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TITANIUM ADDITION AND AGEING INFLUENCE ON THE MICROSTRUCTURE AND MECHANICAL PROPERTIES OF Cu-10Ni ALLOY

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Abstract— **The need to develop alloys with enhanced properties that will perform efficiently has continually become the major concern. In this study, the influence of Ti addition on the microstructure and mechanical properties of Cu-10Ni alloy was investigated. Cu-10Ni alloy was altered by adding Ti in the concentrations of 0.1, 0.2, 0.3, and 0.4wt%. The as-cast samples of Cu-10Ni alloy were solution treated at 900^{o}C for 2 hr, quenched in water, and then aged at three different temperatures (400^{o}C, 450^{o}C and 500^o) for 2hr. Microstructural characteristics were observed using metallurgical microscope, and scanning electron microscope equipped with EDS, while tensile strength, hardness, impact strength and ductility as a function of mechanical properties were determined. Adding Ti contents in Cu-10Ni alloy and ageing at different temperatures greatly increased the properties and grain refinement of the alloy. The improvement in properties were due to slight promotion of precipitation and occurrence of enhanced $TiNi_3$ particles after ageing treatment. The as-cast Cu-10Ni alloy had a peak value of 163MPa tensile strength, 127BHN hardness, and 142J impact strength at 0.1%Ti. Under the ageing condition, the samples with 0.4%Ti had peak tensile strength, hardness, and impact strength values of 574MPa, 193BHN, and 138j, respectively. The variation in the values of the tested properties of the alloys was measured on the role of the ageing temperature. The Ti addition promotes the growth of precipitates, which refines the microstructure during the ageing process and results in an excellent improvement of the properties of the Cu-Ni alloys.**

Keywords: **Cu-Ni-Ti alloy, ageing temperature, precipitates, mechanical properties, microstructure.**

I. INTRODUCTION

It is essential for copper-based alloys used in conduits electrical product, stems valve, rods for ties, fasteners, nuts, bolts, screws, rivets, and nails, as well as other automotive, construction, and electrical components, to have a good balance of mechanical behaviour such as tensile strength, ductility, hardness, and electrical conductivity. Copper and its alloys have great corrosion resistance as well as flexibility for shaping and finishing. Its ductility is due to its face-cantered cubic (FCC) structure, which is non-magnetic and has a high heat conductivity [1,2]. The use of purer copper in these cases is often restricted as a result of its low strength [3].

With a typical 99.3% copper content, pure copper has low strength and hardness but is extremely ductile. Owing to its chemical composition, pure copper is typically soft and malleable. Pure copper is highly challenging to cast, even from a processing standpoint, and is frequently prone to problems with porosity, cracking, and the production of voids in the interiors of cast parts. Thus, metallic components like silicon, zinc, beryllium, nickel, silver, tin, lithium, titanium, and chromium are alloyed with pure copper in order to overcome the processing and physical property limitations [4]. The essential properties of copper alloys, which is a recognized as a suitable element for use in the manufacturing of components for engineering purposes, are greatly influenced by copper

[1,4]. There are a large number of commercially available copper alloys, and each class has unique qualities and uses. However, the performance of the alloying elements, which change the microstructure and improve working conditions in the matrix alloy, determines the applications [2,5]. Studies have revealed that a variety of techniques, including alloying, heat treatment, can greatly enhance the properties of copper-based alloys [6-8].

