Original Research Article

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

ABSTRACT

This paper reports the effect of homogenisation 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 580 ^{o}C for 2, 2.5, 3 and 3.5 hours respectively prior to T6 temper while group II samples were T6 tempered without prior homogenisation. The as-received sample as well as the 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 homogenised 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 homogenisation can prevent the usual concomitant decrease in ductility and toughness of T6 tempered 6063 aluminium alloy.

***Keywords**: Homogenisation, Age hardening, T6 temper, 6063 aluminium alloy and Wrought*

1.0 INTRODUCTION

Aluminium alloy 6063 and 6061 has been identified as a marine grade alloys because to their excellent corrosion resistance in marine environments. 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. 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.

High strength aluminium alloys are usually chosen for automobile and aircraft constructions because of their high strength-to-weight ratio and stiffness, which are derived from precipitation hardening. However, high strength aluminium alloys have poor resistance to stress corrosion cracking (SCC), particularly when they are at near peak strength condition [1, 2, 3]. Precipitation hardening is directly responsible for the Stress Corrosion Cracking susceptibility of high strength aluminium alloys. 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 [4]. 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 [4].

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 homogenisation of aluminium alloys, attention has always been on billets homogenisation prior to extrusion [5, 6, 7]. Several authors studied the influence of the cooling rate after homogenisation on the alloy microstructure. Zajac *et al*. [8], Nowotnik and Sieniawski [9] studied the influence of the cooling rate on the final mechanical properties of 6063, 6082, 6005 alloys. Reiso [10] studied the influence of the cooling rate on the extrusion speed for various chemical compositions of Al-Mg-Si alloys. Birol [11] studied the microstructure evolution of the 6063 alloy during homogenisation for various thermal cycles. Cai *et al*. [12] studied the Mg_2Si dissolution during homogenisation through electrical resistivity measurements and the distribution of the alloying elements with electron microprobe measurements for the 6061, 6069 alloys. Finally, Usta *et al*. [13] studied the dissolution/coarsening kinetics of the Mg_2Si particles during reheating of the homogenised material. This present work investigates the influence of homogenisation treatment on the precipitation hardening of 6063 aluminium alloy.

2.0 MATERIALS AND METHODS

The 6063 aluminium alloy used for this study was sourced from Nigeria Aluminium (NIGALEX), Lagos. Wrought 6063 aluminium alloy of 15 mm diameter and 1000 mm length were given. The extrusion process entails direct chill casting of the ingots, homogenisation of the ingots, preheating of the homogenised ingots, followed by hot extrusion. But the full potentials of homogenisation could not be attained in the homogenisation treatment of the ingots because this will lead to increment in the amount of stress required for extrusion. 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 homogenised at 580 ^{o}C for 2, 2.5, 3 and 3.5 hours and air cooled, solution treated at 540 ^{o}C for 4 hours, quenched in water and artificially aged at 185 ^{o}C for 5 hours. The group II samples were solution treated at 540 ^{o}C for 4 hours, quenched in water and artificially aged at 185 ^{o}C for 5 hours without prior homogenisation. The heat treated and as-received samples were subjected to tensile, impact and microhardness tests. Tensile test was carried out in accordance with British Standard BSEN 10002-1 [14] at room temperature with a crosshead speed of 5 mm/min using an Instron 3369 electromechanical testing machine. The proof stress, ultimate tensile strength, percentage elongation 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 [15]. Three samples were tested from each heat-treated condition and as-received samples. The tests were carried out using Izod impact test method on a Houndsfield balance impact-testing machine. An average value from three tests was taken are recorded. Microhardness testing was done using the LECO ASTM E384 microhardness tester. The tests were performed on the six etched samples used for the scanning electron microscopy. 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 six 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) [16].

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

3.0 RESULTS AND DISCUSSION

The need for further homogenisation is obvious in the microstructures of the as-received sample in Figure 2 and T6 tempered sample in Figure 3. The direct chill casting of ingot is associated with the evolution of plate-like phases that have deleterious effects on the mechanical properties of the alloy. These badly shaped phases must be completely eliminated via homogenisation prior to aging.

