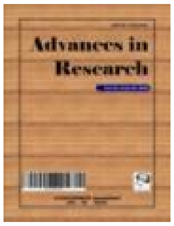

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The Influence of Homogenization Treatment on Aging Response of 6063 Aluminium Alloy

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Authors' contributions

This work was carried out in collaboration between all authors. Author DAI designed the study, wrote the protocol, managed the literature searches and wrote the first draft of the manuscript. Author KMO performed scanning electron microscopy. Author KJA managed analyses of the study and performed the spectroscopy analysis while authors MOA and ARA supervised the work. All authors read and approved the final manuscript.

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ABSTRACT

This paper reports the effect of homogenization treatment on T6 tempering of 6063 aluminium alloy. Wrought 6063 aluminium sample was machined into tensile and impact tests specimens. Samples were also cut for hardness and metallographic works. These samples were divided into two groups; group I samples were homogenised at 570ºC for 2, 2.5, 3 and 3.5 hours respectively prior to T6 temper while group II samples were T6 tempered without prior homogenization. The

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heat treated samples was subjected to tensile, impact and hardness tests and the evolved microstructures was characterised using a scanning electron microscope equipped with energy dispersive spectrometer. The results show improvement in the mechanical properties for those samples homogenized prior to aging as compared to conventionally aged samples and there was also an unusual combination of mechanical properties in terms of ductility, toughness and strength. The resulting microstructures shows the presence of rod-like phases in the as-received and T6 tempered samples while group II samples contain spherical precipitates. The overall result showed that prior homogenization can prevent the usual concomitant decrease in ductility and toughness of T6 tempered 6063 aluminium alloy.

Keywords: Homogenization; age hardening; T6 temper; 6063 aluminium alloy and Wrought.

1. INTRODUCTION

Aluminium alloy 6063 and 6061 has been identified as a marine grade alloys because of their excellent corrosion resistance in marine environments [1]. The high strength-to-weight ratio of these alloys has made them to be very attractive to aviation and automobile industries where there is high demand for light materials to increase the load carrying capacity and reduce fuel consumption [2]. The 6063 alloy seems more prominent than the 6061 because of its excellent extrudability, excellent corrosion resistance, weldability and moderate strength and other structural applications [3]. These alloys are for producing sheets or profiles by extrusion.

However, high strength aluminium alloys have poor resistance to stress corrosion cracking (SCC), particularly when they are at near peak strength condition [4,5,6]. This high susceptibility of 7075 aluminium for example, to corrosion especially in marine environment has shifted the attention of researchers to 6063 aluminium.

Aluminium alloy 7075, exhibits superior strengths (over 1.5 times that of the marine grade alloys) but is much more susceptible to corrosion [1]. This alloy sees heavy use in the aircraft industry where the environment is typically mild and aluminium corrosion is not likely to occur. Even though it is a high performance material in the aircraft industry, it would perform poorly in marine environments [1].

This uniqueness of 6063 aluminium alloy among other aluminium alloys demands special attention and this necessitates the need for further improvement in its mechanical properties for better performance in service, hence this study. In previous investigations on homogenization of aluminium alloys, attention has always been on billets homogenization prior to extrusion [7,8,9]. Several authors studied the influence of the cooling rate after homogenization on the alloy microstructure. Zajac et al. [10], Nowotnik and Sieniawski [11] studied the influence of the cooling rate on the final mechanical properties of 6063, 6082, 6005 alloys. Reiso [12] studied the influence of the cooling rate on the extrusion speed for various chemical compositions of Al-Mg-Si alloys. Birol [13] studied the microstructure evolution of the 6063 alloy during homogenization for various thermal cycles. Cai et al. [14] studied the Mg_2Si dissolution during homogenization through electrical resistivity measurements and the distribution of the alloying elements with electron microprobe measurements for the 6061, 6069 alloys. Finally, Usta et al. [15] studied the dissolution/coarsening kinetics of the Mg_2Si particles during reheating of the homogenized material. This present work investigates the influence of a prior homogenization treatment before T6 tempering on the precipitation hardening of 6063 aluminium alloy.