Due to the rising interest in the usage of Cu-Ni alloys, research has mainly concentrated on the development of alloy mechanical properties and strengthening processes. Cu-Ni alloy is a simple binary alloy. High strength Cu-Ni alloys can be realised through additional alloying elements to its binary alloys [9,10,11]. Cu-Ni alloys containing other alloying elements outperform single binary Cu-Ni alloys in terms of mechanical properties, alloy's ability to resist corrosion in aqueous environments, low sensitivity to hydrogen embrittlement, and good anti-biofouling capabilities [8]. Researchers has posited that doped Cu-Ni alloys gain additional strength over the isomorphous Cu-Ni alloys because of hard secondary phase precipitations [12,13]. The increased strength of Cu-Ni alloys could be attributed to the precipitates that formed during the heat treatment [13]. Studies have been carried out to ascertain different methods of properties enhancement of Cu-Ni alloys, such as increasing Ni concentrations, incorporating a third element as alloying factor, and changing the ageing procedures [7,14-16]. Increasing the Ni contents and alloying compositions in Cu-Ni alloys, the number of δ-Ni$_2$-x strengthening precipitates can be increased, resulting in an increase in the alloy's tensile strength [16,17]. The various third alloying elements includes Cr, Al, Mg, Ag, Si, Ti, P, Zn and Fe [9,11,17,18]. Due to their active chemical capabilities, titanium can produce second phases with other elements when used as a micro-alloying component in copper alloys [20]. It was reported [18] that the grain size is reduced and the tensile elongation is significantly increased when Ti is added to Cu-Ni-Si alloys. For instance, the addition of Ti would boost the tensile strength and electrical conductivity of Cu- δ Ni$_2$Si alloys, which may strengthen the driving force of δ-Ni2Si precipitation from solid solution.

Titanium is effectively used by industries such as aerospace, automotive, chemical plants, and others in a variety of applications that require high levels of reliability. As an alloying element, it replaces heavier and less serviceable and cost effective materials. Systems and components are frequently more dependable, cost-effective, and durable when designed using titanium's unique qualities. The performance and service life requirements are frequently much exceeded by titanium components at a reduced total cost [21]. The present research aims to examine the potential for improving the properties of copper-nickel alloy by investigating the effects of titanium addition in various compositions on the structure and mechanical properties of Cu-Ni alloy. The Cu-Ni-Ti alloy, which can increase strength by altering the compositions of titanium, has not been extensively researched Ti as an alloying element was added micro quantity to Cu-10Ni alloy to refine the primary grains and change the ageing kinetics, ensuing in anticipated mechanical properties.

II. MATERIALS AND METHODS

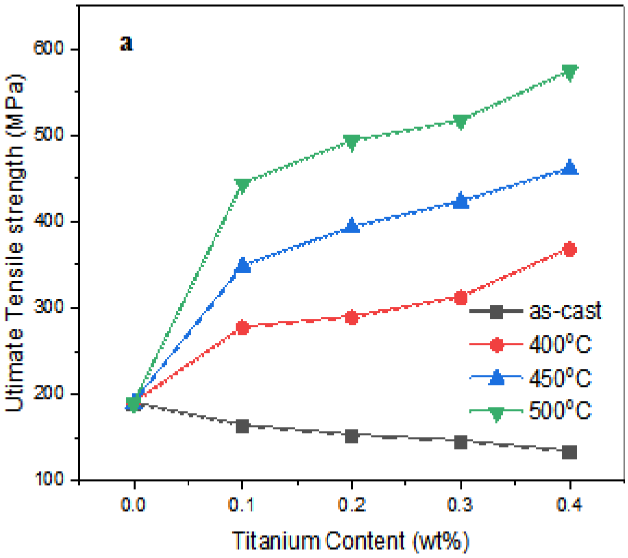
Pure copper wire of 99.5% purity, nickel powder, and titanium powder served fundamental materials for the present research. Cu-Ni-Ti alloy was prepared by melting in a bailout crucible furnace under an inert gas atmosphere to prevent alloy oxidation and then casting into a permanent steel casting mould of 45x55x155 mm^3 dimensions. The concentrations of titanium added were 0.1, 0.3, 0.4, and 0.4wt%. After surface defects from the casting process were removed, the casted ingots were homogenized at 600^{o}C and then air cooled at ambient temperature. The ingots after homogenization were solutionized at 900^{o}C, followed by water quenching. The solution-treated samples were aged at different temperatures of 400, 450, and 500^{o}C for a holding time of 2 hours respectively. The samples were taken out of the furnace and left to cool normally in the open air. The samples were subsequently machined into a variety of conventional shapes and dimensions for tensile, hardness and impact testing as well as microstructure analysis. Universal tensile machine of model 3369 was used to conduct the tensile properties that represents the determination of ultimate tensile strength and ductility.It was done in compliance with ASTM B557M standard. Brinell hardness measuring equipment of model 900-355 was used to measure the hardness property. The standard of ASTM E10-18 was followed in conducting the test. Charpy machine of model IT-30 was used to ascertain the impact strength of the studied alloys. ASTM F2231 standard was adopted. The mechanical results were given as the mean value of three specimens. Utilizing both an energy-dispersive X-ray EDS-equipped scanning electron microscope (Model: JEOL JSM 7600F) and an optical metallurgical microscope (Model: L2003A), the microstructures were examined. A conventional mechanical polishing technique was used to prepare the samples for etching, which it was etched in a solution of water, 3 g $FeCl_3$ + 95 ml C_2H_5OH + 2 ml HCl.