The yield strength values for the samples increased significantly after homogenisation. This is seen in Fig. 1 where there was an increase from 210 MPa for no homogenisation to 240 MPa after homogenisation for 2 hours. However, maximum value was obtained after homogenisation 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. 1. In these cases, homogenisation 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 and structures which are hard to remove by solution treatment only, enriching the solid solution matrix with solute atoms for solution strengthening and release of the solute atoms for subsequent formation of favorable and coherent precipitates.

Figures 2 and 3 are the microstructures of the as-received and samples solution treated and aged but without prior homogenisation. The presence of incoherent and elongated intermetallic phases in these two Figures is responsible for low yield and ultimate tensile strengths values. The sudden increase in the mechanical properties, as shown in Fig. 1 above, after 2 hours homogenisation was as a result of complete spheroidization of plate-like phases present in the alloy matrix and the formation of suitable heterogeneous nucleants (dispersoids) which enhances the quench sensitivity and precipitates formation during sebsequent aging.

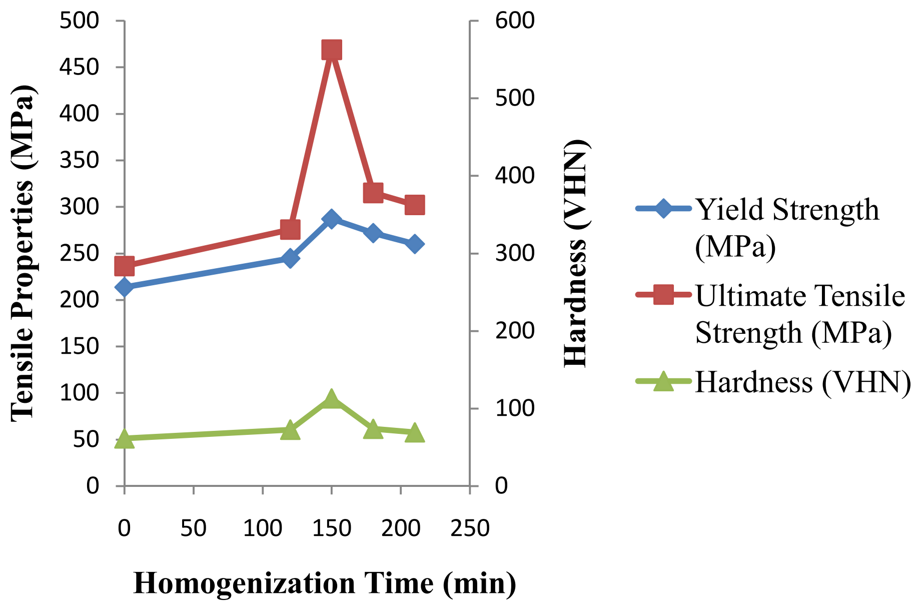


Fig. 1. Variations of yield strength, ultimate tensile strength and hardness with homogenisation time for T6 tempered and homogenized prior to T6 tempered 6063 aluminium alloy.

This increases the density of precipitates formed and thereby strengthening the alloy by exerting great barrier to dislocation movement. The sudden drop at about 30 minutes latter could be attributed to the formation of incoherent precipitates as a result of excessive homopgenisation.

The optimum values of yield and ultimate tensile strength (287 and 470 MPa) were obtained at 2.5 hours homogenisation prior to aging. This means that complete homogenisation treatment was achieved at 2.5 hours during which there was removal of segregations, spheroidisation of dispersoids and transformation of β-Al-Fe-Si to α-Al-Fe-Si for the formation of coherent precipitates during aging and this is in agreement with the results of [5, 17, 18] whose results show that no more than 2.5 hours is required for complete homogenisation of 6063 aluminium alloy. This structure is seen in Fig. 4, where complete spheroidisation took place.

