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INFLUENCE OF INOCULANT ADDITION AND COOLING MEDIUM ON THE MECHANICAL PROPERTIES OF AA 6063-TYPE Al-Mg-Si ALLOY

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Studies have been made on the influence of water and air cooling coupled with inoculation on the mechanical properties of 6063 aluminum alloy. The work was aimed at investigating the combined effects of two crystallization enhancers in order to provide a synergy-form of effect in the mechanical properties using 4.2% wt and 16.5% wt Ni powder particles. The alloying compositions, phase change and micro-hardness were determined by using energy dispersive spectroscopy (EDX), XRD and Brinell micro-hardness tester. The surface morphology of the alloyed sample using scanning electron microscopy (SEM) showed that Ni particles were distributed by virtue of surfactant addition and mechanical stirring. Addition of Ni powder coupled with increase in solidification rate yield size reduction in aluminum alloy structure. The results also revealed that conglomeration of inoculant addition and water cooling increased the fracture strength of the aluminum alloy while both axial and lateral deformations were altered.

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1. Introduction

Aluminium and its alloys have been identified as an important and useful engineering material. It is attracted by its various unique properties; such as appearance, strength-to-weight ratio, excellent thermal properties, workability properties and good mechanical behavior [1-5]. However, to obtain special mechanical properties for aluminium product, some nucleants are essential in a melt. From reviews, it is evidenced that proper casting is aimed at yielding sound and defect - free products. The soundness of every cast product can be achieved by grain refining, which entails increasing the rate of heat extraction (rapid cooling), addition of grain refining agents (chemical grain refinement) and vibration of melt [6-8]. High solidification rate occurs when the rate of heat extraction exceeds the latent heat of solidification and this is concluded to refine grains and enhance the material's strength and other mechanical properties [8-11]. Chemical grain refinement on the other hand, also influences the morphology and exerts a beneficial mechanical property, though it doesn't affect the freezing rate [8,12,13].

Cast aluminum alloys are mostly grain refined by adding mixtures of some essential elements to enhance and impact some important characteristics [14]. Titanium or titanium-boride (Ti or TiB) particles addition in cast bath has been reported to enhance the metal stability [8,12]. Titanium, in their low contents was affirmed to eliminate sludge formation, induce smaller grain size and improve hot cracking resistance in some alloys. Boron is investigated to be insoluble in aluminum compared to titanium, hence, it is said to be more effective as a nucleant than titanium.

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Although grain refiners has been used to enhance aluminium alloy properties, but little have been reported on the effect of nickel nucleants along with cooling media on the mechanical properties of aluminum-silicon alloy. In this work, influence of inoculant addition and water cooling on the mechanical properties of 6063 aluminum alloy and how it affect its metallurgical behavior have been discussed.

2. Experimental procedure

2.1 Material preparation and alloy casting

The commercial alloys were prepared by liquid metallurgy technique in a cast iron mould in the form of cylindrical castings (40 mm in diameter and 200 mm long). An electrical furnace was used at the first stage for melting the Al in a graphite crucible under a nitrogen protective atmosphere. Subsequent to the melting of the Al, the melt temperature was increased to 700 ^{o}C and then Ni particles were introduced to the melt with vigorous stirring under protective gas and the melt temperature was decreased to 650 ^{o}C. The melts were then poured into permanent cast iron mould pre-heated to about 150 ^{o}C. The raw materials were pure Al (95 wt%) and Ni (99.95 wt%). Subsequently, five different Al-Ni based alloys having different cooling systems were prepared. The chemical compositions of the alloys determined by chemical spectroscopy are presented in Table 1.

Table 1. Chemical composition of the produced AA 6063 aluminum alloy using spectrometer analyzer.

Element	Al	Si	Mg	Fe	Cu	Mn	Ti	Cr
Composition wt%	95	0.45	0.50	0.22	0.03	0.03	0.02	0.03

Solidification was facilitated for some samples by full immersion in water at room temperature while some were allowed to cool in air. The processing and designations of these samples are shown in Table 2.

Table 2: Processing method and designation of samples.