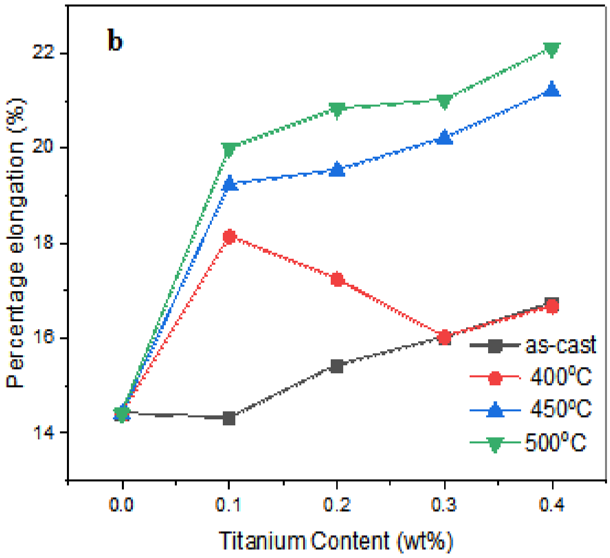
III. RESULTS AND DISCUSSION

Properties

As a function of titanium element concentrations, the mechanical properties of the Cu-10Ni alloy and their ageing at various temperatures of 400, 450, and 500^{o}C are depicted in Fig. 1. A Ti-doped Cu-10Ni alloy's ultimate tensile strength, ductility, hardness, and impact strength properties are revealed to be influenced by the ageing temperature. It was demonstrated that the UTS, hardness, and impact strength of the as-cast Cu-10Ni alloy increased with Ti content up to 0.1% and subsequently decreased with increasing Ti concentration. When 0.1% Ti content was added to the Cu-10Ni alloy, the tensile strength, hardness, and impact strength attained peak values of