2. MATERIALS AND METHODS

The 6063 aluminium alloy used for this study was sourced from Nigeria Aluminium (NIGALEX), Lagos. Wrought 6063 aluminium alloy of 50 mm diameter and 1000 mm length were given. The elemental composition of wrought 6063 aluminium alloy used is presented in Table 1. Standard mechanical test samples were machined from this rod for tensile and impact tests. Samples were also cut for microhardness and metallographic works. These samples were divided into two groups; group I samples were homogenized at 570ºC for 2, 2.5, 3 and 3.5 hours and air cooled. These sets of samples were then solution treated at 530ºC for 4 hours, quenched in water and artificially aged at 180ºC for 5 hours. The group II samples were solution treated at 530ºC for 4 hours, quenched in water and artificially aged at 180ºC for 5 hours without prior homogenization. The heat treated samples were subjected to tensile, impact and microhardness tests. The total number of heat treated samples were 35; 15 for tensile, 15 for impact and 5 for microhardness and metallographic tests respectively. This comprises 3 samples for each of the heat treatment variables in order to obtain a mean value. Tensile test was carried out in accordance with British Standard BSEN 10002-1 [16] at room temperature with a crosshead speed of 5 mm/min using an Instron 3369 electromechanical testing machine. The ultimate tensile strength, elongation, proof stress, and modulus of elasticity values were calculated from Stress – Strain diagrams obtained. Impact testing of all these specimens was conducted in accordance with ASTM Standard E 602-91 [17]. Three samples were tested from each heat-treated conditions (making a total of 15 samples). The tests were carried out using Izod impact test method on a Houndsfield balance impact-testing machine. An average value from three tests were taken and recorded. Microhardness testing was done using the LECO ASTM E384 microhardness tester. The tests were performed on the five etched samples (one from group I and four from group II). The microhardness test was carried out using a test load of 490.3 mN and dwell time of 10s. This test was done at three different points on each sample and the average hardness value reported. The samples for scanning electron microscopy (SEM) in each of the five conditions were grinded with emery grit papers and polished to 0.5 micron finish followed by etching with Keller's solution (1.0 ml HF, 1.5 ml HCl, 2.5 ml HNO_3 and 95.0 ml H_2O) [18]. Figs 1 and 2 show the geometry and dimensions of tensile and impact tests specimens respectively.

Table 1. Elemental Composition of the 6063 Alloy used

Element	Si	Mg	Fe	Cr	Ti	Mn	Zn	Cu	Al
wt. %	0.53	0.43	0.13	0.14	0.02	0.04	0.01	0.17	Balance

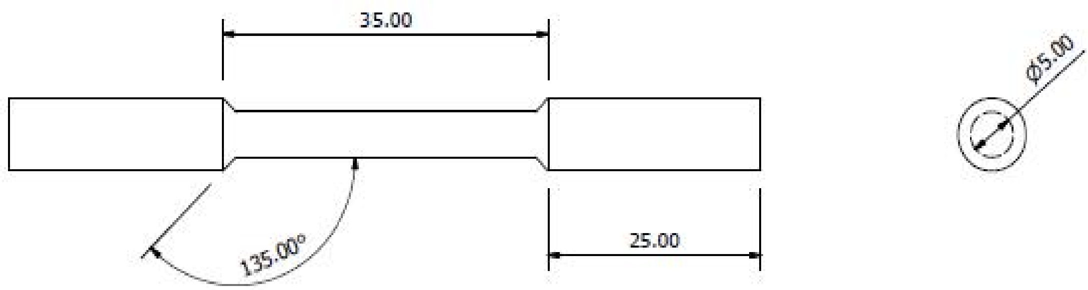


Fig. 1. Tensile test specimen (the dimensions are in mm)

