Effects of Aging Temperature and Time on Microstructure and Mechanical Properties of LM 12 Aluminium Alloy

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Abstract
Mechanical properties of aluminum alloy are mainly dependent on their microstructure which is determined by processing parameters. This study investigates the effects of aging temperature and time on the microstructure and mechanical properties of LM12 aluminium alloy. Scrapped aluminium was melted in 100 Kg muffle furnace and cast into test bars. The as-cast specimens were solution treated in accordance with ASTM B917-01 at a temperature of 500 ºC for 2 hours and aged at 30 ºC-200 ºC for 2-10 hours. Microstructure and mechanical properties in terms of yield strength, hardness, and tensile strength were analyzed after solution heat treatment and aging. The results showed that the highest aging temperature and time was 170 ºC /8 hour at which Ultimate tensile strength, yield strength and hardness attained peak values of 405 MPa, 250 MPa and 125 HB respectively. The presence of fine coherent precipitates; $CuAl_2$ accounted for the peak mechanical properties of the aged samples.

Keywords: *LM12 Aluminium alloy, Aging temperature, Microstructure, Mechanical properties*

1.0 INTRODUCTION

Aluminium alloys are widely used in the application of automobile and aircraft structural components because of their excellent properties such as high strength to weight ratio, low density, and high corrosion resistance (Akhil *et al*., 2014). LM 12 aluminium alloy have been known to have good mechanical properties at both low and high temperature ranges leading to many potential application in automobile parts such as hydraulic brake (Daliam *et al.,* 2017). However, further development is needed with respect to improving the specific strength for a more versatile application.

Hassan and Aigbodion (2009) has established that good mechanical properties such as high strength and good toughness can be achieved by using optimum melting and casting techniques and appropriate heat treatment procedures. Sigworth *et al*. (2004) also reported that age-hardening methods are widely used to strengthen heat treatable aluminium alloys. Age-hardening treatment consists of solutionizing, quenching and aging (Janj *et al*., 2014).

During solution treatment, the alloy exists as a homogeneous α-Al solid solution but on cooling becomes saturated with respect to the second phase θ ($CuAl_2$). The solutionized alloy is quenched to retain the high temperature single phase α–Al solid solution at room temperature because the rapid cooling suppresses the separation of θ (Adeosun *et al*., 2014). During the aging process, the alloy is raised to a temperature high enough for a suitable time to initiate the precipitation of the strengthening phase θ ($CuAl_2$) as finely dispersed particles, which impede the movement of dislocation in the matrix and in effect strengthens the alloy. The successive precipitation sequence in Al-Cu alloys is represented by α-Al → GP Zones (θ^{11}) → θ^1 → θ (CuAl) (Janj *et al*., 2014).

Tao *et al*., (2013) studied the effects of aging time and temperature on the microstructure and mechanical properties of 6082 aluminium extrusions. It was found that the optimum aging temperature was 175 ºC for 4 hours. The tensile strength and yield strength also reached their peak values of 350MPa and 320 MPa respectively.
Ilangovan *et al*. (2014) and Hu *et al*. (2014) also studied the effects of aging time on mechanical properties of sand cast Al-4.5 Cu alloy. They reported that the tensile strength and hardness of the aluminium alloy increases with aging time up to a aging time which depends on the alloy composition and aging temperature.
According to Keshmiri *et al.* (2009), ageing of 2205 Ferritic–austenitic stainless steel at temperatures lower than 550 ºC for different time had negligible effects on mechanical properties. However, aging at 550-650ºC led to a significant decrease in toughness and notable increase in hardness due to the formation of intermetallic phase. Aytekin, *et al*. (2015) also reported that the yield strength, the tensile strength and the elongations of AA6061 alloy decreased with the increasing artificial-aging temperature, but increased with the increasing artificial-aging time. Wen *et al*. (2008), Janj *et al*. (2014) and others studies have established that Precipitation hardening is the most common method used to increase the strength of heat treatable aluminium alloys.
Although many researchers have investigated the effect of heat treatment on mechanical properties and structure of different alloys, research effort on the effect of aging temperature and time on microstructure and mechanical properties of LM12 alloy is rare. Therefore, the current study investigates the effect of aging temperature and time on the microstructure and mechanical properties of LM12, with the aim of determining the appropriate aging temperature of the alloy for improved strength suitable for application in automobile industry.