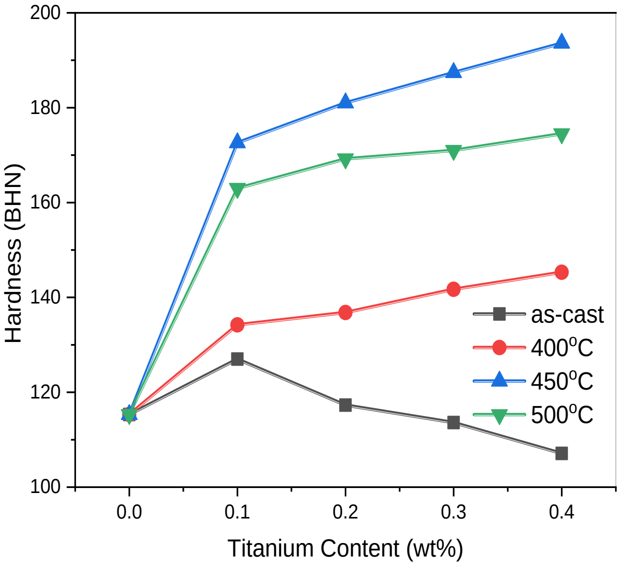
163MPa, 127BHN, and 142J. The alloy's response of ductility improved significantly as Ti contents increased. The value of ductility generated as a result of titanium addition increases with an increase in chemical compositions from 0.1–0.4wt%. The peak ductility value of 14.01% for the as-cast alloy was attained at 0.4wt%. The titanium addition to Cu-10Ni alloy purifies grain boundary, refines microstructure as well as deprives impurities which thus promotes the ductility of Cu-10Ni alloy. The preceding observation agrees with Lee et al. [18] literature reports. Titanium reacts with the matrix to form a mass of second phases, which are distributed both within and between the crystals [21].The mechanical properties evolution of Ti-doped Cu-10Ni alloy after 2hours ageing at different temperatures were also shown in Fig 1. The studied properties enhanced with respect to titanium content as the ageing temperatures increased from 400 to 500^{o}C. The tensile strength, hardness, %elongation, and impact strength of Cu-10Ni alloy increase with titanium content from 0.1 to 0.4wt%. The aged alloy obtained maximum values for the tested properties at 0.4wt%. At an ageing temperature of 400^{o}C, the rate of ductility decreases with increase in the content of titanium; however, the ductility values obtained are higher than those of the as-cast alloy. At ageing temperature of 500^{o}C, Cu-10Ni-0.4Ti alloy reached maximum value of 574MPa and 22.1% (UTS and elongation), and 193BHN and 138J of hardness and impact strength at 450^{o}C. The slight alloy properties decrease at 500^{o}C (hardness and impact strength) was as a result of over-aging that occurs at 500^{o}C for 2 hours. Compared with the as-cast Cu-10Ni-xTi alloy, the properties increased by 49.9%, which shows a great improvement of the heat-treated alloy. It is important to note that the precipitates formed as a result of the ageing treatment make a significant impact to the enhancement of mechanical properties. The precipitates nano-size would pin the motion of the dislocation and grain boundary movements, which significantly contributed to the properties enhancement of the aged Ti-doped Cu-10Ni alloy.





Microstructures

Fig. 2 shows the microstructure of as-cast Cu-10Ni and Cu-10Ni alloys with titanium contents. From the micrographs, microstructure of Cu-10Ni without alloying element revealed coarsen interconnected $(Cu_2Ni)_3$ intermetallic of α-phase. There were no Ti-rich phases, rather α–phase where nickel solidified with the copper matrix. The coarsen nature of the structure attributed to the minimum performance recorded with the Cu-10Ni alloy. The microstructures of Cu-10Ni alloys with different Ti contents are shown in Fig. 2(b-c). The number and volume of second phases increase when the Ti content increases due to the presence of an alloying element [20,22].