However, the reduction in mechanical properties after 2.5 hours homogenisation is likely to be due to formation of non-coherent precipitates caused by excessive dissolution of solute atoms during extensive homogenisation. This has resulted in a condition for over aging. This is evident in the amounts of precipitates in Figures 5 and 6 as compared with Fig. 4.

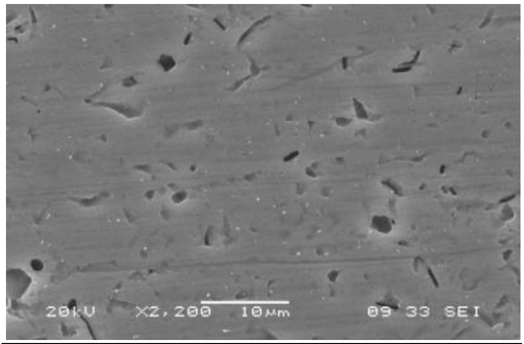


Fig. 2. SEM micrograph of the as-received 6063 aluminium alloy used for this study.

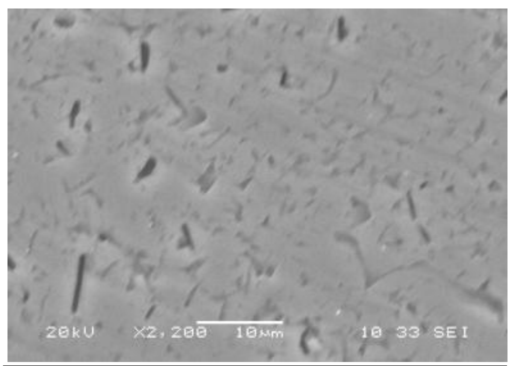


Fig. 3. SEM micrograph of T6 Tempered 6063 aluminium alloy

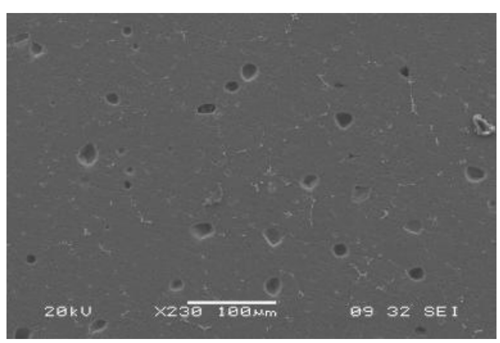


Fig. 4. SEM micrograph of 6063 aluminium alloy homogenised at 580 ^{o}C for 2.5 hours and T6 tempered.

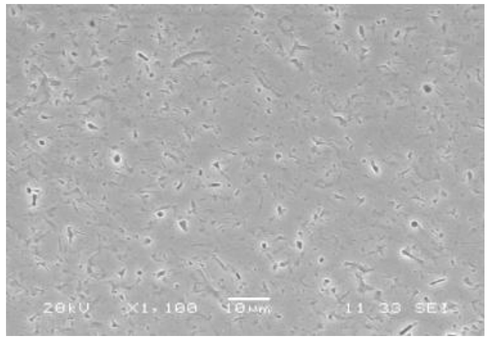


Fig. 5. SEM micrographs of 6063 aluminium alloy homogenised at 580 ^{o}C for 3 hours and T6 tempered.

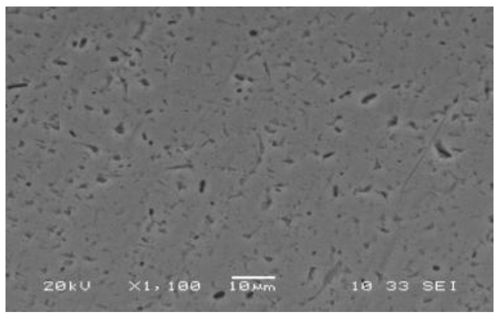


Fig. 6. SEM micrographs of 6063 aluminium alloy homogenised at 580 ^{o}C for 3.5 hours and T6 tempered.

