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A Comparative Study on the Mechanical Behaviour of Copper-12wt% Aluminium Alloy Reinforced with Ti, Cr and Ni Granules

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ABSTRACT
This work centres on the fabrication of copper-12wt% aluminium alloy, reinforced with various weight percentages of titanium, chromium and nickel granules. The mechanical (tensile strength, hardness and percentage elongation) and structural behaviours of copper-12wt% aluminium alloy were examined. The samples were tested according to ASTM standards. Metallographic analysis was conducted by scanning electron microscopy (SEM) equipped with energy dispersive spectroscopy (EDS) to complement observations from the implemented characterisation techniques. Generally, results of the mechanical tests improved the properties of copper-12wt% aluminium alloy with respect to the addition of reinforcing particulates. Moreso, samples reinforced with nickel have superior tensile strength (297MPa) and hardness (412BHN) compared to samples reinforced with titanium and chromium. Percentage elongation decreased as reinforcing elements increased in the alloy. The metallographic analysis revealed an even distribution of reinforcement particulates, precipitations of smaller kappa-phases and the presence of large globular intermetallic compounds within the microstructure, which are responsible for the improvement of the alloy's mechanical properties.

KEYWORDS: *Copper-12wt% aluminium, Microstructure, Mechanical properties. Carbide forming elements.*

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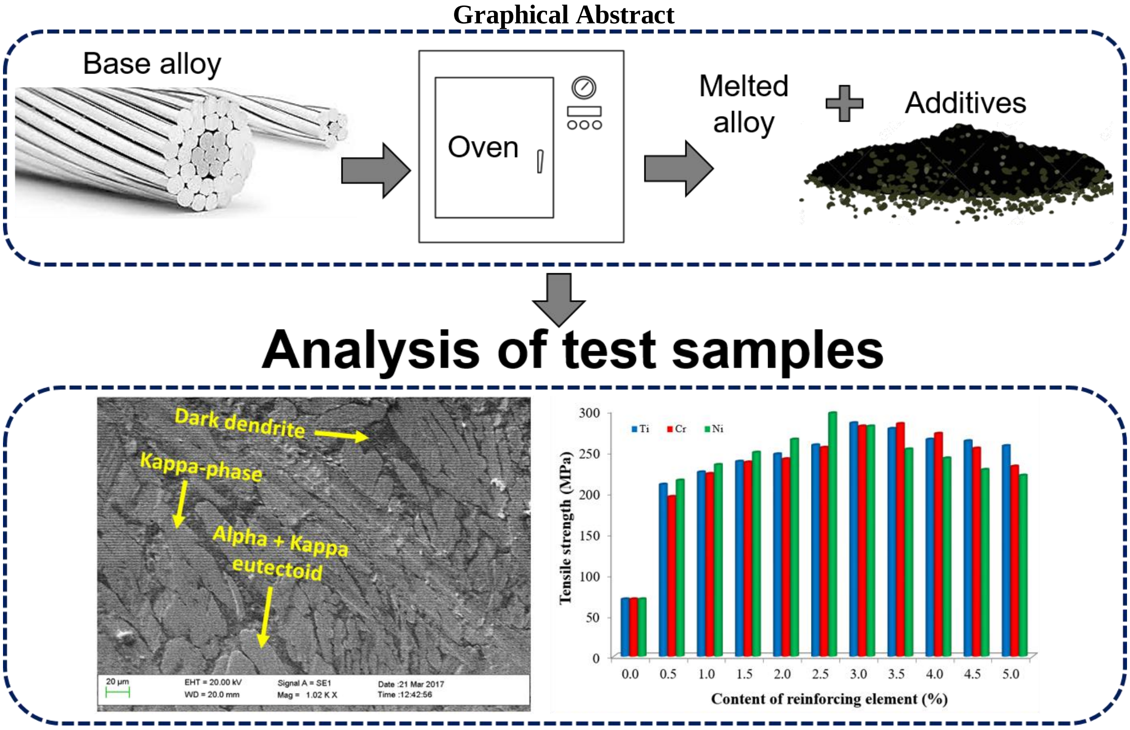
Graphical Abstract