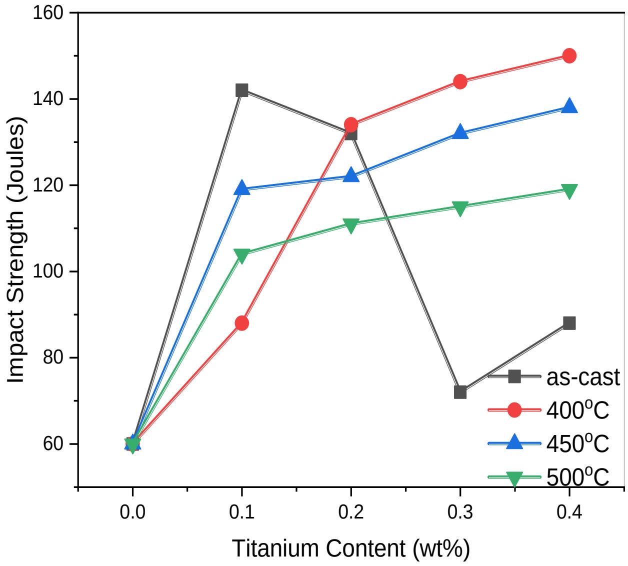
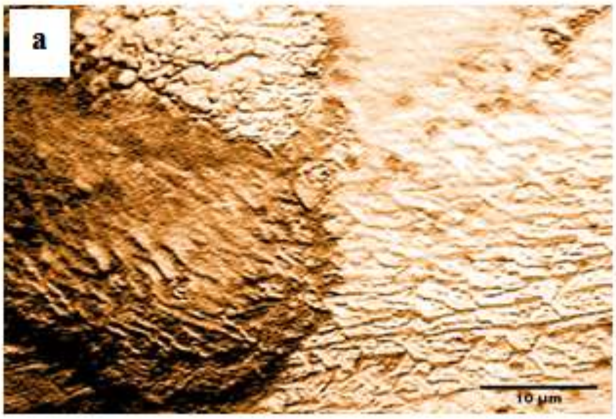


Fig 1. Titanium content effect on the (a) UTS (b) %elongation (c) hardness (c) impact strength of designed as-cast and aged Cu-10Ni-xTi alloy

Titanium positively impacts on the structure of Cu-10Ni; however, Fig. 2(b-c) revealed that the increasing content of Ti in an as-cast state contributed to the coarsening of second phases that are not homogeneously distributed. This attributes indicates that Ti additions above 0.1% led to the coarsening of second phases, which as a result, cannot retard gain boundary motion during grain formation and thus impedes the improvement mechanical properties [20, 21].



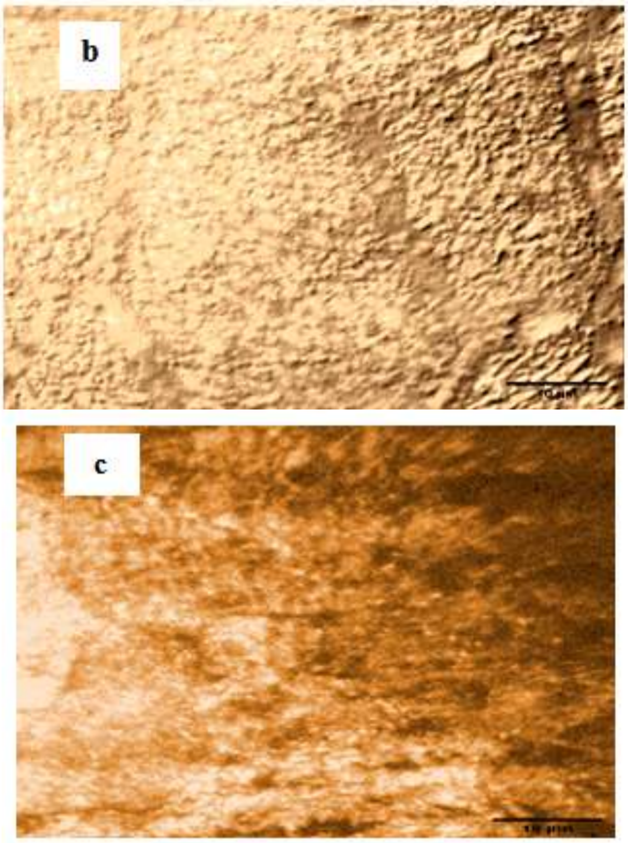


Fig 2. Optical microstructure of designed as-cast Cu-10Ni-xTi alloy (a) Cu-10Ni alloy (b) Cu-10Ni-0.3Ti alloy (c) Cu-10Ni-0.4Ti alloy