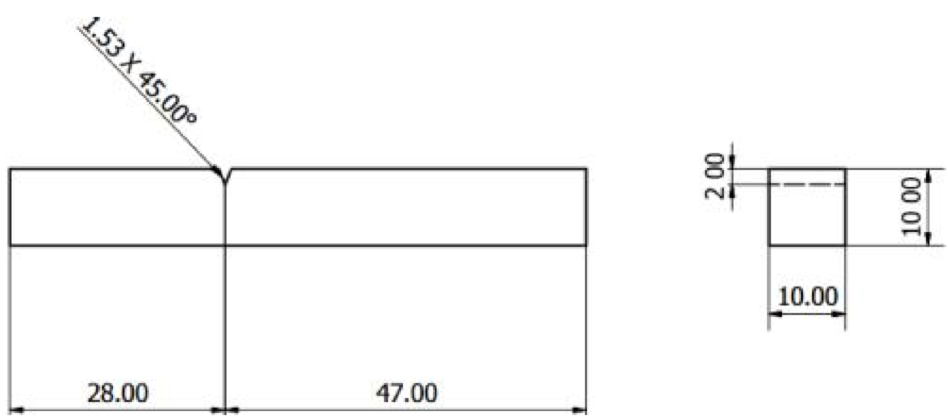


Fig. 2. Notched Izod impact test specimen (the dimensions are in mm)

3. RESULTS AND DISCUSSION

The microstructures of the as-received sample in Fig. 3 and that of T6 tempered sample in Fig. 4 revealed the need for prior homogenization before T6 tempering to either remove or spheroidize the plate-like/rod-like phases present in them. The direct chill casting of ingot used for extrusion of this alloy is associated with the evolution of plate-like phases that have deleterious effects on its mechanical properties [7]. These rod-like phases must be completely eliminated or spheroidized via homogenization prior to aging.

The yield strength values for the samples increased significantly after homogenization. This was seen in Fig. 5 where there was an increase from 210 MPa for no homogenization to 240 MPa after homogenization for 2 hours. However, maximum value was obtained after homogenization for 2.5 hours beyond which it decreased slightly. The same trend, as for the yield strength was observed for the ultimate tensile strength, as seen in Fig. 5. In these cases, homogenization prior to solution treatment has been found to be very necessary. The significant increase has been found to be due to: removal of deleterious intermetallic phases present in Fig. 3 and structures which are hard to remove by solution treatment only Fig. 4; enriching the solid solution matrix with solute atoms for solution strengthening and release of the solute atoms for subsequent formation of favorable precipitates (Figs. 6 a and b).

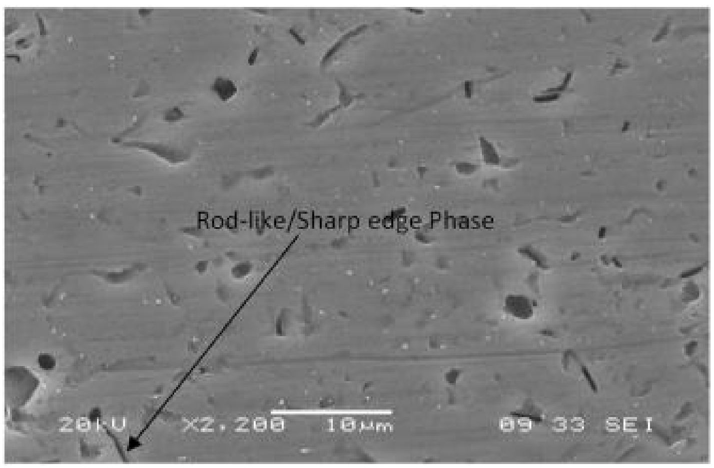


Fig. 3. SEM micrograph of the as-received 6063 aluminium alloy used for this study