I. INTRODUCTION

Copper matrix composites are among the essential materials in engineering industries because of their outstanding mechanical properties; they have a wide range of application in aerospace, marine and automobile industries [2-3, 5, 8]. Also, the desired mechanical properties (light-weight, damage/fracture-resistance, improved strength and corrosion resistance) for engineering applications are highly dependent on the material composition and structure, which in turn relates to the processing conditions and techniques applied [15-17]. Despite some of the desirable characteristics of aluminium-bronze composites, its abysmally inadequate responses in specific applications necessitate mechanical property enhancement [9, 20]. Therefore, researchers have been developing novel approaches to address these issues. Kuppahalli et al. [4] investigated the microstructure and mechanical properties of nickel-aluminium-bronze using permanent and shell moulded castings. The results revealed an outstanding improvement in mechanical properties and extensive grain refinement. Nwaeju et al. [2] investigated the effect of vanadium and chromium macro-additions on the properties of aluminium-bronze using a sand casting technique. The additives were added in different compositions (1.0 – 10wt%). Tensile strength, yield strength, and percentage elongation were the properties analysed. Their findings showed that the properties were generally improved and vanadium gave the best result compared to chromium. Sekunowo et al. [5] performed an investigation on the microstructure and mechanical properties of cast aluminium-bronze reinforced with iron granules composite. The metal mould containing mill scale in a varied amount from 2-10% was used to fabricate the composite samples.

Kalaiselvan et al.[1] studied the fabrication of aluminium (6o61-T6) matrix composites reinforced with various weight percentages of B_4C particulates by a modified stir casting route. The result revealed the homogeneous dispersion of B_4C particles in the matrix and an improvement in mechanical properties with the increase in the additive content in the aluminium matrix. Mechanical property analyses such as tensile, Charpy impact and micro-hardness testing were utilised, while optical microscopy was employed to characterise the structures. The result revealed that the reinforcement provided an optimum enhancement of the mechanical properties. Lei et al. [18] performed experiments on the mechanical properties and microstructure of Cu-1.8Si-8.0Ni-0.6Sn-0.15Mg alloy. They found that the properties were significantly improved. The effect of titanium content on the structure and mechanical properties of Cu-Ni-Si alloy were investigated by Eungyeong et al. [16]. Different ageing times were implemented to characterise the effect on material properties. They discovered that tensile strength and electrical conductivity of the alloy were significantly enhanced. Likewise, the effect of silicon content on the mechanical properties of silicon-bronze was also evaluated by Ketut et al. [17]. The observations depict that the mechanical properties of Cu-Si were higher than Cu-20wt%Sn bronze. Furthermore, Lei et al. [18] reported that the addition of aluminium to Cu-Ni-Si alloy has a significant effect on the physical and mechanical properties of the alloy. Mattern et al. [19] also investigated the microstructure of silicon-bronze and observed suppression of the kappa phase through rapid quenching and the presence of different phases such as gamma, beta and kappa phases within the microstructure of the alloy.

Very limited studies have been reported on the comparative investigation of copper-12wt% aluminium alloy reinforced with different additives. This work investigated the microstructure and mechanical behaviours of copper-12wt% aluminium alloy reinforced with nickel, titanium and chromium granules. The mechanical characteristics and metallographic analyses of these alloys were comparatively studied to provide valuable insights into its industrial applications.

II. EXPERIMENTAL PROCEDURES

2.1. Materials and fabrication

Copper with 12wt% aluminium (Cutix cable Plc, Nnewi, Nigeria) as the base alloy, was melted in a bailout crucible furnace and the additives (Ti, Ni & Cr) particles (Kermel Chemical Reagent Co. Ltd. Hebei, Tianjin, China), were added in concentrations of 0.5wt% to 5.0wt% before the permanent die casting technique was used for casting the 31 samples used in this study. The molten mixtures were stirred for proper homogeneity with the help of a mechanical stirrer [21-22].

