UNIZIK JOURNAL OF ENGINEERING AND APPLIED SCIENCES (UJEAS)

Research Article

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Special Issue
A Themed Issue in Honour of Professor Ekedimogu Eugene Nnuka on His retirement.

This themed issue honors Professor Ekedimogu Eugene Nnuka, celebrating his distinguished career upon his retirement. His legacy of exemplary scholarship, mentorship, and commitment to advancing knowledge is commemorated in this collection of works.

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UNIZIK JOURNAL OF ENGINEERING AND APPLIED SCIENCES

UNIZIK Journal of Engineering and Applied Sciences 3(2), June (2024), 685-690
Journal homepage: https://journals.unizik.edu.ng/index.php/ujeas
PRINT ISSN: 2992-4383 || ONLINE ISSN: 2992-4391

Mechanical Behaviors of Copper-Aluminium-Titanium Alloy

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Abstract
Copper alloy performance enhancement has received a lot of attention in research for industrial applications because of its unique properties. This study investigated the mechanical (tensile strength and hardness) and structural properties of a copper-12wt% aluminum alloy treated with 0.5wt% to 5.0wt% weight percentages of titanium. The metallographic microstructure of the alloy was also investigated by scanning electron microscopy to complement observations from the implemented characterization techniques. The results of the mechanical tests revealed that the addition of titanium particulates composite into copper-12wt% aluminum alloy significantly improved the tensile strength (387 MPa) and hardness (298 BHN) by 42.2%, and 29.5% respectively. Percentage elongation had a downtrend as titanium content increased in the alloy. The microstructure analyses show precipitations of smaller kappa-phases and the presence of a large globular intermetallic compound, which is responsible for improving the alloy's mechanical properties. The developed alloy can be used to improve the service life of alloy components in sub-sea constructions, including propeller shafts.

Keywords: Copper, Aluminum, Titanium, Tensile strength, hardness, Microstructure

1. Introduction

Lightweight engineering materials, such as aluminium bronze, with better mechanical qualities for high-performance applications, are in high demand worldwide for weight reduction in the transportation and engineering industries (Uyime et al, 2012; Sekunowo et al, 2013; Łabanowski & Olkowski, 2014; Moradlou et al, 2011; Eungyeong et al, 2011; Ketut et al, 2011; Lei et al, 2013; Mattern et al, 2007; Nwambu & Nnuka, 2018; Ngozi et al, 2024). Furthermore, the necessary mechanical qualities (lightweight, damage/fracture resistance, increased strength, and corrosion resistance) for engineering applications are strongly dependent on the material composition and structure, which are in turn influenced by the processing conditions and techniques used (Onyia et al, 2024). Despite some of the desirable characteristics of aluminium bronze composites, its abysmally deficient responses in certain applications necessitate mechanical property enhancement (Sekunowo et al, 2013; Lei et al, 2013; Okoye et al, (2023). Therefore, researchers have been developing novel approaches to address these issues. Uyime et al. (2012) produced a dual-phase aluminium bronze alloy with sand casting techniques as a potential replacement for conventional structural materials, particularly steels. Ageing, normalising and solution heat treatment are the selected treatment methods, while ultimate tensile strength, Rockwell hardness and elongation are the essential properties that were characterised. They observed an overall improvement in the properties and effectiveness of the sand casting technique based on its low cost, ease of use and flexibility. The effect of titanium content on the structure and mechanical properties of Cu-Ni-Si alloy were investigated by Eungyeong et al. (2011). Different ageing times were implemented to characterise the effect on the properties. They discovered that tensile strength and electrical conductivity of the alloy were significantly enhanced. Mattern et al. (2007) 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.