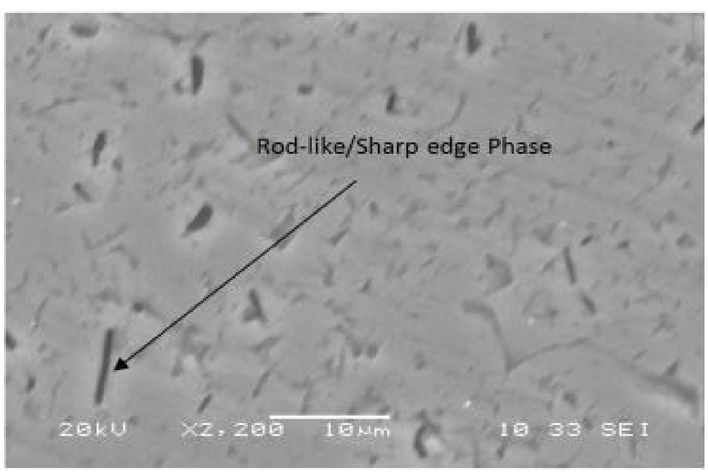


Fig. 4. SEM micrograph of T6 Tempered 6063 aluminium alloy

The discrepancies in the yield strength of T6 tempered 6063 Al alloy (208 MPa) as compared to (215 MPa) in the standard data can be attributed to the presence of unmodified rod-like phases in the T6 tempered samples which could not be completely eliminated by solution treatment alone as evident in the Fig. 4 where there are still some unmodified plate-like phases. Also, there used to be discrepancies in the theoretical and ideal strengths of materials due to defects that are inherently associated with their production processes [19].

The presence of rod-like/elongated phases (indicated by arrow) in Figs. 3 and 4 is responsible for low yield and ultimate tensile strengths values. The sudden increase in the mechanical properties, as shown in Fig. 5 above, after 2 hours homogenization was as a result of complete spheroidization of plate-like phases present in the alloy matrix (Fig. 6) and the formation of suitable heterogeneous nucleants which enhances the quench sensitivity and precipitates formation during sebsequent aging [20]. The sudden drop at about 30 minutes latter could be attributed to grain growth effect as a result of excessive homogenization.

The optimum values of yield and ultimate tensile strengths (287 and 470 MPa) were obtained at 2.5 hours homogenization prior to aging. This means that complete homogenization treatment was achieved at 2.5 hours during which there was removal of interdendritic segregations, spheroidisation of rod-like phases (Fig. 6a) and consequently heterogeneous precipitation and heterogeneous mechanical properties during aging and this is in agreement with the results of [7,21,22] whose results show that no more than 2.5 hours is required for complete homogenization of 6063 aluminium alloy. This structure is seen in Fig. 6a, where complete spheroidisation took place.

However, the reduction in mechanical properties after 2.5 hours homogenization is likely to be due to grain coarsening effect as a result of extensive homogenization. This has resulted in a condition for over aging. This is evident in the amounts of precipitates in Figs. 7 and 8 as compared with Fig. 6b.

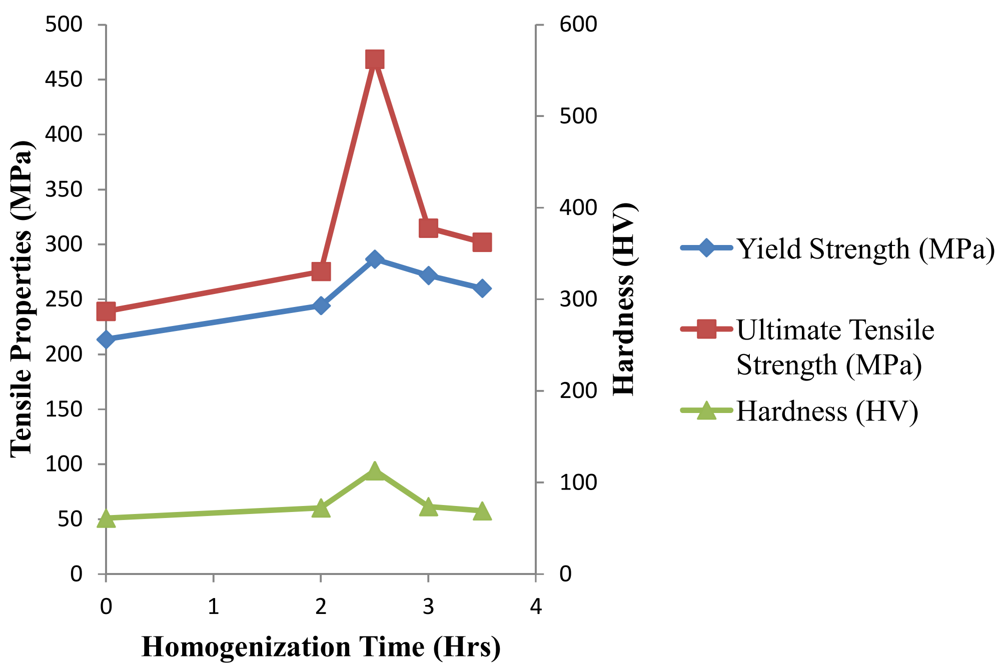
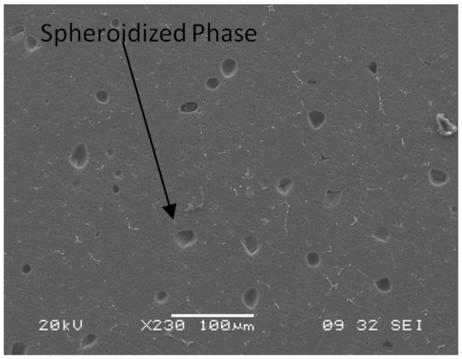
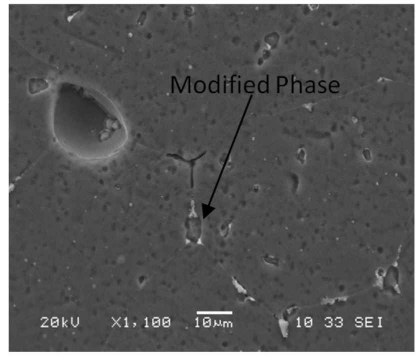


