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EFFECT OF DIFFERENT COOLING RATE AFTER SOLUTION TREATMENT ON THE AGING BEHAVIOR OF 7050ALUMINUM ALLOYS

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ABSTRACT

Effect of heat treatment on hardness change of 7050 aluminum alloy has been studied. Solution treatment for 2 hours at 475◦C followed by different cooling rates (water, oil and brain quenching). Aging behavior of 7050 aluminum alloy were investigated by microstructure evolution and hardness tests conducted at different cooling rates. Large differences in the hardening are observed with different cooling rates and aging temperature and time. Brain quenched specimens shows the maximum hardness after 40min aging at 165◦C. The microscopic observation of these heat treated alloy were investigated and showed interesting difference in precipitated phases.

KEYWORDS: 7050 Aluminum Alloys, Aging Treatment, Cooling Rate, Microstructure, Precipitation Hardening

INTRODUCTION

For over fifty years, aluminum ranks at second to iron and steel in the metal market. The demand of aluminum growths rapidly because it is attributed to unique combination of properties which makes it become one of the most versatile of engineering and construction material [1, 2].

Al 7xxx series alloys based on the Al-Zn-Mg-Cu system are widely used in the aircraft and automotive industries for structural components because of its exceptionally high strength to weight ratio [1-4]. In order to cater the increasing demand of improved and enhanced performance of these alloys in aerospace and automobile sector, it has become a challenging task among material scientists to devise a new processing route for enhancing mechanical properties of these materials further [3-6]. The high strength of the 7xxx series alloys is due to the fine and uniformly distributed precipitates in the matrix which precipitate during the artificial aging. The usual precipitation sequence of the 7xxx series Al alloys can be summarized as: SSSS α→ GP-zones→ β''→ β' → β ($MgZn_2$). Where SSSS α represents supersaturated solid solution, GP-zones are Guinier Preston zones**.** Some authors consider GP zone as GP1 zone while the β'' is called GP2 zone[2-5,7,8]. The most effective hardening precipitate for this type of materials is β'' phase**,** β' is metastable hardening precipitate, while β (MgZn2) is stable phase. Early experimental studies of precipitate hardening were interpreted in different ways [5]. Some studies reported that G.P. zones observed only at low temperature, and assumed that ή phase is formed directly from the solid solution at temperatures above 100-120˚C. On the other hand, some other studies proposed that GP-zones serve as nuclei for β" in a two stage aging process, whereas other researchers suggested that β'' is formed from stable clusters [2,3,7,8]. The high strength is obtained by formation of fine precipitates due to decomposition of super-saturated solid solution [9-12]. These fine precipitates are generally developed by homogeneous nucleation during aging treatments, so many investigations were focused on this topic [13-16]. In order to attain good aging hardening effect, highly super-saturated solid solution is essential. As these alloys are quenching sensitive, rapid quenching is often desirable. Few studies have been carried out on the effect of heterogeneous precipitation on the properties of these alloys by different quenching method, and time temperature properties diagrams have been gotten[17-19]. In order to improve the properties of 7xxx Al alloy it often requires to modify alloy composition, or achieve the required microstructures by heat treatment processes. In this study three different cooling rates have been investigated after solution treatment of 7050 Al alloy. Aging behavior at different temperatures were carried out for different aging times. Hardening of the alloy discussed and analyzed using hardness measurements and microscopic investigations.

EXPERIMENTAL WORK

The present study was carried out on the 25mm diameter hot rolled 7050 aluminum alloy rod with chemical composition of Al-5.9% Zn-2.3% Mg-2.4% Cu-0.12% Zr-0.04% Fe-0.04% Si (wt.%). The rods were solution treated in air furnace at 475◦C for 2hs followed by quenching in room temperature water, oil and brain. The solution treated samples were aged at 120 ◦C, 165◦C, 185◦C and 205◦C for different times up to 6hs. The evolution of microstructure was monitored by hardness measurements using HVS-1000 Digital Display Microhardness Tester. Five points were tested in each specimen to obtain a reliable average value. Microscopic observation were carried out on the solution treated and aged samples using Meiji-MX8500 optical microscope. The samples for metallographic observation were prepared through a conventional mechanical polishing and followed by etching in Keller reagent (2mL HF, 3mL HCl, 5mL HNO_3 and 190mL H_2O).

RESULTS AND DISSECTIONS

Hardness Changes of Water Quenched 7050Al Alloy

Aging treatment for the water quenched 7050Al alloy was carried out at different temperatures of 120, 165, 185 and 205˚C for different times up to 6hrs, the hardness changes with aging shown in **Figure 1**. At temperature 120˚C, the hardness increase to about 135Hv after 30min aging. With farther aging time the hardness increased to maximum of 160Hv after long time of 4hrs, then decreased. With increasing temperature to 165˚C, the hardness of the alloy reveals the highest value of 145Hv after short aging time of 20min. Increasing aging temperature to 185˚C shows lower hardness to reach maximum of 125Hv after longer time of 40 min. Farther increase of aging temperature to 205˚C slightly increase the hardness of the alloy, this due to over-aging.