2.2 Mechanical and structural characterisation

After solidification, these samples were prepared for mechanical testing (by machining to ASTM testing standards), and structural analysis by etching with alcoholic ferric chloride for 60 seconds. The tensile strength test was conducted according to ASTM E8 standard, and hardness, according to ASTM B929-17 standard. The analyses were performed with a digital hydraulic universal tensile testing machine (Satec series, Instron 600DX) for tensile strength and portable dynamic hardness testing machine (DHT-6) for hardness, respectively. Scanning electron microscopy (SEM) equipped with energy dispersive spectroscopy (EDS) and optical metallurgical microscope (L2003A) were used to analyse the microstructure of the samples.

III. RESULTS AND DISCUSSION

3.1 Evaluation of mechanical properties

According to the mechanical analyses presented in **Figure 1a**, it is evident that the tensile strength of Copper-12wt% aluminium alloy generally increased significantly with the inclusion of the additives. The improvement on the tensile strength was caused by the modification of the microstructure, which led to an increase in the grain boundary area and the impediment of dislocation motion. Tensile strength gradually increased as the composition of reinforcing elements increased. For instance, nickel content recorded a maximum value at 2.5wt %, (297MPa), titanium at 3.0wt% (285 MPa) and Chromium at 3.5wt% (284MPa). Their tensile strength values decreased afterwards as a result of the excess amount of reinforcing elements, which made the alloys brittle.

Figure 1b, depicts the improvement of the hardness of copper-12wt% aluminium alloy as the composition of reinforcing elements increased in the alloys. It is observed that the hardness of copper-12wt% aluminium alloys are linearly increasing when the reinforcement particulate content increases, but decreased at certain weight percentages. The presence of such hard surface area of particles offers more resistance to plastic deformation, which leads to an increase in the hardness of the composites. The samples with nickel had their maximum value at 2.5wt% (412BHN), followed by titanium content at 3.0wt% (295BHN) and chromium at 3.5wt% (396BHN). Ramesh et al.[23] also reported that the presence of a carbide forming element, such as nickel, in the soft, ductile matrix reduces the ductility of the alloy and causes a significant increase in the hardness. It was observed that the percentage elongation decreased all through (**Figure 1c**), as the reinforcing elements increased in the alloy.

3.2 Evaluation of microstructure

Metallographic examination with a scanning electron microscope (SEM) revealed the precipitation of different phases (**Figures 3a, 4a & 5a**), which are beta phase, small k-phases and α + k eutectoid (coarsened intermetallic compound) in the alloy structure. These precipitations of a small k-phase increase the tensile strength, while the presence of large globular precipitates improves the hardness of the alloy. These phases were precipitated from the α-phase and $CuAl_2$ intermetallic phase (dark dendrite).