2.0 METHODOLOGY

Aluminium ingot was used for this work. The chemical composition of the cast alloy is shown in Table 1.

Table 1: Chemical Composition of the cast alloy

Metal	Al	Fe	Si	Mn	Pb	Zn	Cu	Mg	Others
Percentage (%)	96.1	0.7	0.3	0.6	0.1	0.8	0.7	0.2	0.5

Melting was carried out in a muffle furnace and cast into test bars of 16 mm and length of 120 mm meant to be subjected to the following heat-treatment temperature: 30 ^{0}C, 100 ^{0}C, 170 ^{0}C and 240 ^{0}C. The cast specimens were then machined to ASTM standards for tensile, impact and hardness test specimens. These specimens were solutionized by heating to 500 ^{0}C at 10 ^{0}C/s, soaked at this temperature for 4 hours before quenching in cold water. The quenched specimens were afterward naturally aged at room temperature (30 ^{0}C) and artificially aged at 100 ^{0}C, 170 ^{0}C, and 200 ^{0}C for 2-10 hours. Tensile tests were performed in an Instron testing machine (the strain rate is 10^{-3}/s,) Impact test was performed using a universal impact testing machine model IT30 with maximum capacity of 360J±1 (J). Hardness was measured by HB-3000 Brinell hardness tester. All tests were repeated 3 times on both as-cast, heat treated and aged condition and the data from the experiment was obtained by averaging the values. Specimens for microstructural analysis were prepared by polishing on disc polisher followed by etching with diluted hydrofluoric acid while the microstructural features were obtained using an optical microscope at 200 magnifications.

3.0 **RESULTS AND DISCUSSION**

3.1 Mechanical Properties of LM12 Aluminium alloy

Figure 1 shows the effect of aging temperature on the ultimate tensile strength (U.T.S.) of LM12 aluminium alloy. The UTS increase initially up to a peak value and then decrease with the increase in time. The UTS reaches its peak values of 405 MPa at 170 ^{0}C. However, when aged at 200 ^{0}C, a decrease was observed which indicates over aging of the sample.

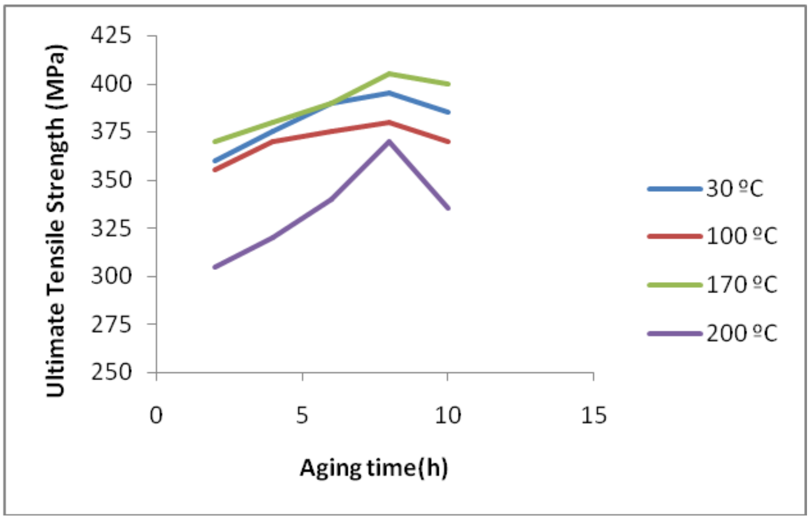

Figure 1: Effect of aging temperature on the UTS of LM12

Figure 2 shows the effect of aging temperature on hardness of LM12 aluminium alloy. The result indicates that hardness increases firstly and then decrease with the increasing of aging temperature and reaches peak value of 125 HB at 170 ^{0}C. The reason for the increase in hardness may be attributed to the presence of Guinier-Preston (GP) zones and the intermediate θ^{I} ($CuAl_2$) coherent precipitates. Further aging tends to decrease the hardness as illustrated by the drooping of the curve in Figure 2 due to coarsening of the precipitates. The best combination of properties is achieved when aged at 170 ^{0}C for 8 hours during which ultimate tensile strength and hardness values reached 405 MPa and 125 HB respectively.