The same result was observed for the hardness values as in the yield and ultimate tensile strengths in Fig. 1. Hardness values increased from 65 VHN (for no homogenisation) to 117 VHN (for 2.5 hours homogenisation). Thereafter, it significantly dropped to 74 VHN and 69 VHN for 3 and 3.5 hours homogenisation 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 homogenised for 2.5 hours prior to aging at 180 ^{o}C for 5 hours affirmed the theory that srength and hardness are constant multiples of each other [19, 20].

From Fig. 7, the ductility as indicated by the % elongation increased with homogenisation time. Generally, the % elongation was not significantly increased with homogenisation period and seemed to reach a low maximum level after 2.5 hours homogenisation. The comparatively high % elongation obtained when no prior homogenisation was carried out is not expected. It appears that solution treatment alone resulted in stress relief annealing of the as-received structure Fig. 2. The % elongations values for specimens homogenised for 3 and 3.5 hours were still considerably higher than when no homogenisation was carried out. This was also confirmed by the microstructure in Fig. 3, where there is substantial quantity of unmodified second phase particles. Fig. 7 shows that, the impact strength increased with homogenisation time except for those samples homogenised for 2 hours and above reaching a maximum level for 2.5 hours. The low toughness values for samples homogenised for less than this period could be attributed to the presence of brittle intermetallic compounds present in their structures (Figures 2 and 3).

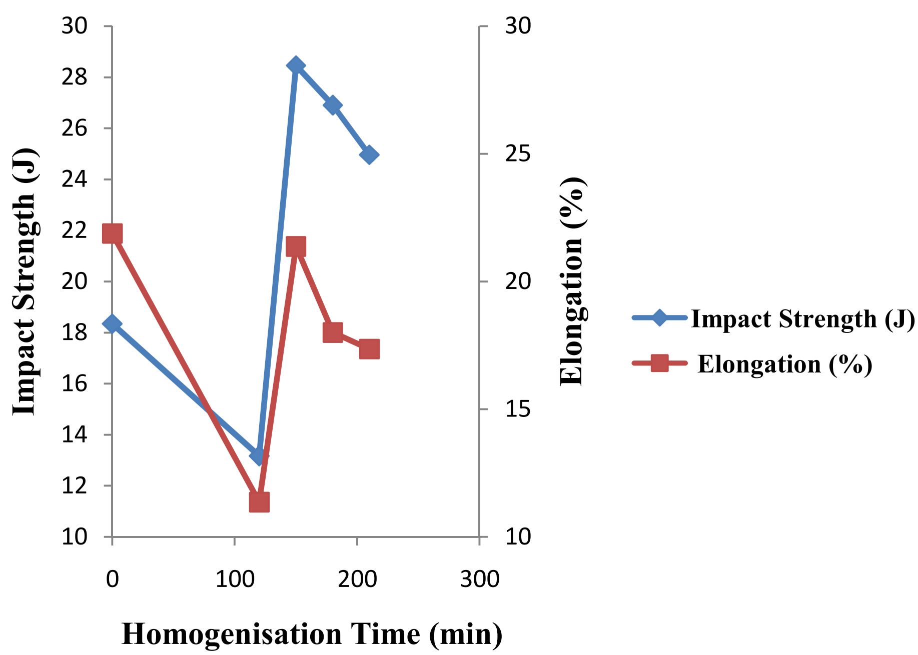


Fig. 7. Influence of prior homogenisation treatment on impact strength and percentage elongation of T6 tempered 6063 aluminium alloy.

The high toughness values observed for those samples homogenised 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 homogenisation was as a result of very low tensile strength level caused by low homogenisation during solution treatment [5, 21].

The high toughness values observed for those samples homogenised for 2.5, 3 and 3.5 hours prior to aging were due to complete transformation of monoclinic β-Al-Fe-Si to a face-centered cubic α-Al-Fe-Si phase and complete spheroidisation of other dispersoids present in this alloy (Figures 4, 5 and 6). The monoclinic β-Al-Fe-Si has low high-temperature ductility [16, 22].