Mass of Ni powder (wt%)	Solidification medium	Sample designation
-	Water	A
4.2	Water	B
4.2	Air	C
16.5	Water	D
16.5	Air	E

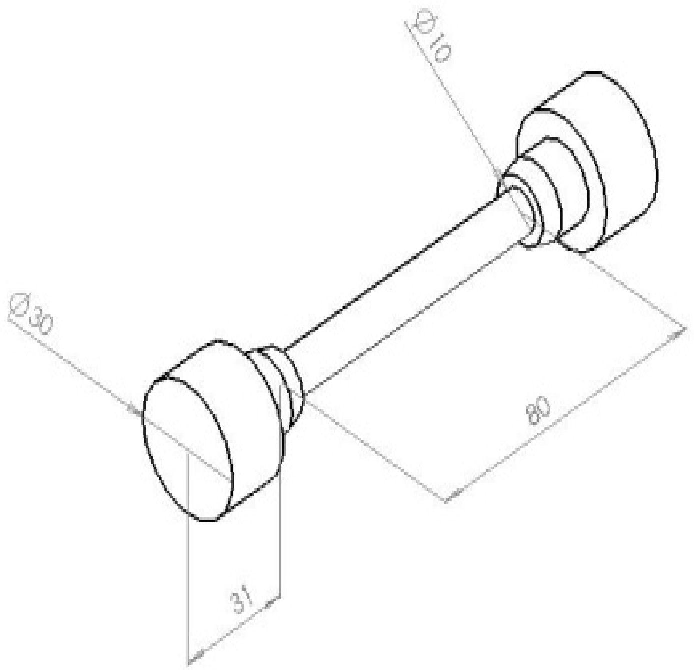

Fig. 1. Schematic diagram of the tensile test piece dimension (mm).

2.2 Tensile test

Tensile tests were carried out with the use of universal testing machine (TQSM 1000), which had digital load and displacement meters attached for the measurement of applied tensile loads (in kN) with corresponding specimen longitudinal displacements (mm).

2.3 Hardness test

The TQSM 1000 Universal Testing machine was used for the Brinell's hardness test, where a 10 mm diameter indenter was used. A digital load meter, attached to the machine, measured the load (kN) that created indentations on the specimens with 20 s dwell time. While a microscope was used in measuring the diameter (mm) of indentations. The Brinell hardness number, HBN, was computed by fitting the values of the measured parameters into the Brinell's hardness formula. Five impressions were made to determine the mean value of the hardness at different positions to evade the possible effect of any alloying element segregation.

2.4 SEM/EDS examination

After the casting process, a thorough morphology of the alloyed and phase change was undertaken in terms of microstructure, composition and phases. Chemical reactions between molten aluminium and the metallic alloying agent led to the precipitation of different intermetallic compounds within the surface matrix. The new phases formed were studied. Sectioning, grinding and polishing of alloyed layers were carried out. The polished surfaces were etched using Keller's reagent. The new phases were characterized by Field Emission Scanning Electron Microscope (Joel JSM-7500F) equipped with energy dispersive spectroscopy which was used to assessed the constituent elements.

3. Results and discussion

3.1 Effects of inoculant on stress-strain behavior

Mean values obtained from the mechanical behaviour of the experimental alloys containing Ni powder, in the range of 4.2 and 16.5 wt% Ni were shown in Figure 2. From the stress- strain curve, sample D, which had its melt inoculated with 16.5 wt% of Ni powder and rapid cooled in water, had the highest tensile strength of approximately 10.4 x 10^7Pa (104MPa), followed by sample E, fracturing at its highest strength of 9.8 x 10^7 Pa ,i.e (98Mpa). From the tensile strength behavior it can be said that cooling rate and the amount of particulate is a major factor to be carefully considered during plastic deformation [15]. This result also express the synergetic effect which high cooling rate and higher nickel content could offer to the mechanical strength rand ductility of aluminum as compared to the control sample (sample A) whose melt had no nickel added and made to cool in air. However, the detrimental influence of the coarsening of the phases may occur to some extent in the presence of additive containing particles [16]. Hence, addition of 4.2%wt Ni powders had little significant effects on strength. From Figure 2, the fracture stress of samples A ssand B are similar (≈9.5 x 107Pa, i.e 95MPa) and higher than sample C which had 4.2%wt of nickel inoculants and air cooled. This implies that the increasing solidification rate (by water cooling) enhanced the fractured strength of sample B to that level. In terms of samples with profound plastic deformation, the hierarchy (in increasing order) goes thus: sample E < sample D <sample C < sample B < sample A.