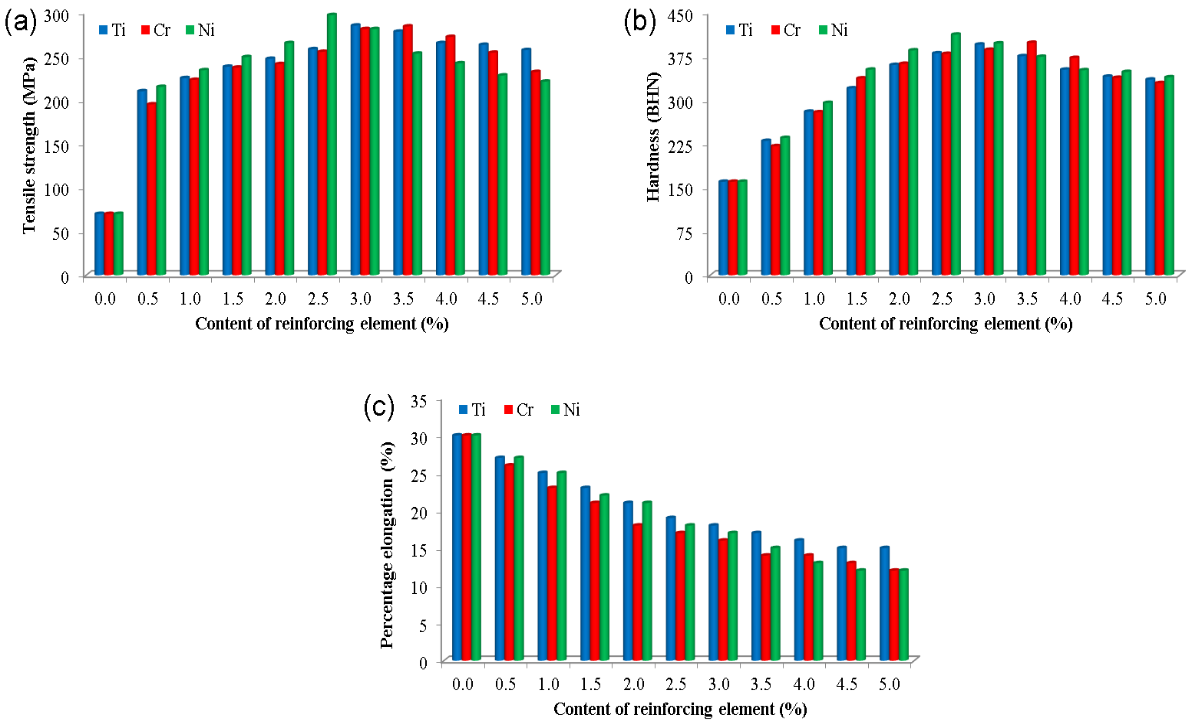


Figure 1: Impact of reinforcing element concentration on alloy mechanical properties.

Therefore the addition of carbide forming elements modified the microstructure of the alloy, which allowed the precipitation of k-phases, and the α+k-eutectoid phase, thereby impeding the dislocation motion. As shown in **Figure 5a, s**amples that contain nickel have better grains refinement with more of refined grains and kappa phases present in the microstructure, compared to the samples with titanium (**Figure 3a)** and chromium **(Figure 4a).** This corresponds with the findings of Lei et al. [18] on the microstructures of alloys. Scanning electron microscopy (**Figures. 2a, 3a, 4a & 5a**) revealed all the phases present in the alloy, such as the α-phase, k- phase, and α+k-phase with white and dark spots, while energy dispersive spectroscopy analyses (**Figures. 2b, 3b, 4b, & 5b**) indicated several peaks corresponding to the presence of significant elements in the alloys.