Fig. 5. Variations of yield strength, ultimate tensile strength and hardness with homogenization time for T6 tempered and homogenized prior to T6 tempered 6063 aluminium alloy



(a)



(b)

Fig. 6. SEM micrograph of 6063 aluminium alloy homogenized at 570°C for 2.5 hours and T6 tempered at a) 100 µm and b) 10 µm respectively

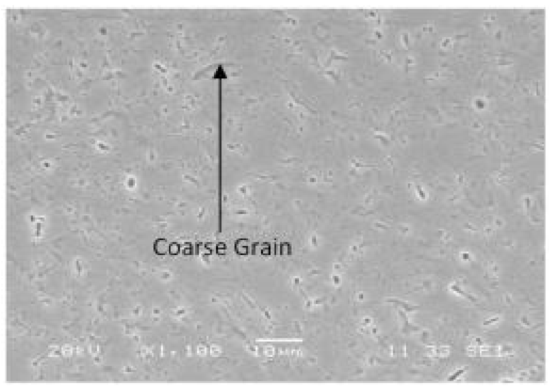


Fig. 7. SEM micrographs of 6063 aluminium alloy homogenized at 570°C for 3 hours and T6 tempered

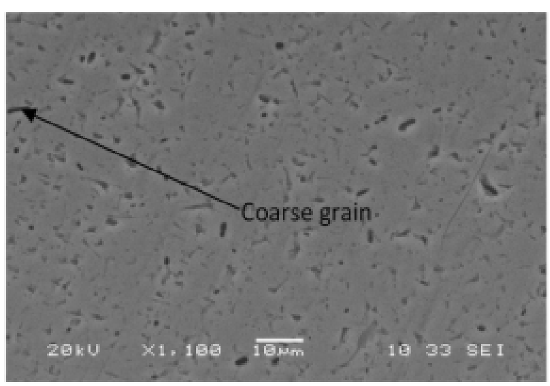


Fig. 8. SEM micrographs of 6063 aluminium alloy homogenized at 570°C for 3.5 hours and T6 tempered

The same result was observed for the hardness values as in the yield and ultimate tensile strengths in Fig. 5. Hardness values increased from 65 HV (for no homogenization) to 117 HV (for 2.5 hours homogenization). Thereafter, it significantly dropped to 74 HV and 69 HV for 3 and 3.5 hours homogenization respectively. This reduction is likely to be due to the same reasons given above for drop in yield and ultimate tensile strengths. The high hardness value of samples homogenized for 2.5 hours prior to aging at 180ºC for 5 hours affirmed the theory that srength and hardness are constant multiples of each other [23,24].