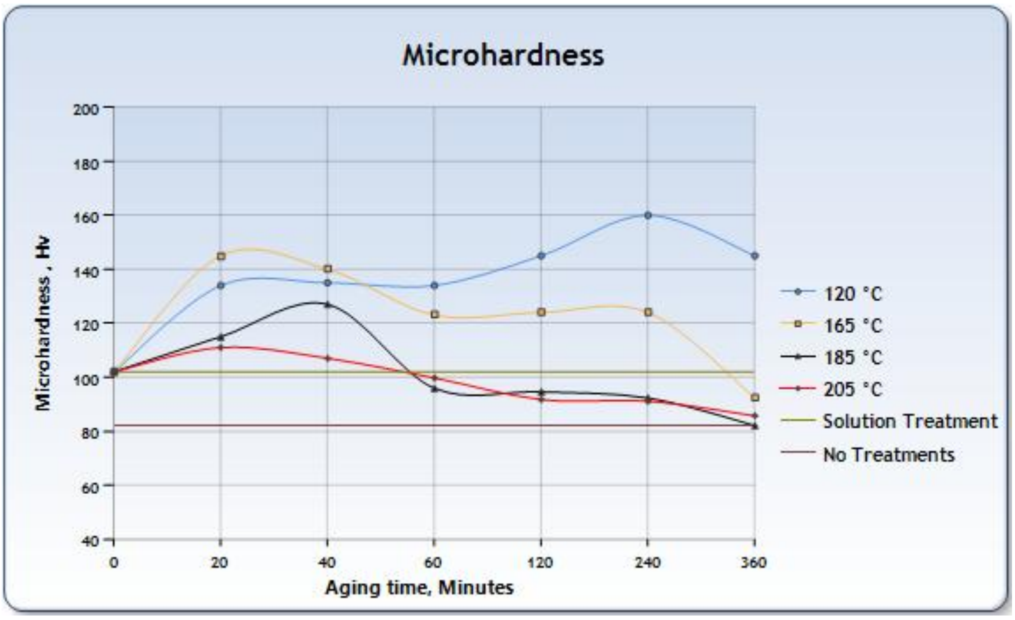

Figure 1: Effect of Aging Time and Temperature on the Hardness Changes of 7050 Al Alloy Quenched in Water

Microstructure of Water Quenched 7050Al Alloy

Micrograph of as received and water quenched 7050Al alloy shown in **Figure 2-a** and **b** respectively. As received specimen shows equiaxed structure, while water quenched specimen after solution treatment for 2hrs at 475˚C reveals network of precipitates. **Figure 3-a** shows precipitates of β" (responsible phase for hardening the alloy), with farther aging to 60min the precipitate appears as network at the grain boundary as shown in **Figure 3-b.** Increasing aging temperature to 165˚C reveals high hardness after short time of 20min, **see Figure 1.**

This result could be explained from micrograph shown in **Figure 4-a** where large precipitates of β" revealed clearly (marked by arrow). With farther aging time, the precipitates changed to appear along grain boundary (see **Figure 4-b**) leading to hardness decrease. Hardness of water quenched 7050 Al alloy slightly increased to 125Hv after 40min aging at 185˚C. This result could be explained as the β" did not appear after aging at this temperature, thus GP zone change directly to β' then β stable phase as shown in **Figure 5-a** and **5-b** respectively. Farther aging temperature of 205˚C slightly increased the hardness due to overaging of the alloy, see **Figure 1**.

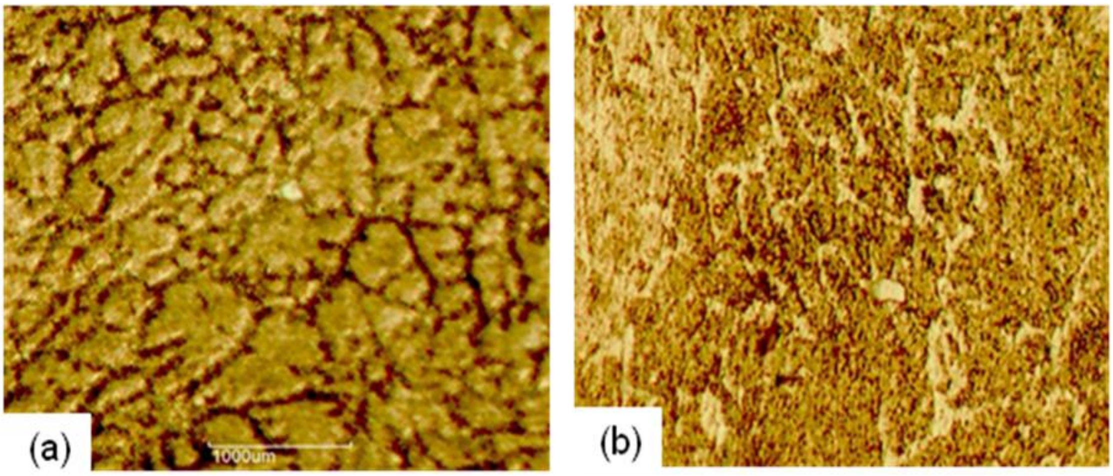

Figure 2: Micrograph of 7050 Al Alloy, (a) As Received, (b) Solution Treated Followed by Water Quenching, X200