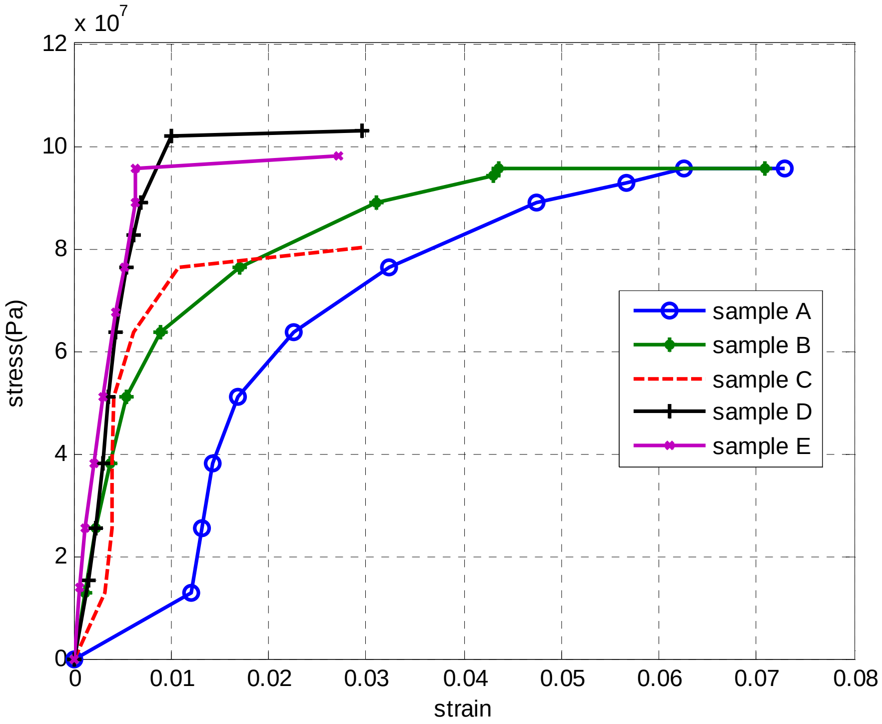

Fig. 2.: Variation of stress-strain value for the investigated samples.

3.2 Effects of inoculant on percentage elongation and reduction

The absence of nickel has engendered the greatest amount of percentage elongation and reduction of sample A as shown in Figure 3. Samples rapid cooled though, having similar nickel content showed lower response to deformation both in the axial and lateral axes as this can be seen in samples B, C and D, E having 4.2%wt and 16.5%wt of nickel powders which were slow cooled and rapid cooled respectively. Samples C and D elongated by the same amount (≈3%). Samples express more of lateral deformation than that of axial with the exception of sample E whose percentage reduction is lower than its percentage elongation.