The microstructures of a Ti-doped Cu-Ni alloy after ageing at 400, 450, and 500°C are shown in Fig. 3. It can be observed that the microstructures are composed of homogenous, uniform fine grains with twins within the grains that are evenly distributed. The movement of dislocation and grain boundary motion is pinned down by the presence of finely dispersed precipitates. The precipitates act as an impediment that prevents the movement of dislocation during the ageing process, which invariably allows the alloy to gain excellent properties [22,23] Additional fine precipitates were observed as the ageing temperature increased to 500°C. The addition of titanium and ageing at different temperature accelerated the rate of nucleation of the precipitates, resist the coarsening of the precipitated phase, and significantly improved the mechanical properties. For Cu-10Ni-0.3/0.4 Ti alloys aged at 400°C, it was seen in Fig. 3(a-b) that some of the precipitates were coarsened and somewhat evenly distributed. It was also evident that the quantity and average size of these coarse precipitates reduced as the temperature increased to 500°C (Fig 3e–f).

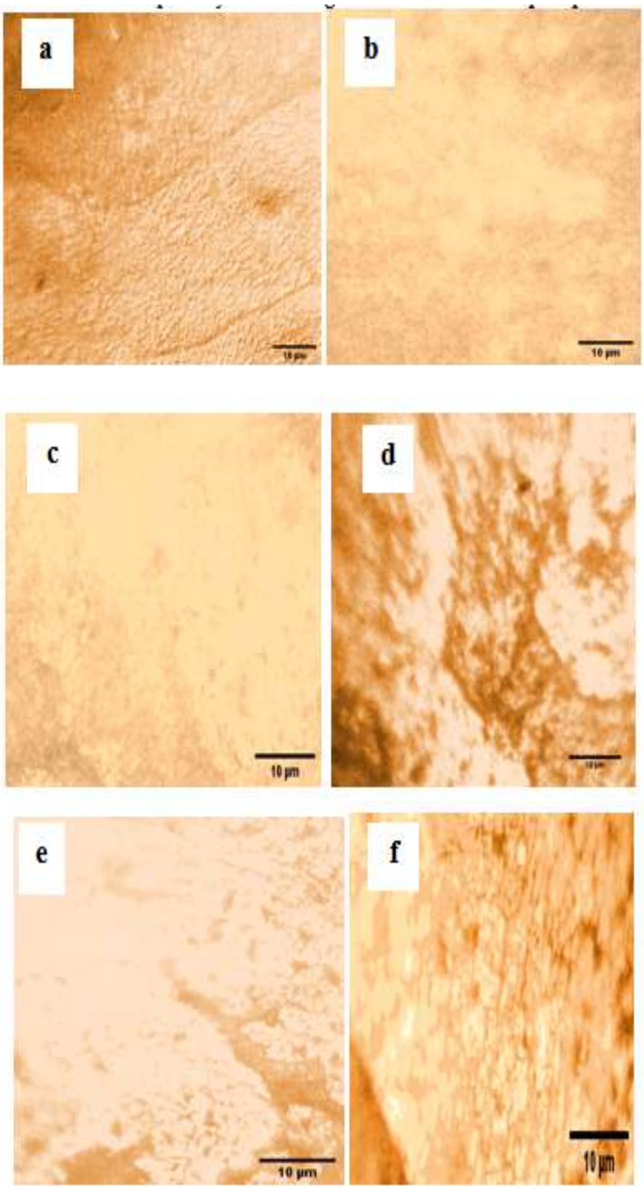
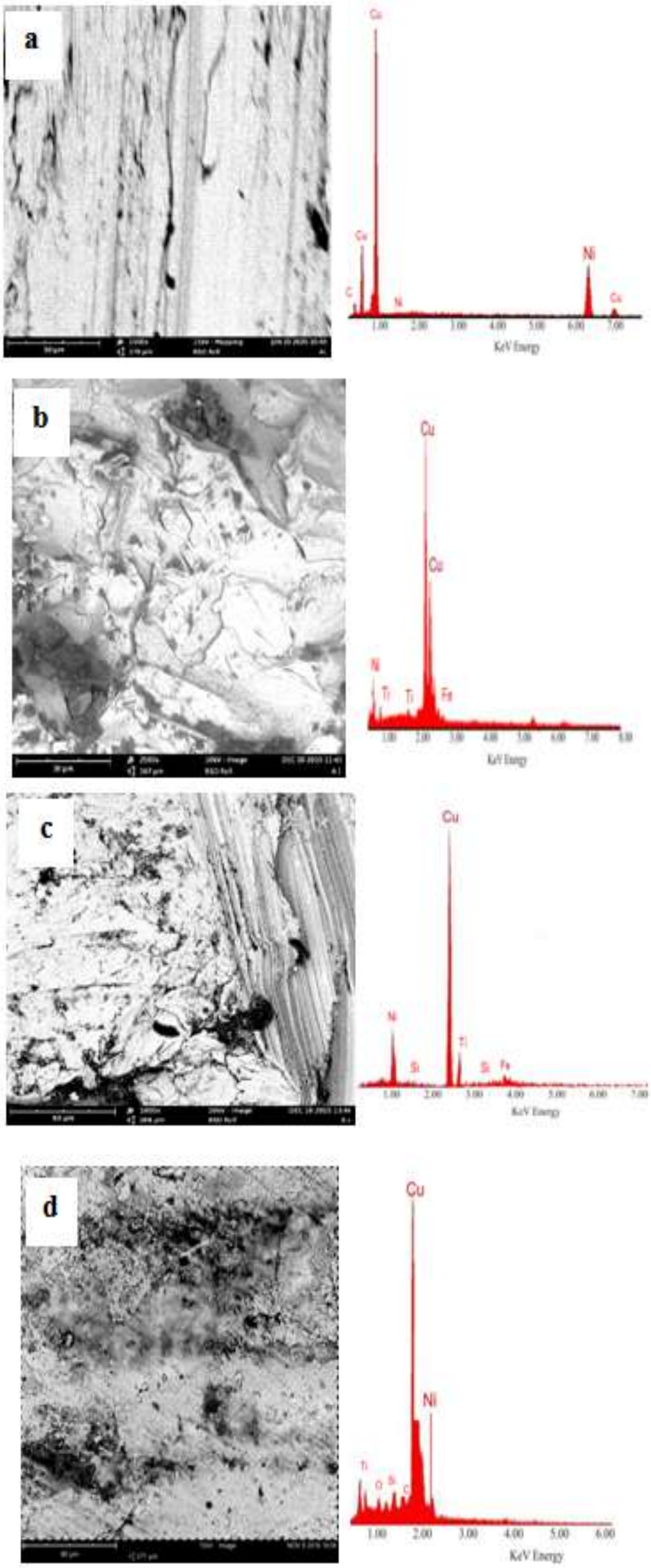