This observation agrees with Keshimiri *et al.* (2010), that hardness increases with the formation of Guinier-Preston zones and the intermediate precipitates and that maximum hardness is obtained when there is a critical dispersion of GP zones or an intermediate precipitate (θ^1 or θ^{11}).

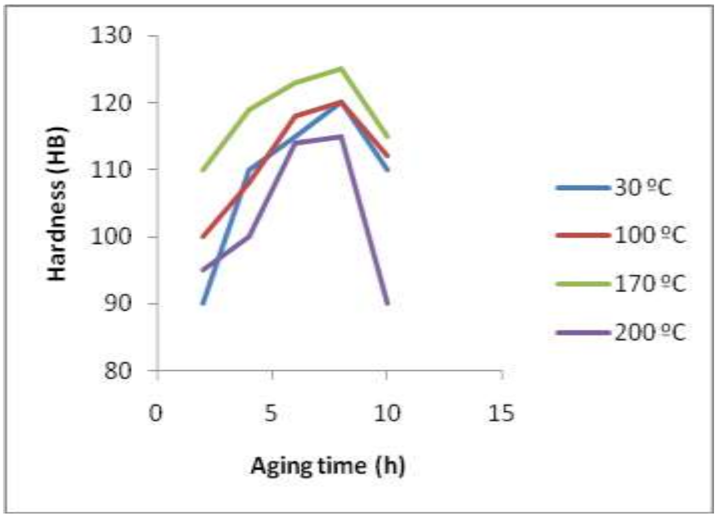

Figure 2: Effect of aging temperature on the Hardness of LM12

Figure 3 shows the effect of aging temperature on the yield strength of LM12 Aluminium alloy. The yield strength of the alloy first increased and then decreased with increasing aging temperature. This may be attributed to the gradual increase in the amount of precipitate from the super saturated α-Al solid solution during aging process. However, at 200 ^{0}C, there was a decrease in yield strength value, characteristic of over aging. Yield strength attains maximum value of 250 MPa at 170 ^{0}C.

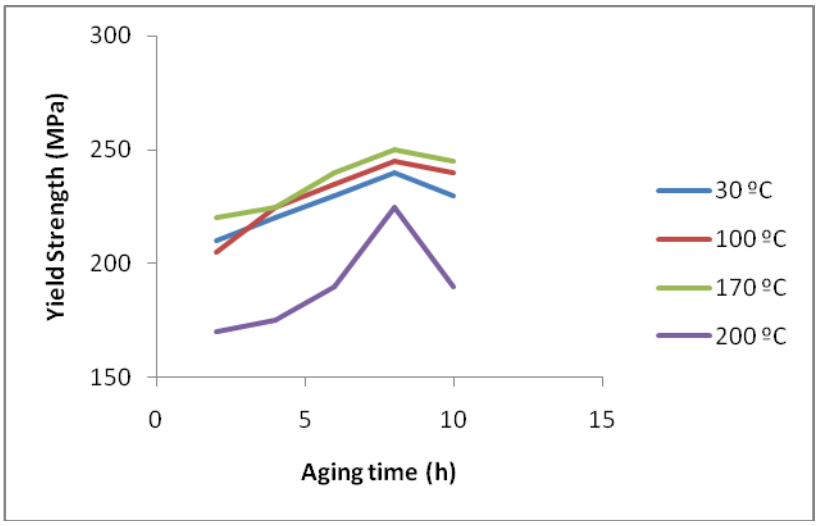

Figure 3: Effect of aging temperature on the yield strength of LM12

3.2 Microstructures of LM12 Aluminium alloy

Plate 1 presents the optical microstructures of LM12 aged at 30 ^{0}C under different aging times. It can be seen from Plates 1(a-e) that the microstructure is α-Al solid solution. At low aging temperature, secondary phase precipitate was not observed.