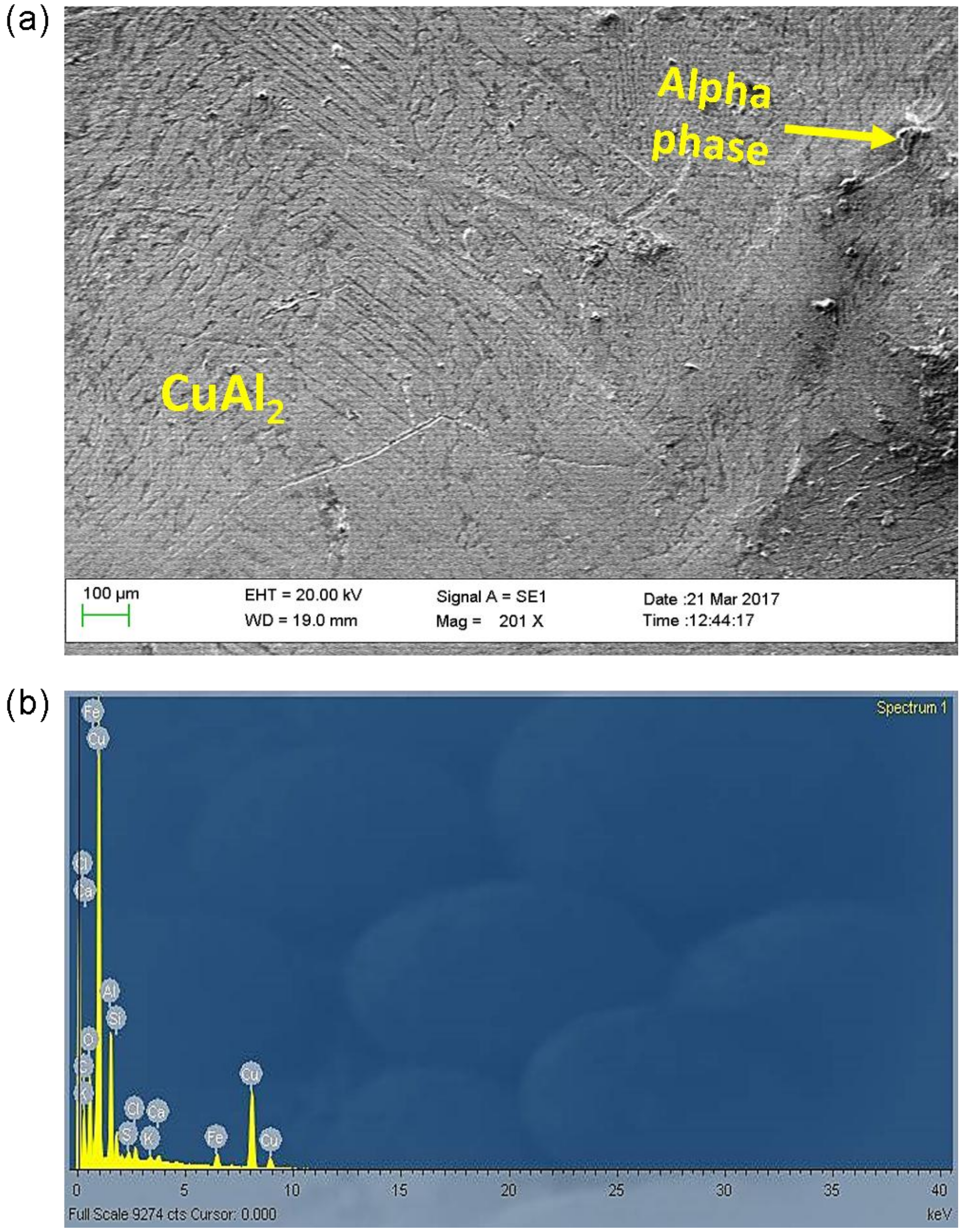


Figure 2: Scanning electron micrograph (a) and energy dispersive spectrum (b) of copper-12wt % aluminium alloy.