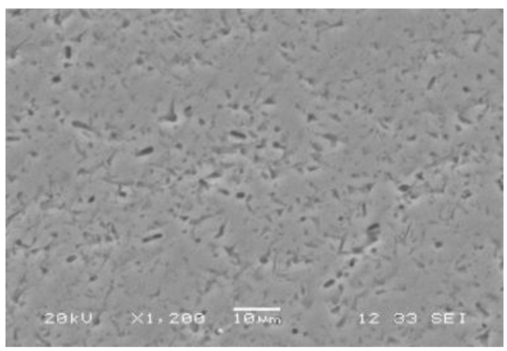


Fig. 8. SEM micrograph of 6063 aluminium alloy homogenised at 580 ^{o}C for 2 hours and T6 tempered.

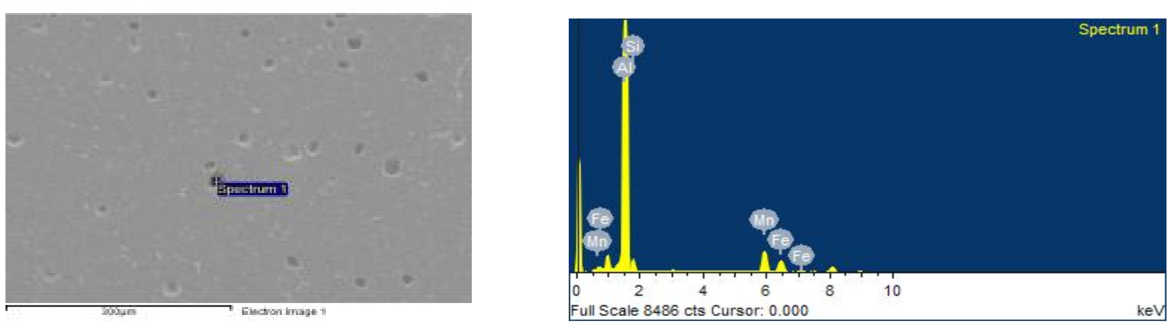
The presence of manganese and chromium in this alloy also has a beneficial effect on its toughness. The presence of dispersoids in manganese/chromium containing alloys promotes intragranular precipitation and avoids precipitation on grain boundaries and formation of precipitate free zones adjacent to grain boundaries. This prevents weakening of grain boundaries and maintains the toughness of 6063 aluminium alloys [21]. This prevents the usual corresponding decrease in toughness and ductility of T6 tempered aluminium alloys. Because those samples homogenised prior to aging have the highest number of grain boundaries, dislocation movement becomes more and more difficult during plastic deformation.

The strong increase in the mechanical properties as a result of homogenisation prior to aging can be attributed to the attainment of full potentials of homogenisation treatment. These according to the literatures [5,7] includes removal of microstructure inhomogeneities such as microsegregation, complete spheroidisation of the plate-like/sharp edges phases/dispersoids present in the as-received samples, formation of secondary dispersoids of favourable morphology and uniform distribution of alloying elements. Homogenisation ensures complete dissolution of sharp edge phases that are associated with direct chill casting of the ingot used for the extrusion of this alloys and formation of better ones at homogenisation temperature. All the alloying elements except for copper increase the quench sensitivity of this alloy [4]. These Al-Fe-Mn/Cr-Si dispersoids act as heterogeneous nucleants for magnesium-silicide precipitates during aging thereby increasing the quench sensitivity of this alloy. This leads to an increased in the density of precipitate formed. The finer these grains are the more the grain boundaries. During plastic deformation, dislocation movement must take place across these grain boundaries. Since polycrystalline grains are of different crystallographic orientations at the grain boundaries, a dislocation passing from one grain to another will have to change its direction of motion. Such changes of direction causes impediment to dislocation movement and thereby strengthening the alloy. Age hardening samples have the highest number of grain boundaries; dislocation movement becomes more and more difficult during plastic deformation. This is responsible for optimum combination of mechanical properties for those samples homogenised prior to aging as compared to those that were just T6 tempered.