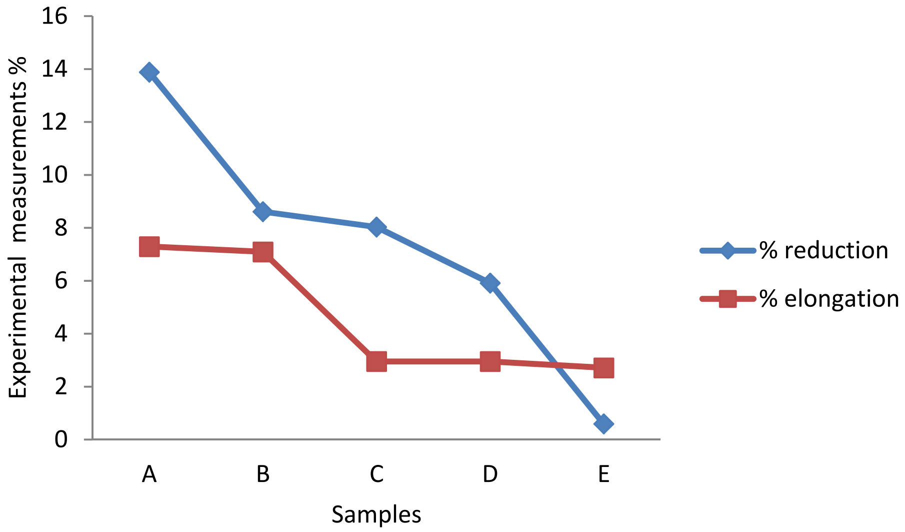

Fig. 3. Variation of percentage elongation and reduction of samples

A decrease in the elongation and reduction of the cast at 16.5 wt% Ni could be due to higher particle solid solution and coarsening of the micro constituents which results in strain hardening.

3.3 Effect of inoculant on hardness behaviour of samples

Fig. 4 shows that sample D possesses the highest hardness value while the sample devoid of nickel (sample A) has the lowest. Combined effects of higher nickel powder inoculants and water cooling of samples have led to the increase in hardness as compared to samples inoculated with lower amount of nickel powders and slow cooled in air.

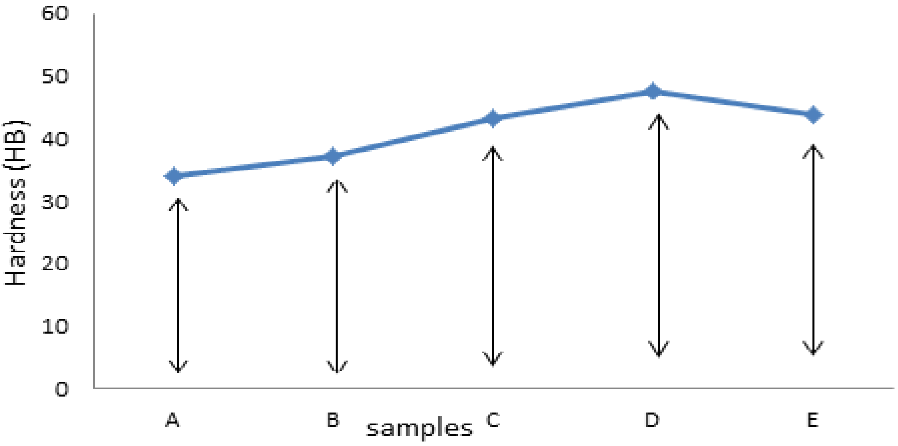

Fig. 4. Variation of hardness values of samples

3.4 Effects of inoculant and cooling medium on microstructural changes in the samples

Figures 5-8 show the microstructure and phase transformation of the as-cast Al-based alloys with and without inoculant at various concentrations and cooling medium. The influence of water as coolant was felt with sample a Figure (5) revealing the visibility of fine α – Al crystals at the surface. Fine crystal distribution of Al cluster was spread across the entire cast region with EDS showing the chemical composition and XRD spectrum revealing the present phase.