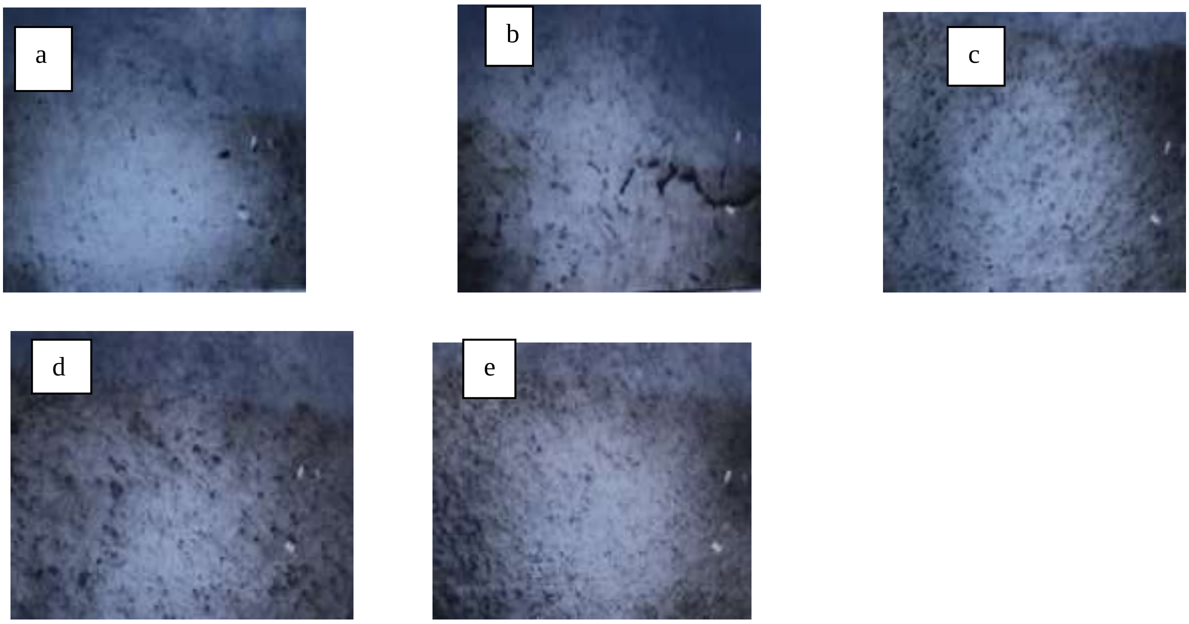

Plate 1: Optical micrographs of LM12, aged at: 30 ^{0}C for 2 h; (b) 30 ^{0}C for 4 h; (c) 30 ^{0}C for 6 h; (d) 30 ^{0}C for 8 h;(e) 30 ^{0}C for 10 h (200X)

Plate 2 shows the microstructure of LM12 aged at 100 ^{0}C under different aging times.
At 100 ^{0}C, secondary phase precipitates start appearing in the structure as dark patches of aluminium oxide inclusion.