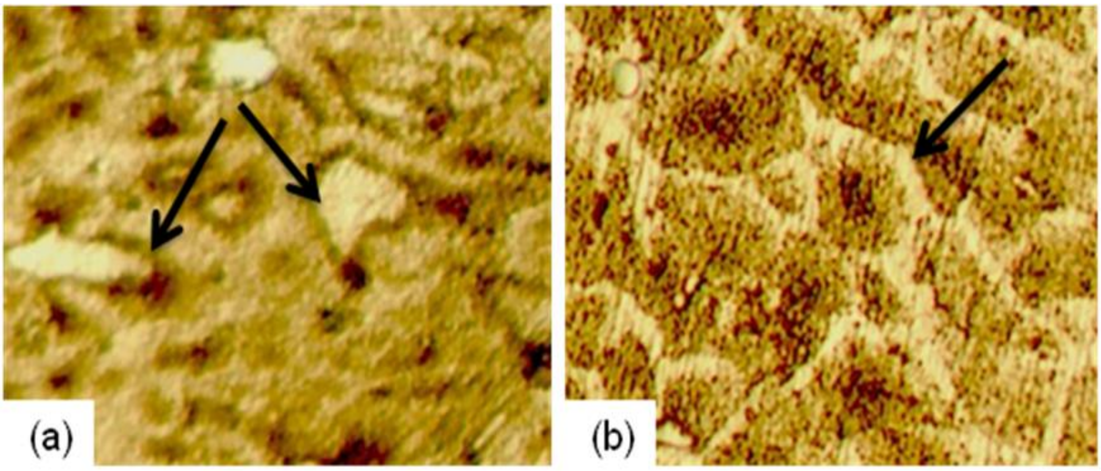

Figure 3: Micrograph of Water Quenched 7050 Al Alloy, (a) Aging at 120˚C for 20min, (b) Aging at 120˚C for 60min, X200

Hardness Changes of Oil Quenched 7050Al Alloy

Aging treatment for the oil quenched 7050Al alloy was carried out at different temperatures of 120, 165, 185 and 205˚C for different times up to 6hrs, the hardness changes with aging shown in **Figure 6**. At temperature of 120˚C, the hardness increase to about 150Hv after 30min aging; the hardness decreased with farther aging time to 60min.

With increasing temperature to 165˚C, the hardness of the alloy reveals maximum value of 135Hv after aging for 30min. Increasing aging temperature to 185˚C shows maximum hardness of 128Hv after 20 min aging then decreased. Farther increase of aging temperature to 205˚C increase the hardness of the alloy to maximum of 140Hv after 35min.

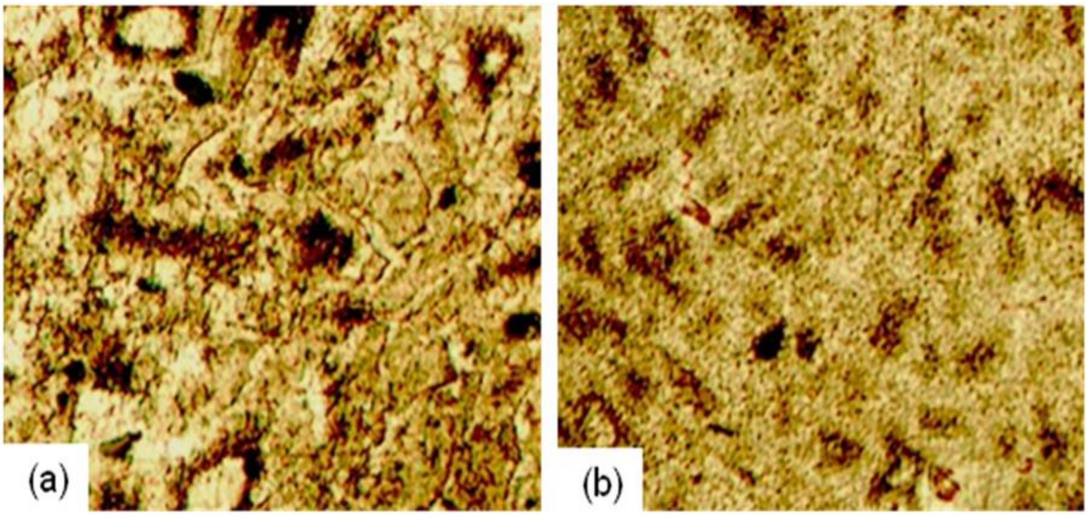

Figure 4: Micrograph of Water Quenched 7050 Al Alloy, (a) Aging at 165˚C for 40min, (b) Aging at 165˚C for 60min, X200