From Fig. 9, the ductility as indicated by the % elongation increased with homogenization time. Generally, the elongation was not significantly increased with homogenization period and seemed to reach a low maximum level after 2.5 hours homogenization. The comparatively high elongation obtained when no prior homogenization was carried out is not expected. It appears that solution treatment alone resulted in stress relief annealing of the as-received structure, as there are still some rod-like phases in Fig. 4. The elongations values for specimens homogenized for 3 and 3.5 hours were still considerably higher than when no homogenization was carried out. This was also confirmed by the microstructure in Fig. 4, where there is substantial quantity of unmodified second phase particles.

Fig. 9 shows that, the impact strength increased with homogenization time except for those samples homogenized for 2 hours, reaching a maximum level for 2.5 hours. The low toughness values for samples homogenized for less than this period could be attributed to the presence of brittle intermetallic compounds present in their structures (Fig. 4).

The high toughness values observed for those samples homogenized for 2.5 hours and longer prior to solution treatment were due to the high strength and high elongation values obtained earlier. The comparatively low impact value for precipitation hardening without a prior homogenization was as a result of very low tensile strength level caused by low homogenizing effect of solution treatment [7,20].

The high toughness values observed for those samples homogenized for 2.5, 3 and 3.5 hours prior to aging were due to complete transformation of plate-like phases to spherical phases present in this alloy (Figs. 6a, 7 and 8).

Fig. 10 shows the micrograph of the samples homogenized for 2 hours and T6 tempered; the structure revealed the presence of some partly modified phase which is responsible for its low mechanical properties compared to other higher homogenization times.

The presence of manganese and chromium in this alloy also has a beneficial effect on its toughness. According to Heathcock [20], the presence of intermetallics in manganese/ chromium containing alloys promotes intragranular precipitation and avoids precipitation on grain boundaries and formation of precipitate free zones adjacent to grain boundaries. This prevents weakening of grain boundaries and maintains the toughness of 6063 aluminium alloys.

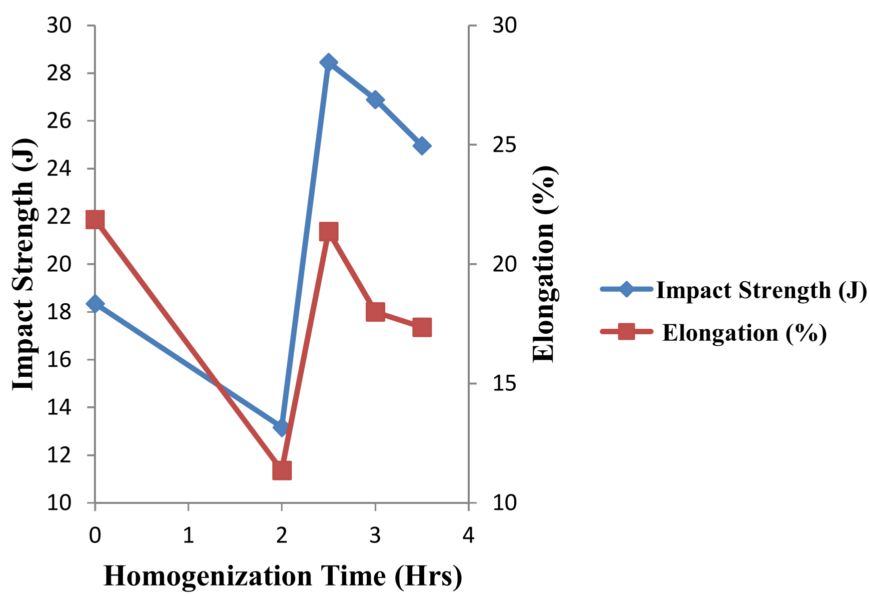


Fig. 9. Influence of prior homogenization treatment on impact strength and percentage elongation of T6 tempered 6063 aluminium alloy

The EDX analysis of the phases present is presented in Figs. 11 and 12 respectively. These Figures indicated the spherical and rod-like phases to contain Al-Fe-Si-Mn (Fig. 11) and Al-Cu-Cr (Fig. 12) respectively. These serve as second phase particles and contribute to the improvement in final mechanical properties. Fe in combination with Si can formed the ternary phase AlFeSi, or else with Cr, Mn the quartenary phase AlFeCuMn. This is in agreement with Samaras and Haidemenopoulos [9] who stated that several phases may be present in commercial alloys containing Al–Mg–Si–Fe–Mn–Cu–Cr–Zn.