Fig 3. Optical microstructure of designed aged Cu-10Ni-xTi alloy (a) Cu-10Ni -0.3 alloy at 400^{o}C (b) Cu-10Ni-0.4Ti alloy at 400^{o}C (c) Cu-10Ni-0.3Ti alloy at 450^{o}C (d) Cu-10Ni-0.4Ti alloy at 450^{o}C (f) Cu-10Ni-0.3Ti alloy at 500^{o}C (e) Cu-10Ni-0.4Ti alloy at 500^{o}C

The scanning electron microscopy with their corresponding energy dispersive spectrometer (EDS) of some of the selected alloys are presented in Fig. (a–e), respectively. According to the SEM observations (Figs. 4), Ti significantly accelerates the kinetics of strengthening (Cu$_2$Ni)$_3$ particles precipitating in Cu-Ni alloys, aiding the formation of lamellar structures and the precipitation of fine and coarse Ni$_2$Ti particles both inter- and intra-granularly[14,18].



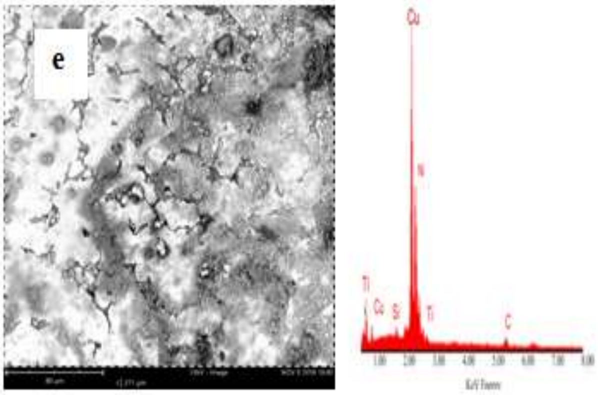


Fig 4. SEM micrograph and the corresponding EDS of (a) as-cast Cu-10Ni (b) as-cast Cu-10Ni-0.4Ti alloy(c) Cu-10Ni-0.4Ti alloy aged at 400^oC (d) Cu-10Ni-0.4Ti alloy aged at 450^oC (e) Cu-10Ni-0.4Ti alloy aged at 500^oC

Figure 4a depicts the α-phase as a single phase with a distinct distribution of undissolved $(Cu_2Ni)_3$. No nano-scale particles precipitated in the Cu matrix were observed, however, there was uniform distribution of Ni in the Cu-matrix. In the Cu-Ni-Ti alloys, equilibrium precipitate particles were plainly visible (Figs. 4b-e). With increasing ageing temperature for 2hours, more precipitates and secondary phases were observed (Fig.5c-e), and they progressively grew in size. Energy Dispersive Spectrometer (EDS) results indicates that the intermetallic particles have compositions that are similar to Ni_2SiTi, $TiNi_3$ and Ti_2Al respectively, as the EDS spectra of the varied aged specimens indicated Fe, Si, O, C, Al, in reduced intensity [23,25].

IV. CONCLUSION

In this work, the impact of various titanium alloying compositions and ageing treatment on the mechanical properties and microstructural characteristics of the Cu-10Ni alloy were examined. The key findings are summarized as follows:

1. The correct Ti additions enhance the mechanical characteristics of Cu-10Ni and refine its microstructure. With 0.1% Ti concentration in its as-cast state, Cu-10Ni alloy obtained optimum UTS, hardness, and impact strength properties.
2. Through the formation of precipitates and secondary phases, the ageing treatment method successfully improved the mechanical characteristics of the Cu-10Ni alloy
3. The nucleation rate of the precipitates was accelerated and the coarsening of the precipitated phase was resisted when Ti-doped Cu-10Ni alloy was aged at various ageing temperatures. The alloy exhibits noticeably better UTS, hardness, and impact strength characteristics as the Ti content rises from 0.1 to 0.4 weight percent.
4. Cu-10Ni alloy reached its maximum as-cast values of 163 MPa, 127 BHN, and 142 J for ultimate tensile strength, hardness, and impact strength at 0.1 weight percent, whereas under ageing conditions, the ideal values of 574 MPa, 22.1%, 198 BHN, and 138 J were attained at 0.4 weight percent at ageing temperatures of 500 °C for UTS and %elongation, and 450 °C for hardness and impact.
5. During the ageing process, fine dispersion precipitates were generated in the Cu-Ni-Ti alloy, and the interaction of the matrix with the crystal orientation of the precipitates improved the properties.

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CRediT roles

CCN, EEN: Conceptualization; Data curation; **CCN, FOE**: Formal analysis; **CCN**: Funding acquisition; **CCN, FOE**: Investigation; Methodology; Project administration; Resources; EEN: Supervision; Validation; Visualization; **CCN**: Roles/Writing - original draft; **CCN, FOE, EEN**: Writing - review & editing.

V. REFERENCE

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