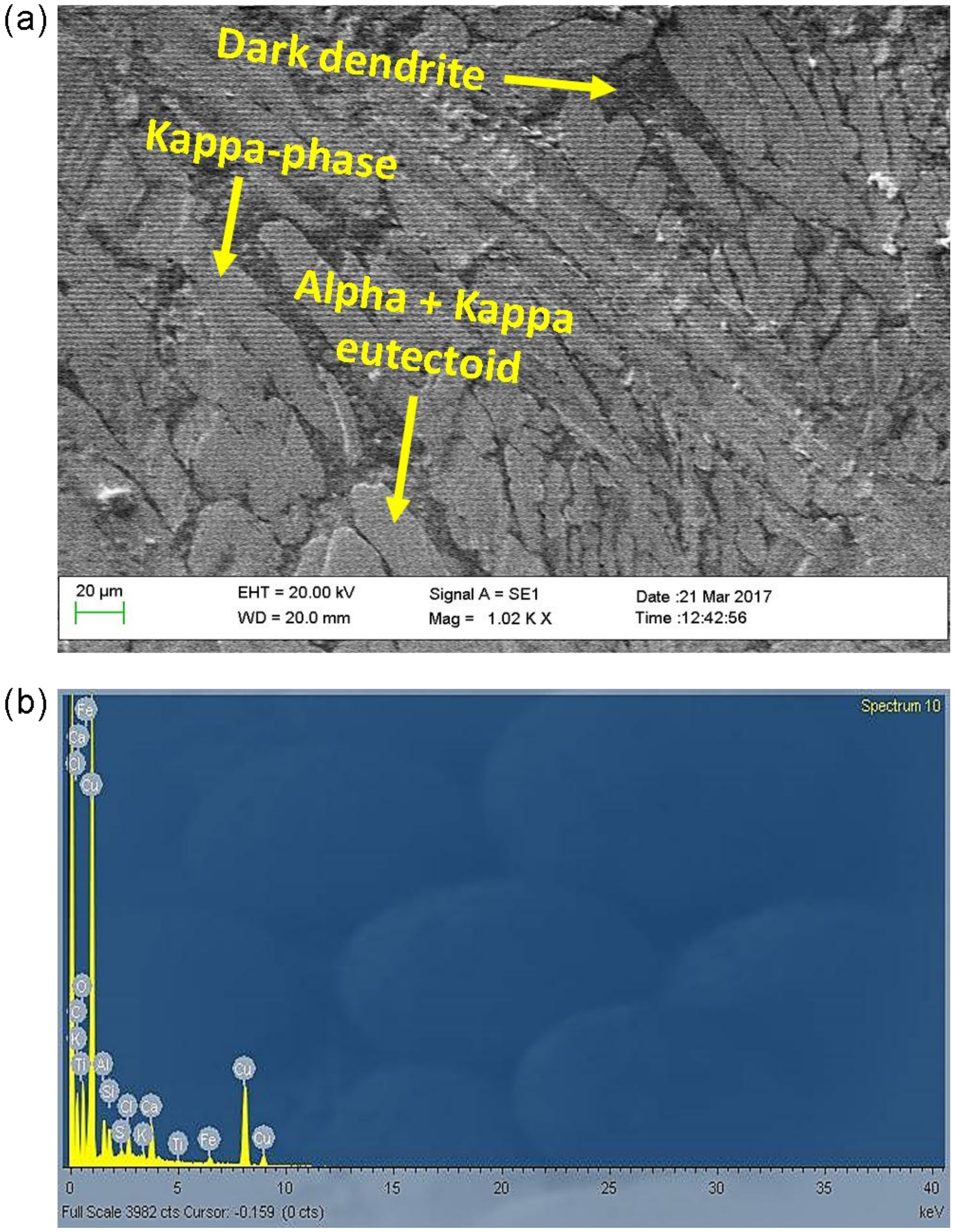


Figure 3: Scanning electron micrograph (a) and energy dispersive spectrum (b) of copper-12wt% aluminium + 3wt% titanium alloys.