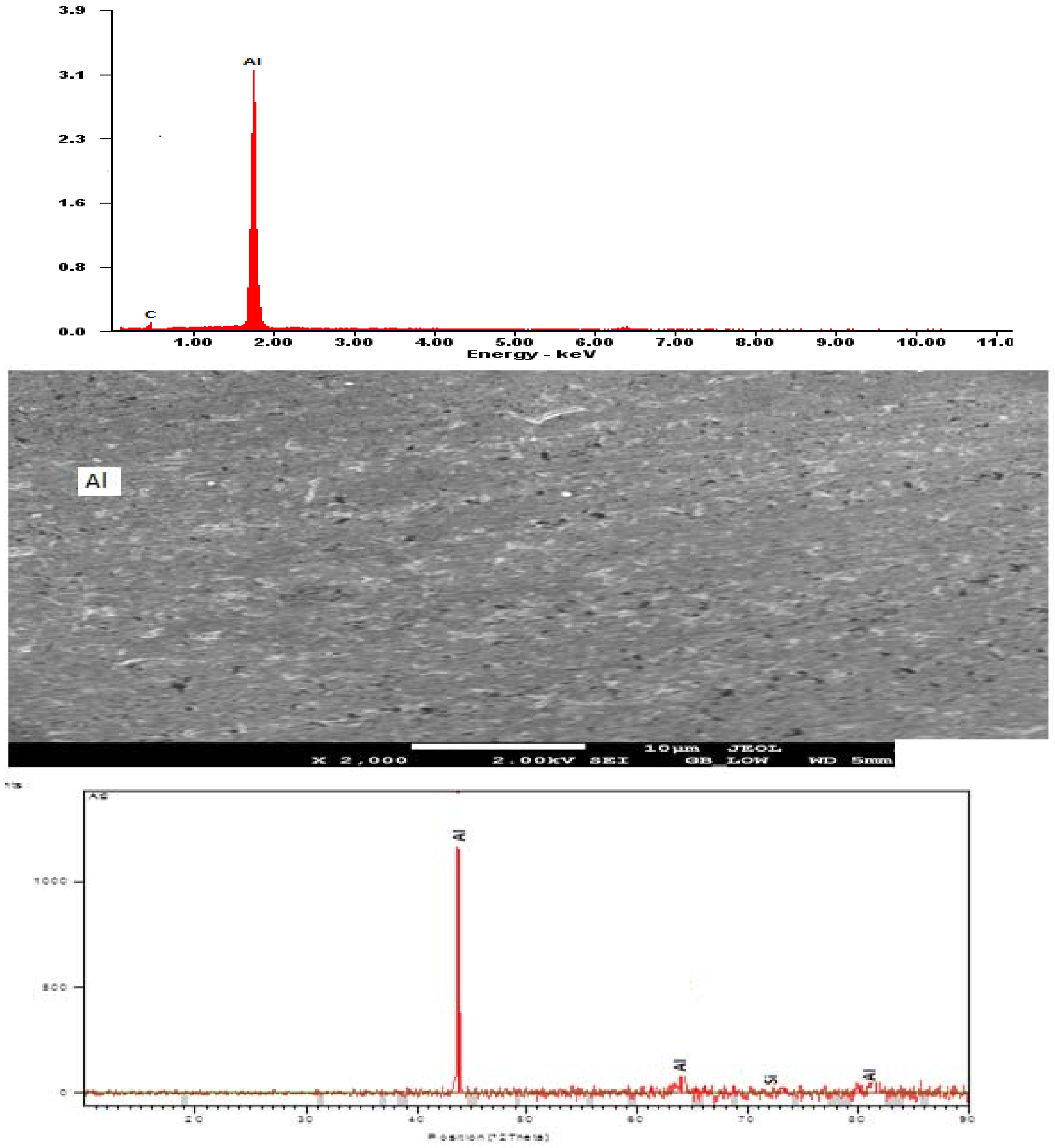

Fig. 5. SEM/EDS/XRD of Al cast using water as coolant.

In Figure 6a, 4.2% nickel in the Al melts drastically change the morphology of the working sample. The dendritic structure of a nickel alloy is evident. It is reported that the microstructure of castings is of great importance due to its role in mechanical properties [17]. A magnified view clearly reveals a primary dendrite surrounded by the eutectoid and eutectic phase presence indicating the small particle of Ni, although not evenly distributed within the as-cast matrix. It can also be said that with 4.2% nickel and water cooled system revealed the as-cast containing a complex nickel-based intermetallic compound.