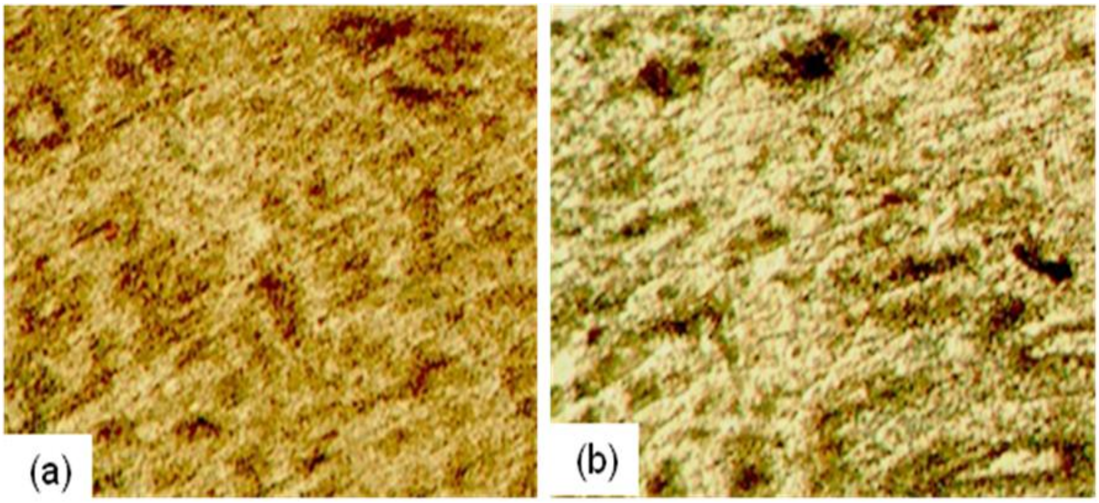

Figure 5: Micrograph of Water Quenched 7050 Al Alloy, (a) Aging at 185˚C for 40min, (b) Aging at 185˚C for 60min, X200

Microstructure of Oil Quenched 7050Al Alloy

The microstructure of oil quenched and aged alloy at 120˚C for different aging times shown in **Figure 7**. Oil quenched micrograph shows large grain structure with some precipitates at the grain boundaries, see **Figure 7-a.** After 20min aging, fine precipitates of β" revealed as shown in **Figure 7-b,** this in a good agreement with hardness increase in **Figure 6.** Increasing aging time to 40min leads to change of the precipitated phases to appear along the grain boundary as shown in **Figure 7-c,** this could be β" and some β' phases**.** Farther increase of aging time to 60min reveals course precipitates of β' phases shown in **Figure 7-d,** this explain the hardness decrease after this time. Hardening of the oil quenched 7050 Al alloy decreased with increasing aging time to 165˚C as shown in **Figure 6**.

This could be explained from the microstructure shown in **Figure 8**. Continues network of precipitate revealed along the grain boundary in **Figure 8-a**, to be wider in **Figure 8-b** after longer aging time of 40min. Farther decrease of hardness revealed as the aging temperature increase to 185˚C as shown in **Figure 6**.

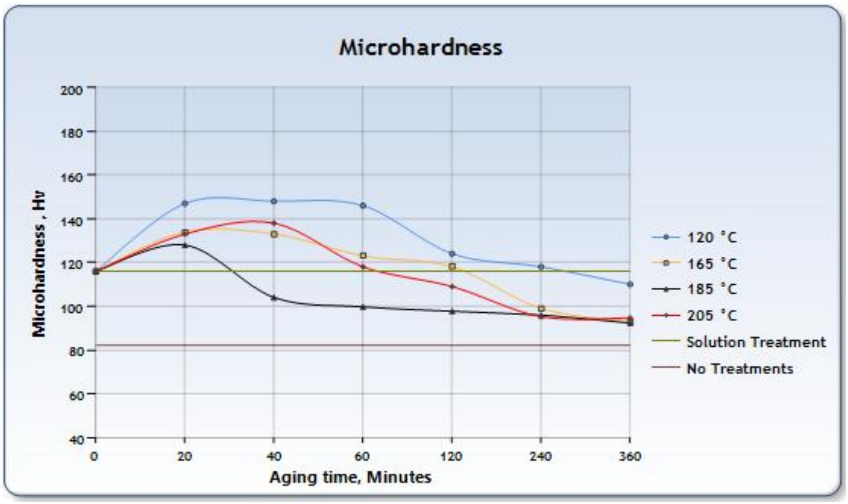

Figure 6: Effect of Aging Time and Temperature on the Hardness Changes of 7050 Al Alloy Quenched in Oil

Increasing aging temperature to 205 leads to an increase in hardness to 140Hv after 35min. **Figure 9-a** and **9-b** shows micrograph of specimens aged at 185˚C for 20min and specimen aged at 205˚C for 40min respectively.