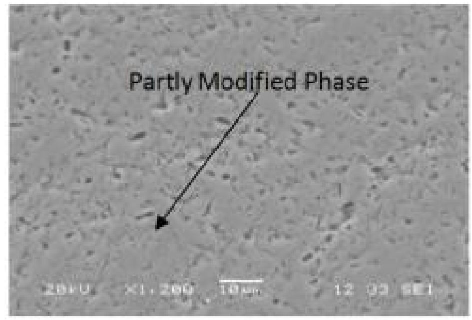


Fig. 10. SEM micrograph of 6063 aluminium alloy homogenized at 570°C for 2 hours and T6 tempered

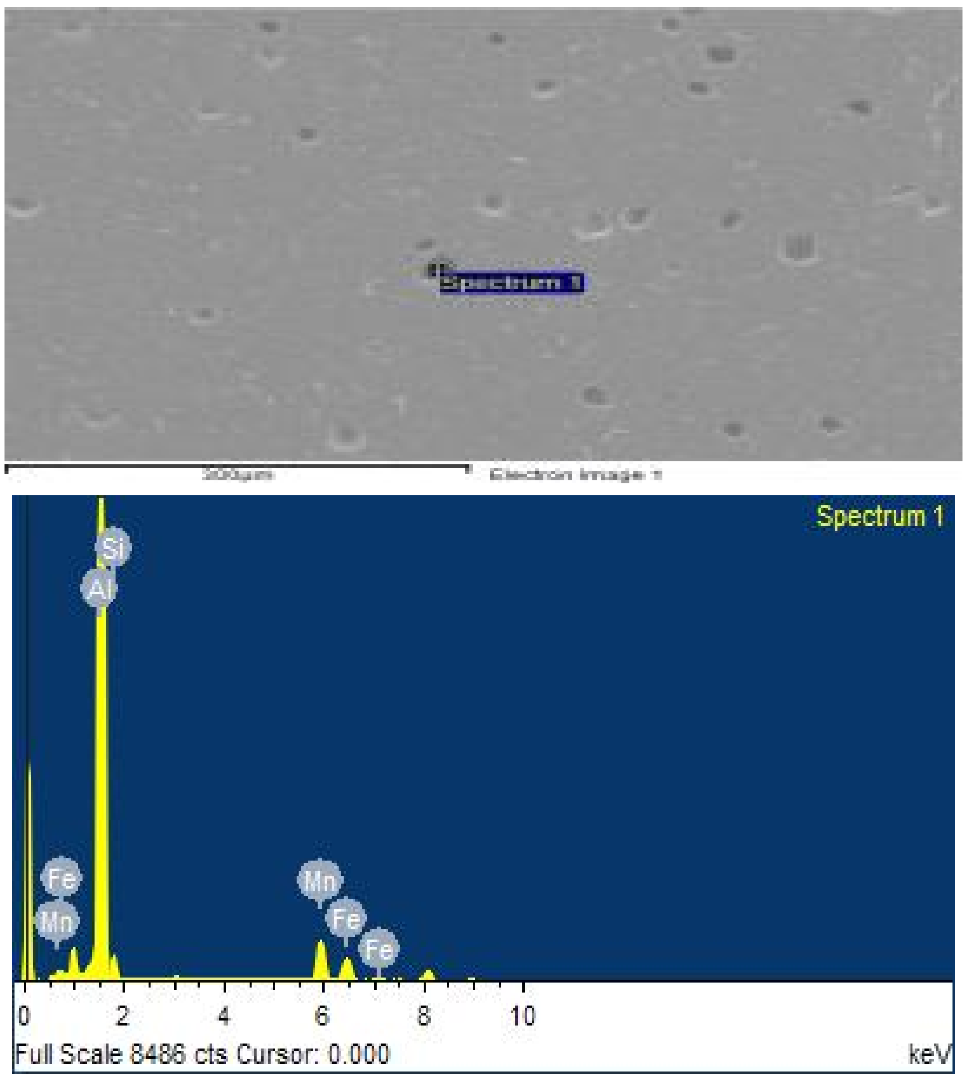


Fig. 11. Shows the EDX analysis of spherical precipitate

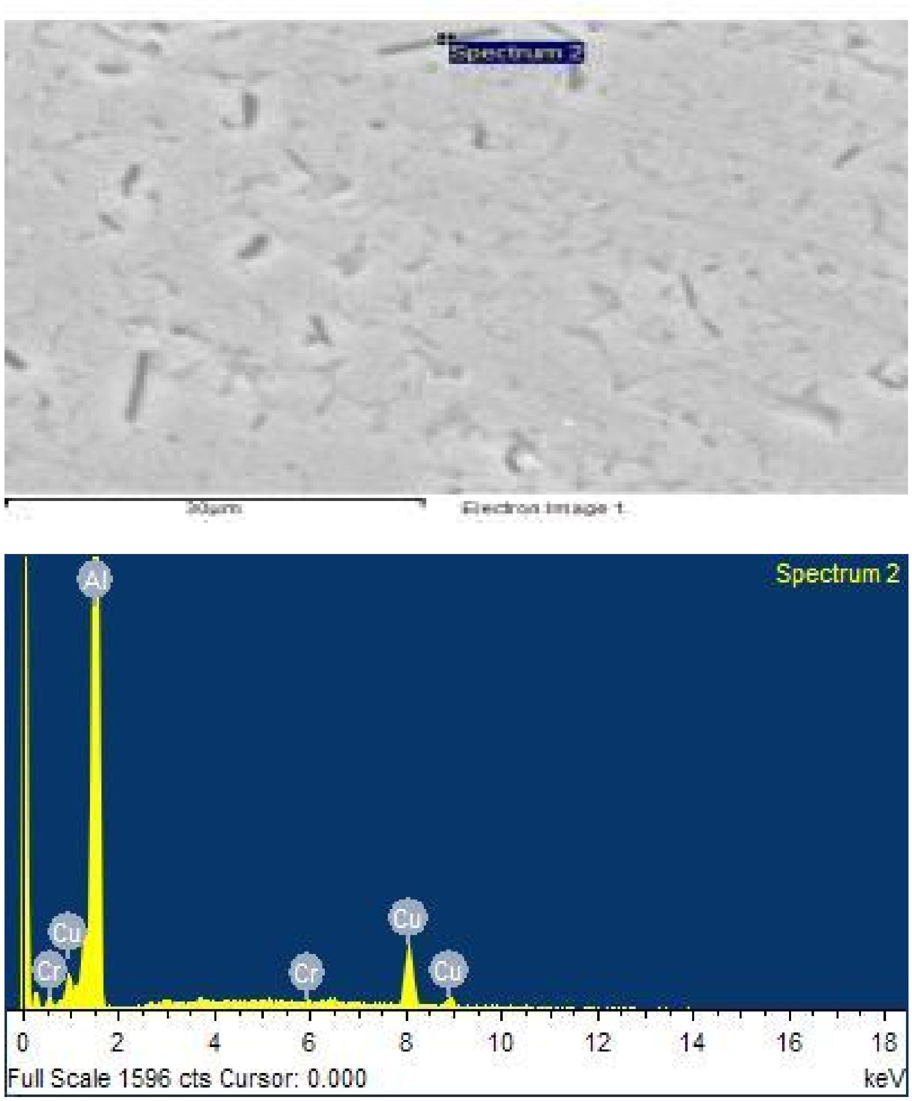


Fig. 12. Shows the EDX analysis of rod-like precipitate

4. CONCLUSION

The following conclusions can be drawn from the results of this work.

1) The rod-like phase in the as-received 6063 Al alloy can be transformed into spherical phase by appropriate homogenization treatment.
2) Fragmentation and spheroidisation of sharp edges phases in 6063 Al occur during homogenization and greater degree of spheroidisation was achieved at 2.5, 3 and 3.5 hours of homogenization at 570ºC.
3) The optimum combination of strength and toughness values was obtained at 2.5 hours homogenization prior to aging.
4) Unlike in conventional aging where an increase in hardness and strength usually leads to corresponding decrease in ductility and toughness, homogenization treatment prior to aging helps to maintain the ductility and toughness values of the age-hardened 6063 aluminium alloy.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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