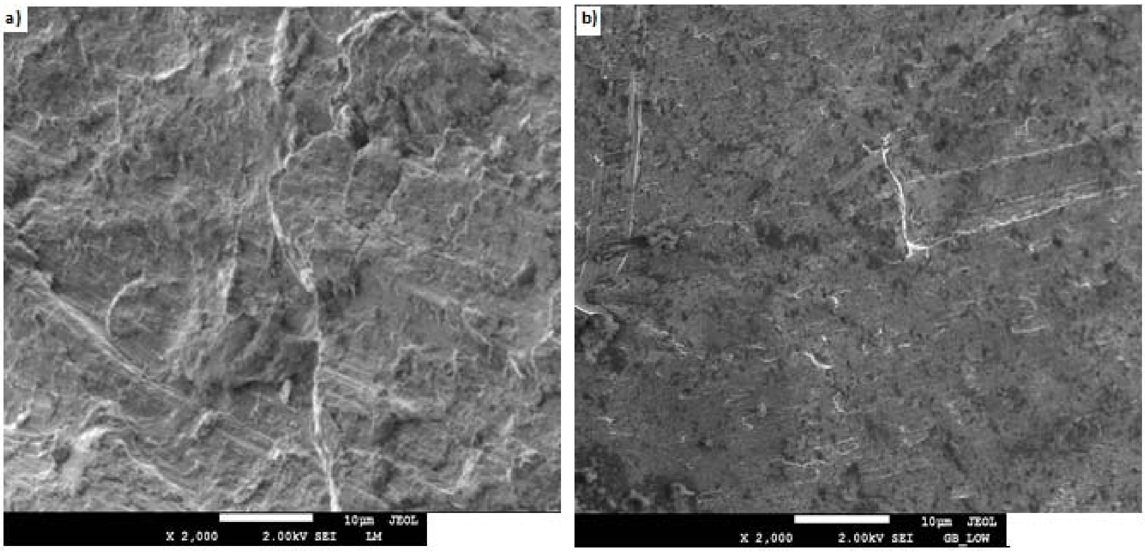

Fig. 6. SEM micrographs of 4.2% Ni (a) water cooled and (b) air cooled.

Figure 6b is similar to Figure 6a, which indicates the same percentage of inoculant but was freely cool on air. The cooling medium has great impact on the surface characterization property of the as-cast. The grains possess smaller dark crystal unlike the water quench which have fine grain size and interlock which we might assumed it occurs during solidification as a result of grains refinement thus, restricted the casted product from fracture and increasing strength .Metallographic studies showed that addition of additive resulted in microstructural modifications of the alloy involving the formation of complex intermetallic compound on metal surface [18]. Hence, differences in the microstructure across the samples might probably be attributed to its degree of cooling and the intermetallic phases which significantly altered the mechanical behavior of the cast product.

In Figure 7 similar trend was observed in the alloy containing 16.5% nickel with air cool system, except that nickel particles were also present at larger quantity with partial homogenization and well dispatch formation in its microstructure forming a suitable phase of Al_2Ni and Al_3Ni_2 clusters along the cast surface. The nucleation of a nickel conformed to the hypereutectoid composition as far as their aluminium content is concerned. Micro-segregation resulting from the water cooling point of aluminium with nickel also causes limited eutectic transformation to occur forming eutectic within the region [15,19]. It is noted that the first phase to solidify is the aluminium rich appearing as primary dendrites which is attributed to the melting temperature of Al. This is followed by the eutectoid and of eutectic transformation leading to the occurrence of the phases in the inter-dendritic regions [16]. Although, nickel addition enhanced the strength but beyond 16.5 wt% formation, metastable phase and initiation of crack is likely to be induced.