Hardness Changes of Brain Quenched 7050Al Alloy

Aging treatment for the brain quenched 7050Al alloy was carried out at different temperatures of 120, 165, 185 and 205˚C for different times up to 6hrs, the hardness changes with aging shown in **Figure 10**. Brain quenching revealed the maximum hardening of the 7050 Al alloy compared with water and oil quenching. The lowest hardening of the alloy after brain quenching revealed at temperature of 120˚C. With increasing temperature to 165˚C, the hardness of the alloy reveals its maximum value of 168Hv after aging time of 40min. Increasing aging temperature to 185 ˚C shows decrease in maximum hardness of about 140Hv after 30 min aging. Farther aging temperature of 205˚C reveals two peaks after 20 and 60min with 140 and 160Hv respectively.

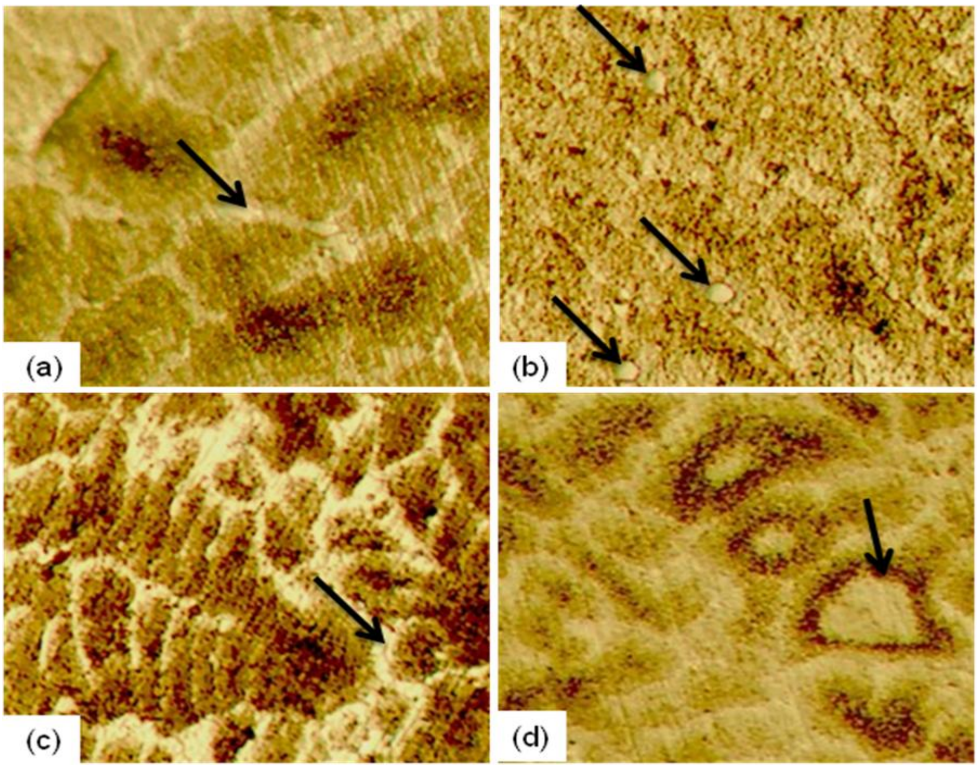

Figure 7: Micrograph Oil Quenched 7050 Al Alloy, (a) Solution Treated, (b) Aging at 120˚C for 20min, (c) Ageing at 120˚C for 40min and (d) Aging at 120˚C for 60 min, X200