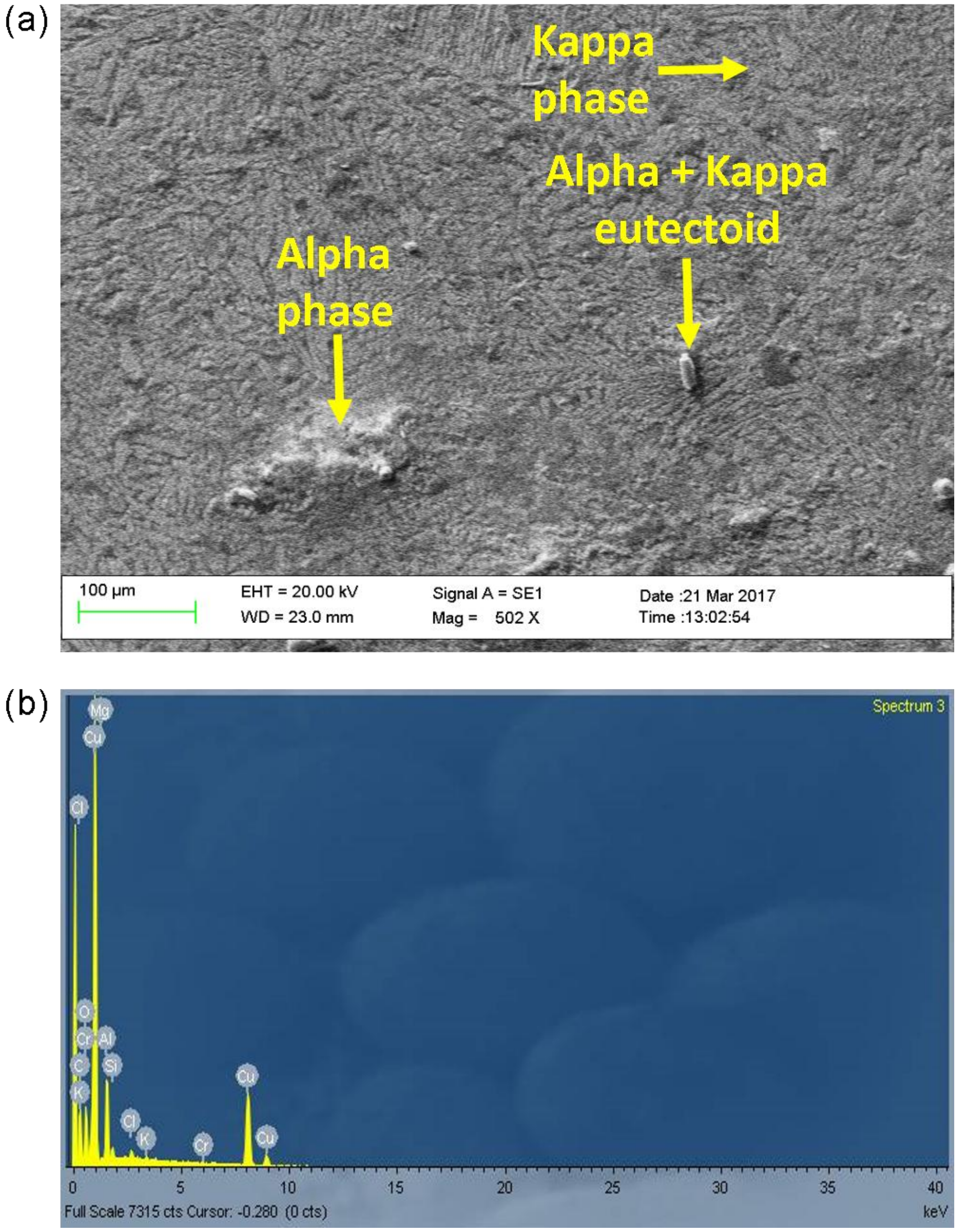


Figure 4: Scanning electron micrograph (a) and energy dispersive spectrum (b) of copper-12wt% aluminium + 3wt% Nickel alloys.