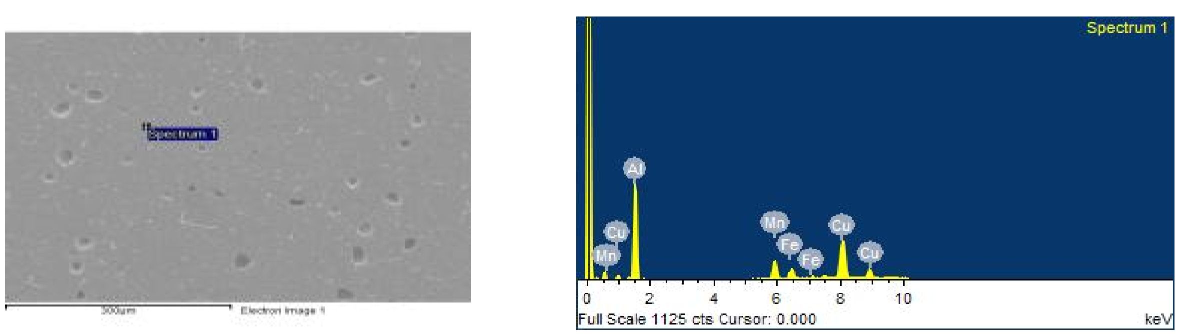
The discrepancies in the yield strength of T6 tempered 6063 Al alloy (208 MPa) as compared to (215 MPa) in the standard data can be attributed to the presence of defects in the as-received alloy (Figure 2) which could not be completely eliminated by solution treatment alone as evident in the Figure 3 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 [23].

The EDX analysis of the phases present is presented in Figures 9 a, b and c respectively. Besides the prominent Mg_2Si phase, which serves as second phase particle and contributes to the final mechanical properties, Fe in combination with Si can formed the ternary phase AlFeSi, or else with Cr, Mn the quartenary phase AlFeCuMn. It also indicates the presence of $CuAl_2$. This is in agreement with Samaras and Haidemenopoulos [16] who stated that several phases may be present in commercial alloys containing Al–Mg–Si–Fe–Mn–Cu–Cr–Zn.

(a)



(b)



(c)

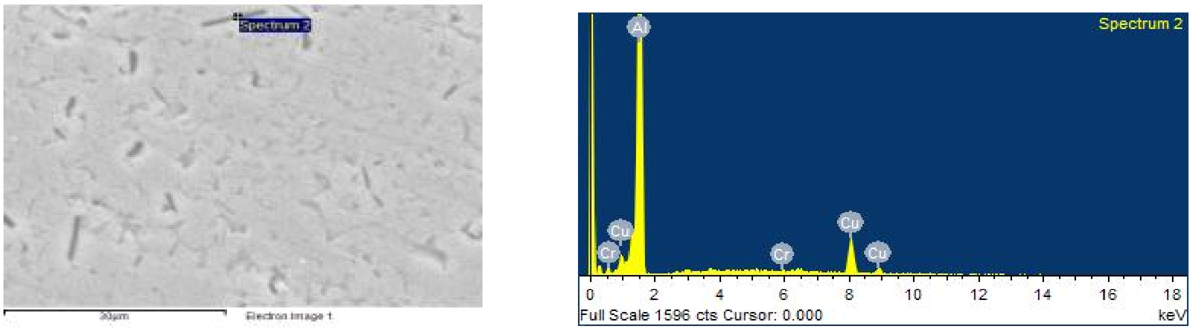


Fig. 9. a and b) shows the EDX analysis of spherical precipitates, c) shows the EDX analysis of Rod-like precipitates

4.0 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 homogenisation treatment.
2) Fragmentation and spheroidisation of sharp edges dispersoids in 6063 Al occur during homogenisation and greater degree of spheroidisation was achieved at 2.5, 3 and 3.5 hours of homogenisation at 580 °C.
3) The optimum combination of strength and toughness values was obtained at 2.5 hours homogenisation prior to aging.
4) Unlike in conventional aging where an increase in hardness and strength usually leads to corresponding decrease in ductility and toughness, homogenisation treatment prior to aging helps to maintain the ductility and toughness values of the age-hardened 6063 aluminium alloy.

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