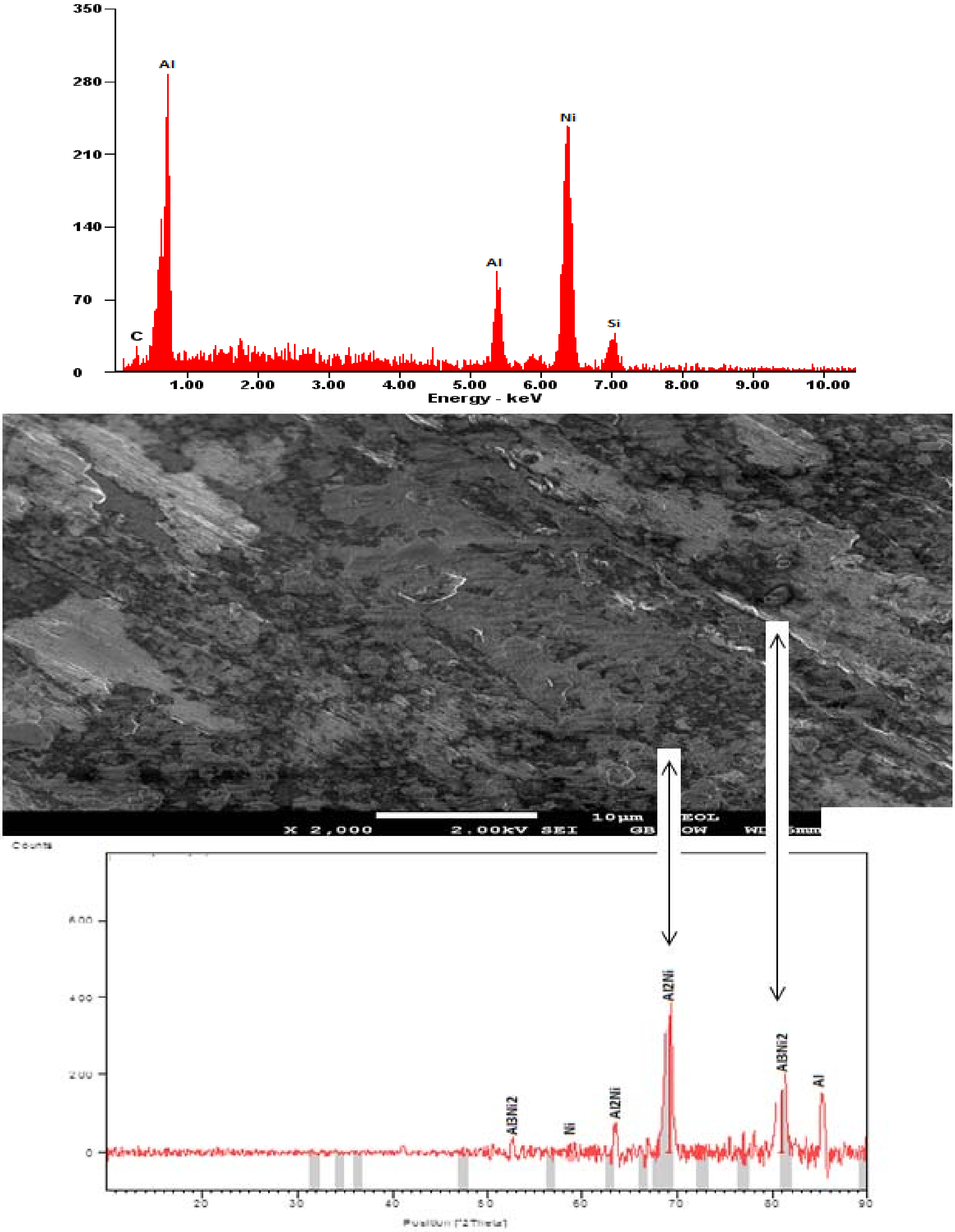

Fig. 7: SEM/EDS/XRD of 16.5% Ni using water as coolant.

With Figure 8, the influence of air cooling rate on the physical property was also felt on the mechanical strength of the as-cast product.It can be seen that addition of above 4.5 %wt of Ni to the alloy system marginally reduced strain behavior and this may alter the morphological tendency as well as ability of nickel forming complex intermetallic compounds.

The nucleation of nickel containing phase(s) could be attributed to the favourable sites for the nucleation offered by the aluminum particles that are formed first during solidification. Solidification process also may have contributed to the redistribution of the solute elements and to the breaking of the dendritic structure. These factors caused the alloy(s) to homogenize. The redistricted structure of the resolidified regions, where partial melting had taken place Figure 8 was due to a significantly higher rate of solidification experienced by the regions during quenching from the high casting temperature. It may be noted that the solid regions surrounding the molten ones act as a heat sink during the process of cooling thereby facilitating a higher rate of solidification and formation of stable phase.