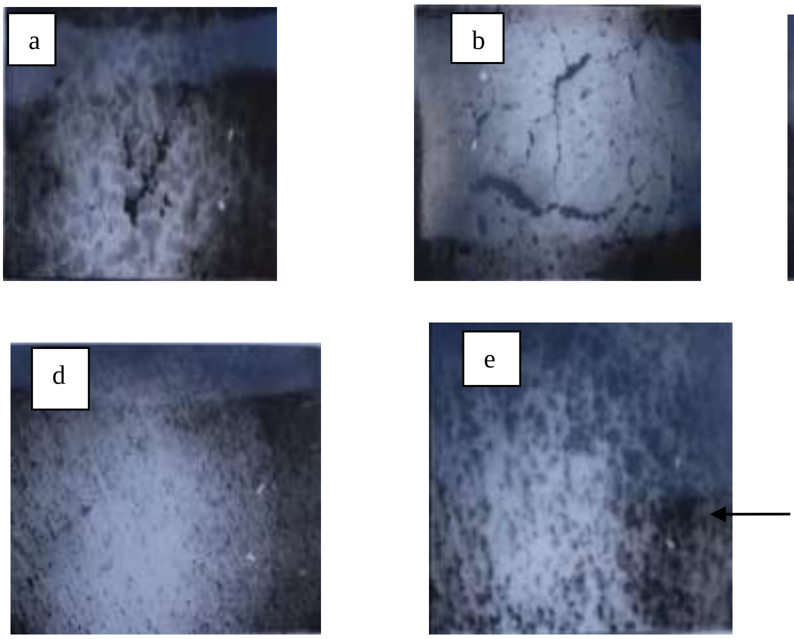

Plate 2: Optical micrographs of LM12 alloy aged at: (a) 100°C for 2 h (b) 100°C for 4 h (c) 100°C for 6 h (d) 100°C for 8 h (e) 100°C for 10 h (200X)

Plate 3 shows the microstructure of LM12 alloy aged at 170 ºC under different aging time. The structure reveals a mixture of intermediate coherent precipitates θ^{I} (CuAl) and Guinier Preston (GP)–zone precipitates which manifested as black streaks in the grains and in lesser quantity along the grain boundaries. The precipitates are not so dense and could not be resolved under the optical microscope, hence their nature could not be determined. The existence of these precipitates is likely to be responsible for improvement in the strength and hardness of the aged samples.

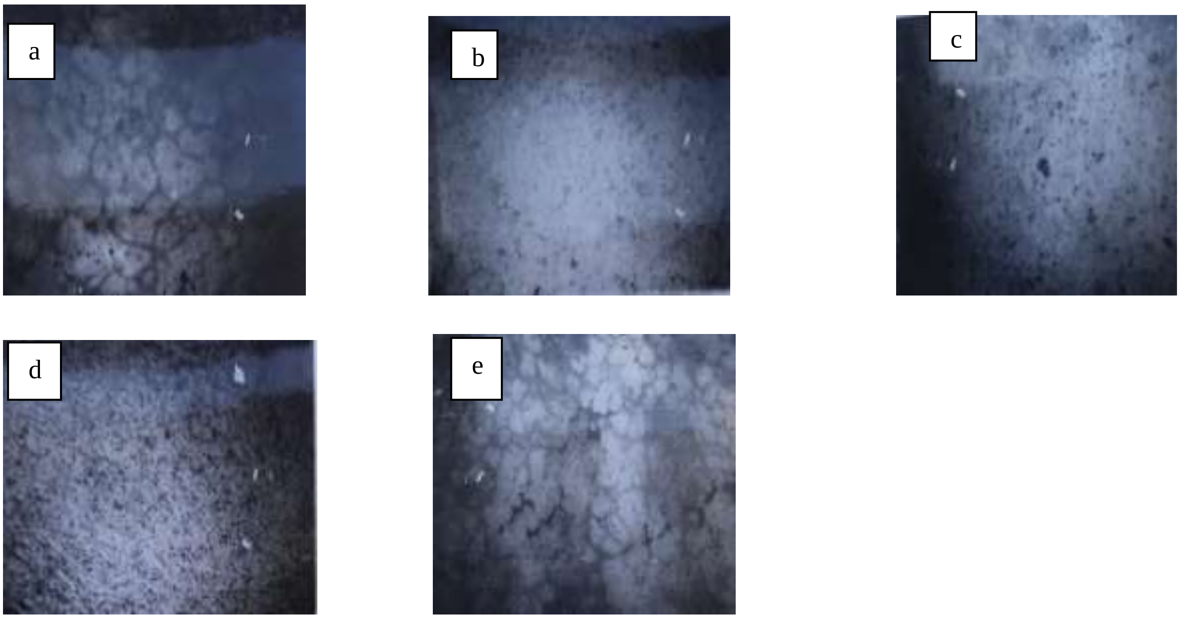

Plate 3: Microstructure of LM12 alloy (a) aged at 170 ºC/2 h; (b) aged at 170 ºC/4 h; (c) aged at 170 ºC/6 h; (d) aged at 170 ºC/8 h; (e) aged at 170 ºC/10 h (200X)