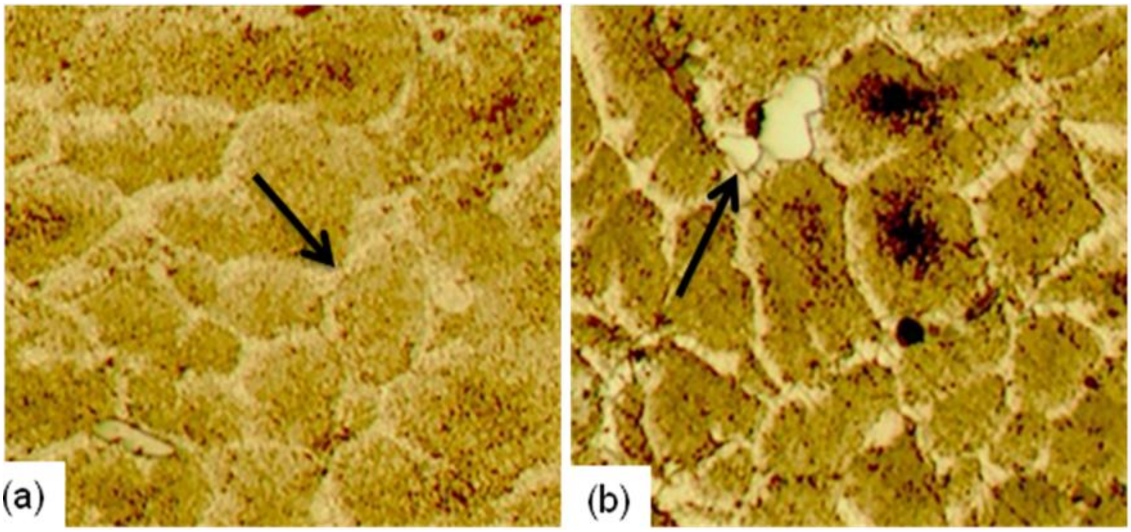

Figure 8: Micrograph of Oil Quenched 7050 Al Alloy, (a) Aging at 165˚C for 20min, (b) Aging at 165˚C for 40min, X200

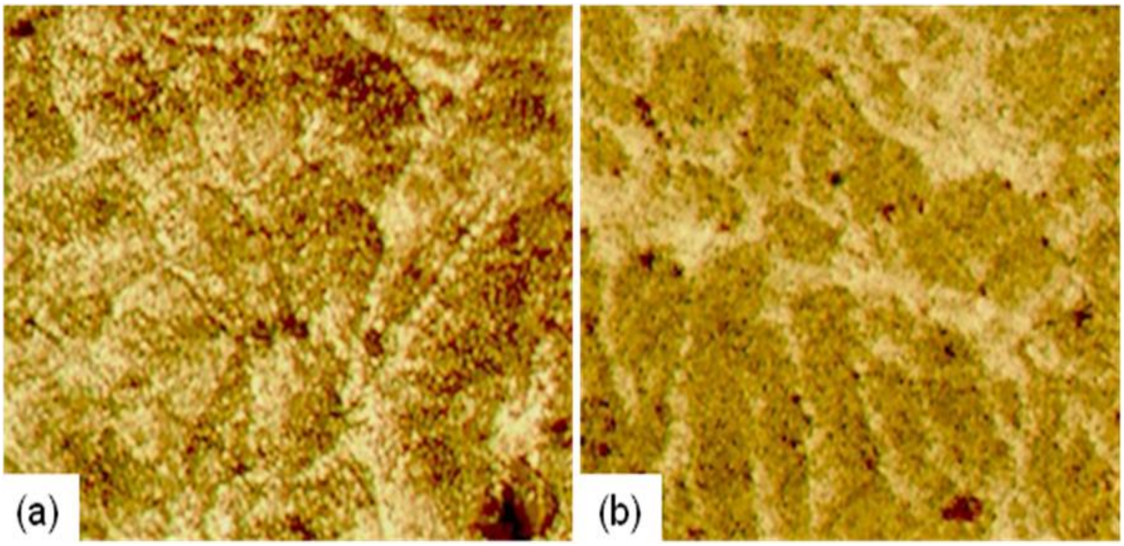

Figure 9: Micrograph of Oil Quenched 7050 Al Alloy, (a) Aging at 185˚C for 40min, (b) Aging at 205˚C for 20min, X200

Microstructure of Oil Quenched 7050Al Alloy

The microstructure of brain quenched and aged alloy at 120˚C for different aging times shown in **Figure 11**. After 20min aging, β'' elongated precipitates revealed as shown in **Figure 11-a.** Increasing aging time to 40min leads to change of the precipitated phases to appear bigger as shown in **Figure 11-b,** this could be β'phases**.** this explain the hardness decrease after this time. Hardening of the brain quenched 7050 Al alloy remarkably increased to maximum of 168Hv after aging for 40min at temperature of 165˚C as shown in **Figure 10**. This could be explained from the microstructure shown in **Figure 12**. Two types of precipitates revealed shown as arrowhead and doted arrowhead in **Figure 12-b**.

These precipitates could be β'' and ή**,** respectively**.** Hardness of the brain quenched alloy decreased as the aging temperature increase to 185˚C as shown in **Figure 10**. At this temperature the hardness increased to 140Hv after 30min, this due to β'' precipitates shown in **Figure 13-a** and **13-b.** Increasing aging temperature to 205 leads to an increase in hardness to 140Hv after 20min aging then increased again to 160Hv after 60min aging. **Figure 13-c** shows micrograph of specimens aged at 205˚C for 60min, large area of precipitates revealed, these precipitates could be the reason of hardness increase.