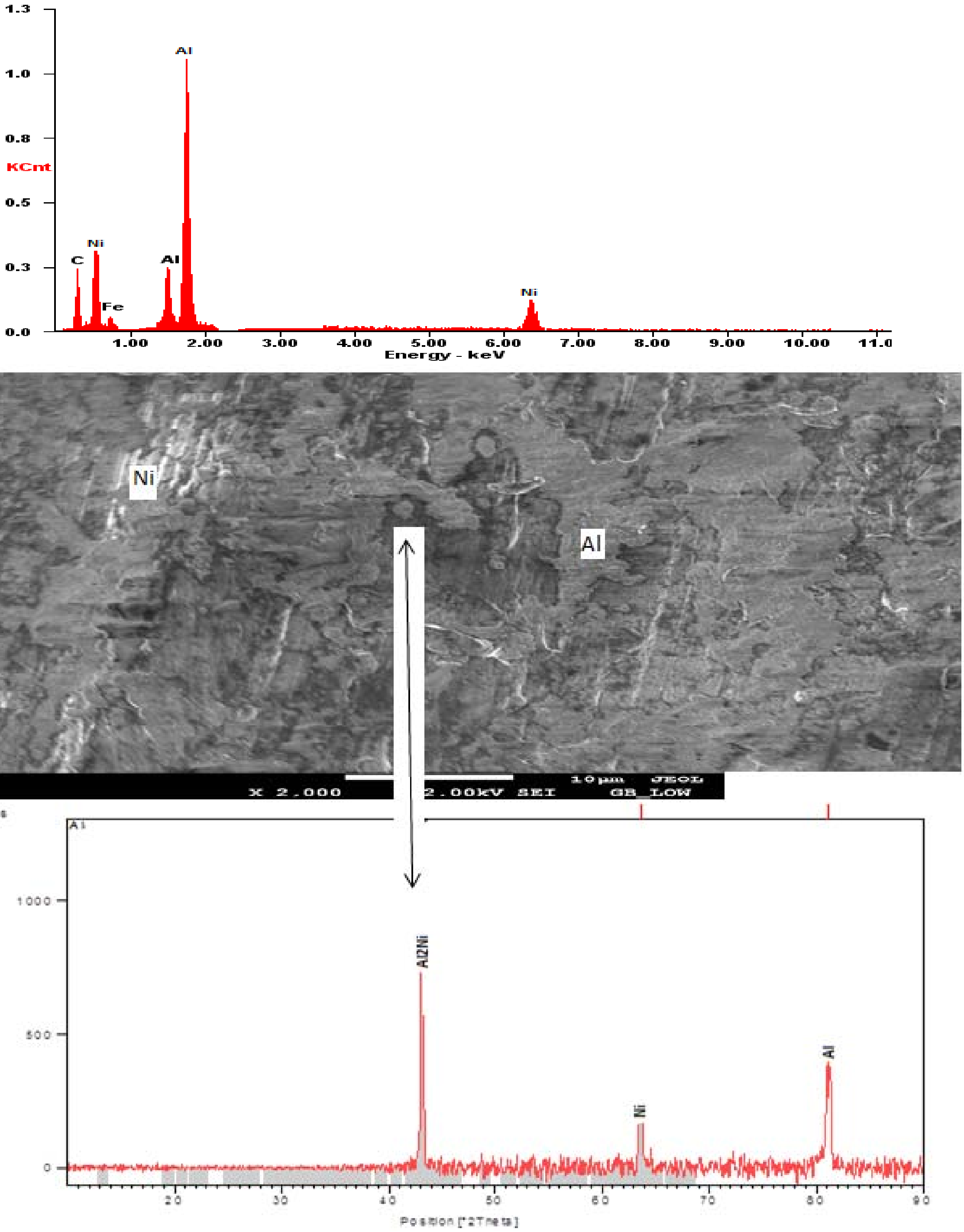

Fig. 8: SEM/EDS/XRD of 16.5% Ni cooled in air.

4. Conclusions

1. Addition of Ni powder coupled with increase in solidification rate yield size reduction in aluminum alloy structures.

2. Conglomeration of innoculant addition and water cooling increases the fracture strength of 6063 aluminum alloy. While 4.2 wt% of Ni powder and air cooling the melt lowers fracture strength.
3. Aluminum with better hardness can be obtained when 16.2 wt% of Ni powder coupled with water cooling are adopted.
4. Hastening solidification rate via water cooling and 4.2% wt inoculation yields a better ductility in direction parallel to the applied load in tension.

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