.1	82.3	84.2	84.4	85.2
2	82.9	84.4	83.8	84.5	85.7
3	82.2	82.3	82.2	81.6	85.3
4	84.8	82.1	81.7	84.1	84
5	83.9	82.5	80.7	85.9	81.6
Average	**82.78**	**82.72**	**82.52**	**84.1**	**84.36**

The aging process also affects the electrical conductivity value [14]. 7075-T6 Al alloy samples were tested for electrical conductivity by Eddy Current Test at several spots then averaged. These results are presented in TABLE 3. From the results, there has been a tendency for the electrical conductivity value to decrease along with as far as the sample from the furnace door. Sample A has the highest electrical conductivity value of 33.42 %IACS followed by sample C with 33.32 %IACS, sample B and D have almost the same electrical conductivity values, with 32.84% IACS and 32.82% IACS respectively and the lowest electrical conductivity value was sample E.

In aircraft industry, the lower electrical conductivity value, the more it is actually required as it still within the range of acceptance limit according to BAC 5946 [10]. The relationship between hardness and strength with electrical conductivity was non-linear [15]. It can be said that the value of the hardness increases while the electrical conductivity decreases. Salazar-Guapuriche et al. [15] reported that all known metallic additions to Al reduce its electrical conductivity, and these additions in solid solution depress the conductivity to a greater extent than when out of solution. The electrical conductivity is therefore largely determined by the amount of alloying elements in the solid solution and the amount and nature of precipitates.

TABLE 3. Results of Eddy Current Test

Spot	**Electrical Conductivity (%IACS)**				
	A	**B**	**C**	**D**	**E**
1	33.45	32.86	33.40	32.53	32.64
2	33.38	32.86	33.29	32.83	32.72
3	33.36	32.81	33.28	32.93	32.79
4	33.45	32.83	33.33	32.90	32.72
5	33.47	32.83	33.31	32.90	32.74
Average	**33.42**	**32.84**	**33.32**	**32.82**	**32.72**

CONCLUSIONS

From this study, there are the effects of samples placement during heat treatment 7075-T6 Al alloy on the hardness, electrical conductivity, and microstructure. A linear correlation has been established between the microstructure and hardness of 7075-T6 Al alloy. Hardness was increased with increasing number of precipitates in the microstructure as far as the sample from the furnace door. The highest hardness value in this experiment is sample E. Later these precipitates can restrain and impede the movement of dislocations so that hardness can increased. There is a non-linear correlation of electrical conductivity, hardness and microstructure. The electrical conductivity value decreased with increasing hardness value and number of precipitates in the microstructure.

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