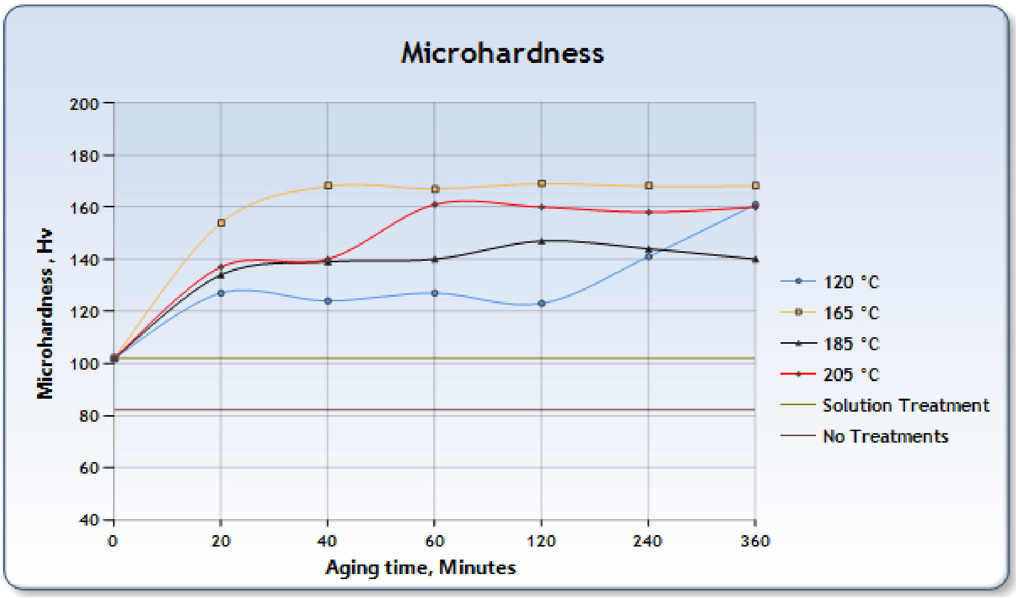

Figure 10: Effect of Aging Time and Temperature on the Hardness Changes of 7050 Al Alloy Quenched in Brine

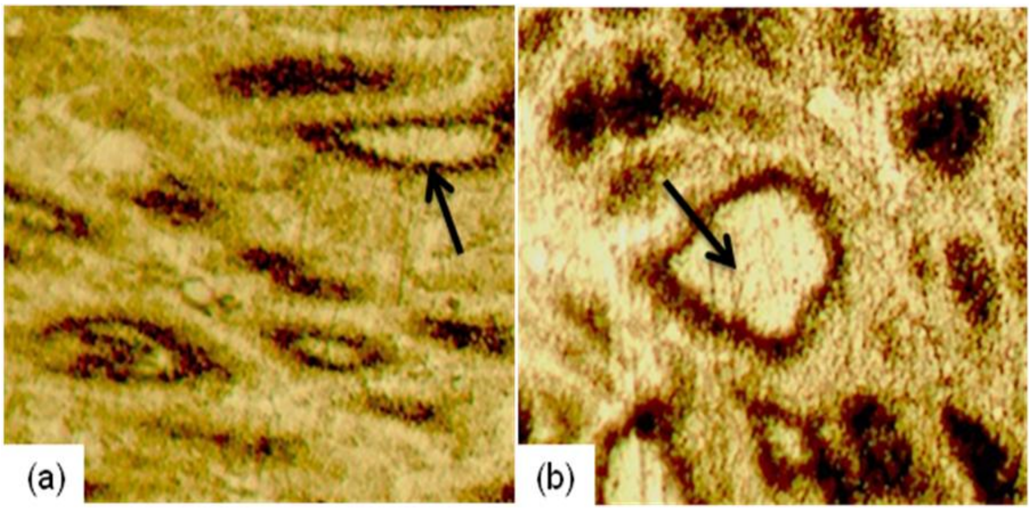

Figure 11: Micrograph of Brain Quenched 7050 Al Alloy, (a) Aging at 120˚C for 20min, (b) Aging at 120˚C for 40min, X200