Several authors (Łabanowski & Olkowski, 2014; Moradlou et al, 2011; Eungyeong et al, 2011; Ketut et al, 2011; Lei et al, 2013; Mattern et al, 2007; Nwambu & Nnuka, 2018; Ngozi et al, 2024) studied the microstructure and mechanical properties of copper alloys. However, published research is scarce on the modification of copper-12wt% aluminum alloy with titanium particulates, and the importance of copper and its alloys' excellent mechanical and functional properties has made them appealing to industries for use in a variety of engineering applications (Nwambu et al. 2017; Nwaeju et al. 2023; Okelekwe et al. 2024). As a result, some earlier researchers (Nwambu et al. 2017; Nwaeju et al. 2023) found that copper-aluminium alloy alone is insufficient for high-rate physical and mechanical performance, particularly in an aggressive corrosive environment, such as salt saltwater. It has been reported that the components of binary Cu-Al alloy fail over a longer length of time, such as 2000-3000 hours of operation. To ensure the expected service life, the addition of further alloying elements at specific percentage compositions has been suggested and will be studied in this study. This study investigates the microstructure and mechanical properties of copper-12wt% aluminium alloy composites treated with titanium granules. The mechanical properties of these alloys provide important insights into their application. Metallographic investigations were also conducted to examine the impact on the microstructure.

2.0 Material and Methods

2.1 Materials and Fabrication

The base alloy for this investigation was made with commercial pure copper (99.99%) and commercial pure aluminum, titanium, nickel, and chromium (99.98%). Cutix Cable Plc, Nnewi, Nigeria, provided the copper and aluminum, while Kermel Chemical Reagent Co. Ltd., Hebei, Tianjin, China, supplied the additives (Ti, Ni, and Cr) particulates. They were melted in a backup crucible furnace, and the additives were added in quantities ranging from 0.5wt% to 5.0wt% before casting using the permanent die casting technique; 10 samples were cast for each dopant. Each experiment employed three (3) samples, and the average value was calculated at the end of the experiment. A mechanical stirrer was used to ensure the molten liquids were homogeneous (Lei et al, 2013).

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 the ASTM B208-14 standard likewise the hardness was 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 a portable dynamic hardness testing machine (DHT-6) for hardness, respectively. Before the structural investigation, the specimens' surfaces were ground with various emery paper grades (400, 600, 800, and 1200μm). Following grinding, the specimens were polished to a mirror shine using aluminum oxide powder, washed with water, and dried with a hand dryer. The dried samples were etched for 60 seconds with a solution containing 10g of iron (III) chloride, 30 cm3 of hydrochloric acid, and 120 cm3 of water. Finally, the surface morphology of the etched samples was studied with an optical metallurgical microscope (Model L2003A). Scanning electron microscopy (SEM)/energy dispersive spectroscopy (EDS) of the experimental alloys was performed on the samples with a TESCAN scanning electron microscope (VEGA III LMH model).

3.0 Results and Discussions

3.1 Mechanical properties analysis

According to the mechanical investigation, as shown in Figure 1, the tensile strength of Copper-12wt% aluminum alloy was greatly increased by increasing titanium granule content within the range of 0.5-3.0wt%. The increase in tensile strength was induced by a change in the microstructure, which increased the grain boundary area and impeded dislocation motion. The inclusion of titanium granules into the base alloy resulted in a fine precipitate of intermetallic particles that inhibited recrystallization. The tensile strength of copper-12wt% aluminum recorded a maximum value at 3.0wt% (285 MPa) of titanium content before rapid decrease due to the brittleness of the alloy caused by an excess amount of titanium content, 3.5wt% to 5wt%. It was observed that the percentage elongation decreased all through (**Figure 1b**), as the titanium content increased in the alloy. **Figure 1a** shows the improvement of the hardness of copper-12wt% aluminum alloy with the increment of titanium content at a range of 0.5wt% to 3.0wt%. It has an outstanding increase from 160 BHN to 395 BHN. The introduction of titanium granules content into the copper matrix modified and increased the precipitation of the kappa phase in the alloy, which reduced the ductility of the alloy; thereby improving its hardness.