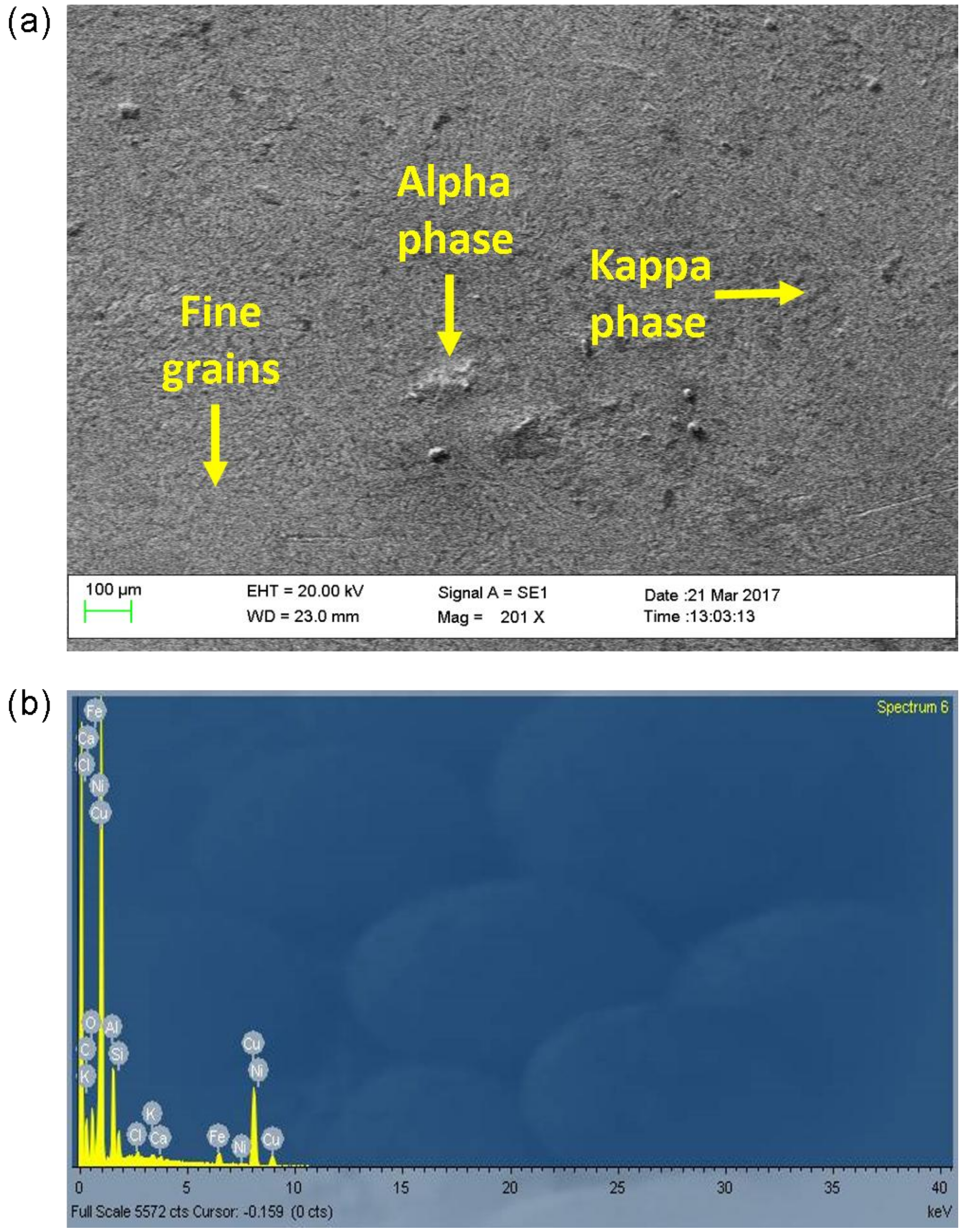


Figure 5: Scanning electron micrograph (a) and energy dispersive spectrum (b) of copper-12wt%Aluminium + 3wt% Chromium alloys.

IV. CONCLUSION

A study to reinforce the microstructure of copper-12wt% aluminium alloy with nickel, titanium and chromium granules was conducted, and the following conclusions were drawn from the results of the study.

- The reinforcement of copper-12wt% aluminium alloy with particulates of carbide forming elements (Ti, Ni & Cr) was completed successfully.
- The metallographic study revealed the presence of the particulates of carbide forming elements in the alloys with homogeneous dispersion, which corresponded to the findings of Kalaiselvan et al. [1].
- The mechanical properties such as tensile strength and hardness of the alloy increased with an increase in the weight percentage of nickel, titanium and chromium, with peak values of 297 MPa and 412 BHN at 2.5 wt.%, 285 MPa and 395 BHN at 3.0 wt.%, 284MPa and 398 BHN at 3.5 wt.% observed. However, further additions of the particulates yielded a decrease in both properties.
- The overall observation shows that the alloys that contain nickel particulates have the highest values of tensile strength and hardness (297 MPa and 412 BHN), while samples which were reinforced with titanium and chromium particles have slight differences among them.
- The reinforcement has enhanced the mechanical properties of the alloy, which corresponds to the precipitation of the kappa phase and a large globular phase within the microstructure. However, an increase of coarse intermetallic compound caused by excess reinforcement of the particulates affected the mechanical properties of the alloy negatively.
- These observations correspond with those of Lei et al. [18], Eungyeong et al. [16] and K.C Nnakwo, [7] on mechanical responses of alloys. These findings are essential for structural engineering applications.

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