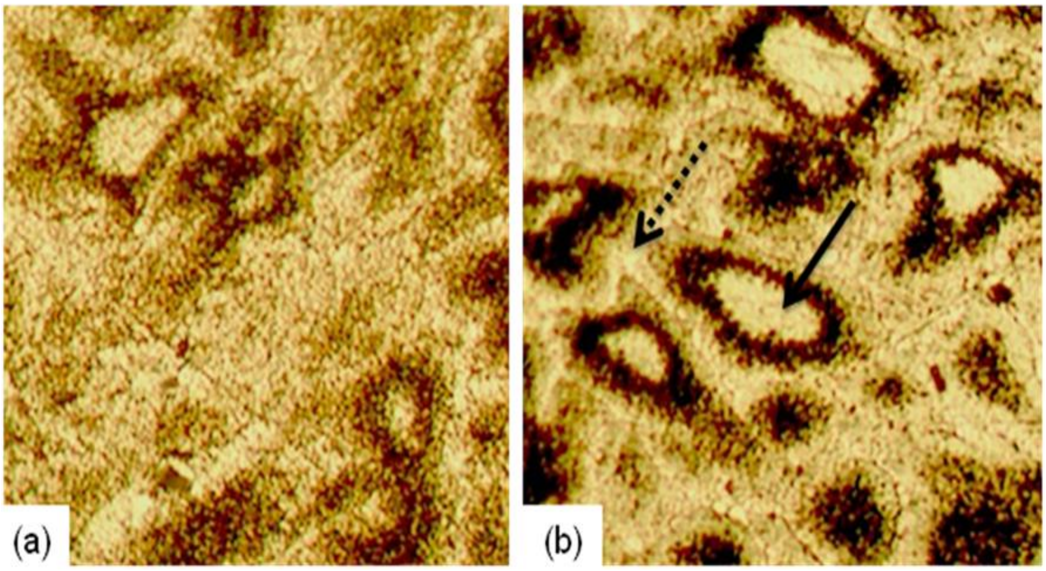

Figure 12: Micrograph of Brain Quenched 7050 Al Alloy, (a) Aging at 165˚C for 40min, (b) Aging at 165˚C for 60min, X200

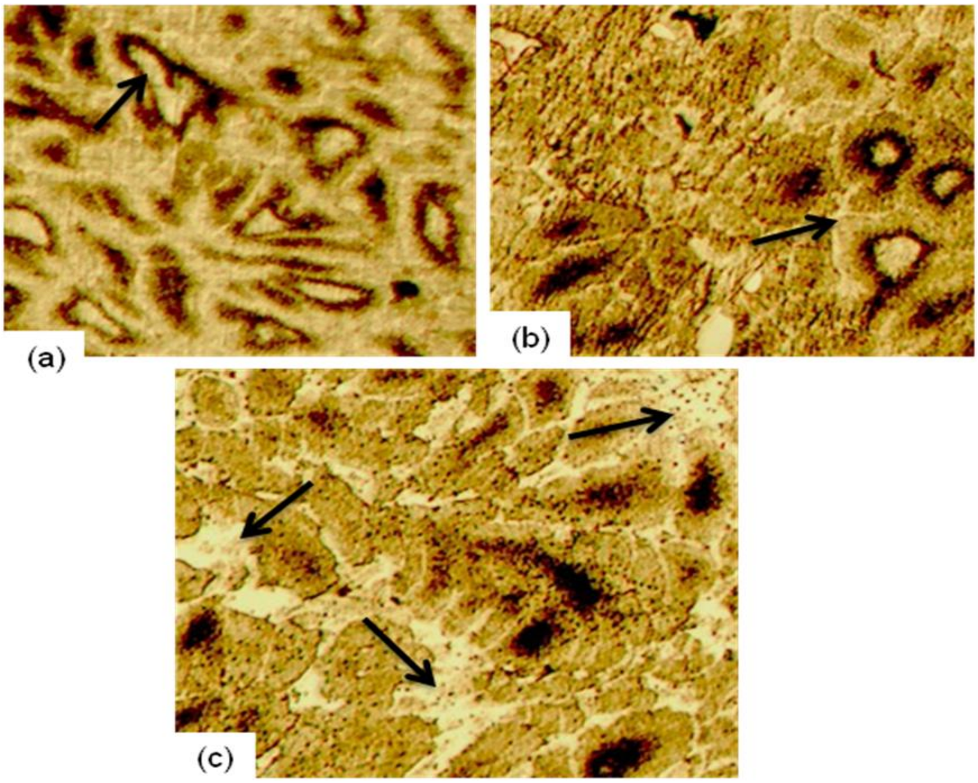

Figure 13: Micrograph of Brain Quenched 7050 Al Alloy, (a) Aging at 185˚C for 20min, (b) Aging at 185˚C for 40min, (c) Aging at 205˚C for 60min, X200

CONCLUSIONS

Aging of water quenched 7050Al alloy revealed hardness of 145 after 20min aging at 120˚C. Increasing aging temperature to 165˚C leads to higher increase of hardness but after longer aging time of 4hrs. It seems that responsible phase for hardening the alloy β" revealed clearly from the microstructure at the maximum hardness. Hardness slightly increased to 125Hv after 40min aging at 185˚C. GP zone could be change directly to β' then β stable phase with absence of β" phase.

Aging at 120˚C of oil quenched 7050Al alloy revealed maximum hardness of 147Hv after 20min, this due to the precipitation of β" and β' phases revealed from microstructure. By increasing aging temperature, the maximum hardness decreases to 138Hv, 130Hv after 20min aging at 165˚C and 185˚C respectively. Farther increase in aging temperature to 205˚C, reveals maximum hardness of 140Hv after 40min aging. This difference in hardening behavior is mainly due to change of the precipitated phases.

The application of brain quenching after solution treatment is found to be most effective in increasing the hardness the of 7050 aluminum alloy. Hardness remarkably increased to maximum of 168Hv after aging for 40min at temperature of 165˚C. Two types of precipitates revealed as β" and β' phases within the grain and along the grain boundary. Increasing aging temperature to 205˚C leads to an increase in hardness to 160Hv after 60min aging this due to large area of β" precipitates. Thus, brain quenching revealed the highest hardness of 7050Al alloy compared with water and oil quenching.

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