Plate 4 shows microstructure of LM12 alloy aged at 200 ºC under different aging times. Comparing the microstructure of specimen aged at 200 and 170 ºC under the same time, the precipitates have increased and the fine precipitates have gradually been replaced by coarse precipitates with aging temperature. It can be concluded that coherent precipitate formed at higher temperature and longer time. However, prolonged aging at 200 ºC resulted in reduction in mechanical property due probably to over aging and coarsening of the grains.

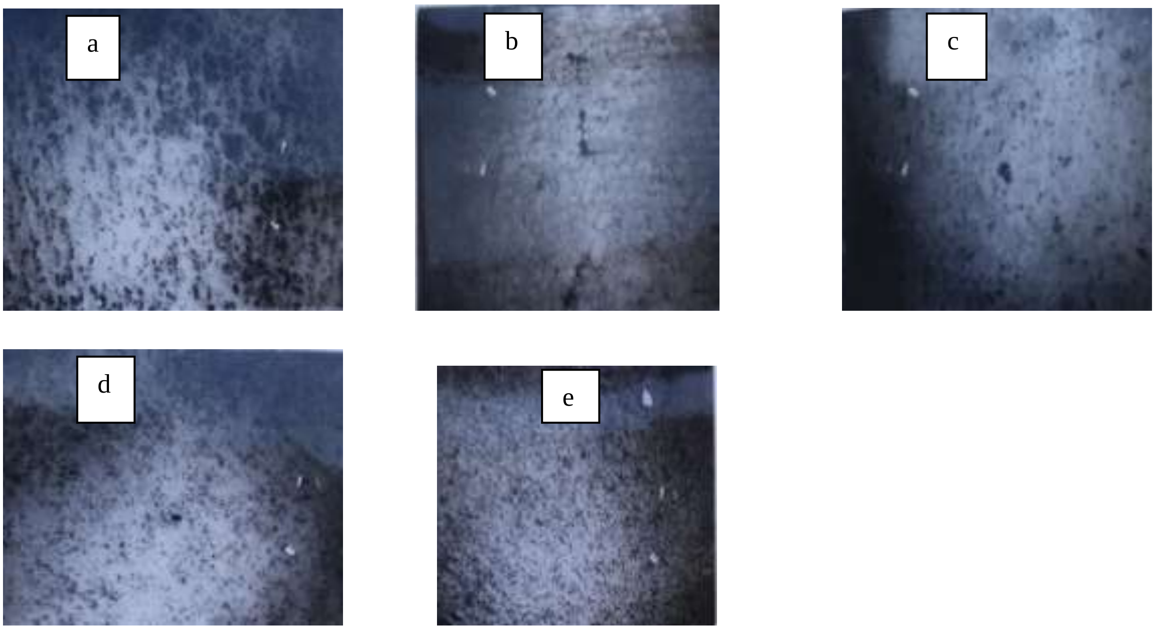

Plate 4: Microstructure of LM12 alloy (a) aged at 200 ºC/2 h; (b) aged at 200 ºC/4 h ; (c) aged at 200 ºC/6 h;(d) aged at 200 ºC/8 h;(e) aged at 200 ºC/10 h (200X)

4.0 CONCLUSION

The results obtained from the present work indicate significant effect of aging temperature and aging time on the microstructure and mechanical properties of LM12 alloy quenched in water after solution heat treatment. From the results and their analyses, the following conclusions are drawn:

(1) The mechanical properties of the alloy are more sensitive to aging temperature than to aging time.

(2) The optimum aging temperature for LM12 alloy is 170 ºC for 8 hours during which tensile strength and yield strength attained their peak values of 405 MPa and 250 MPa respectively with hardness value of 125 HB.

(3) Improvement in mechanical properties is attributed to the presence of fine coherent precipitates; $\vartheta^{/}$ ($CuAl_2$) in heat treated and aged samples.

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