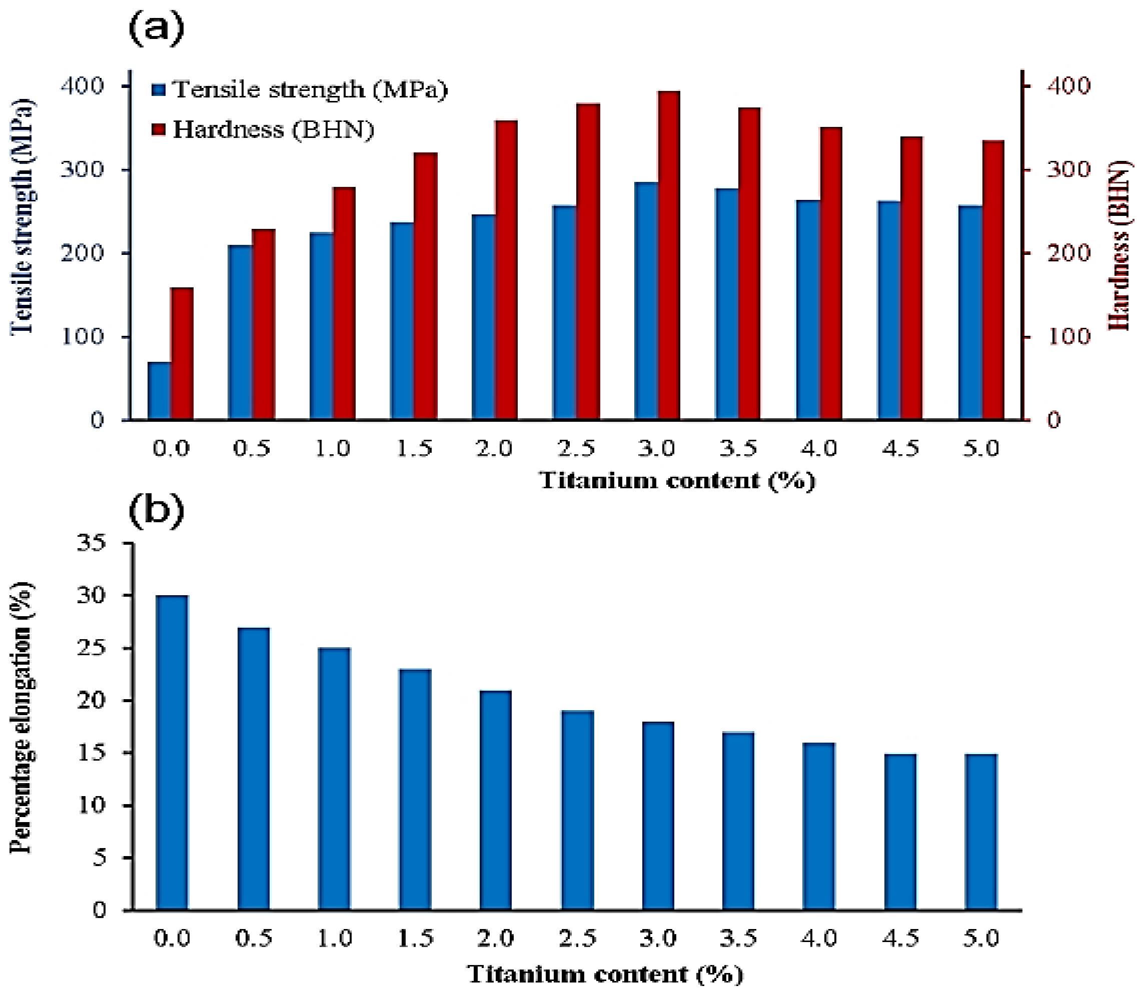

Figure 1. (a) Tensile strength, Hardness, and (b) Percentage elongation of copper-12% aluminum alloy.

3.2 Microstructure analysis

In addition, the microstructural analysis with a scanning electron microscope (SEM) revealed precipitation of two regions (**Figures 2 – 5**), which are small kappa (k) -phases and alpha + kappa (α +κ) 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), but the addition of titanium modified the microstructure of the alloy by providing sites for the nucleation of the k-phase, to a large extent; thereby impeding the dislocation motion. This corresponds with the findings of Sekunowo et al. (2013) on the microstructures of alloys. Łabanowski and Olkowski (2014) state that additives suppress the growth of the alpha (α) and gamma (γ^2) phase, and instead, cause the formation of a new phase kappa (κ), which is more desirable. **Figure 4** depicts dendritic gains, which are $CuAl_2$ while **Figure 5** revealed large grains of Cu_3Ti, which have superior mechanical properties over base alloy. Scanning electron microscopy (**Figures 2 & 4**) revealed all the phases present in the alloy, such as the α-phase, β- phase and (α+γ^2) phase with white and dark spots, while energy dispersive spectroscopy analyses (**Figures 3 & 5**) indicated the peak and presence of nine major elements such as Cu, Al, Fe, Ca, K, S, Cl, O and C in the alloy

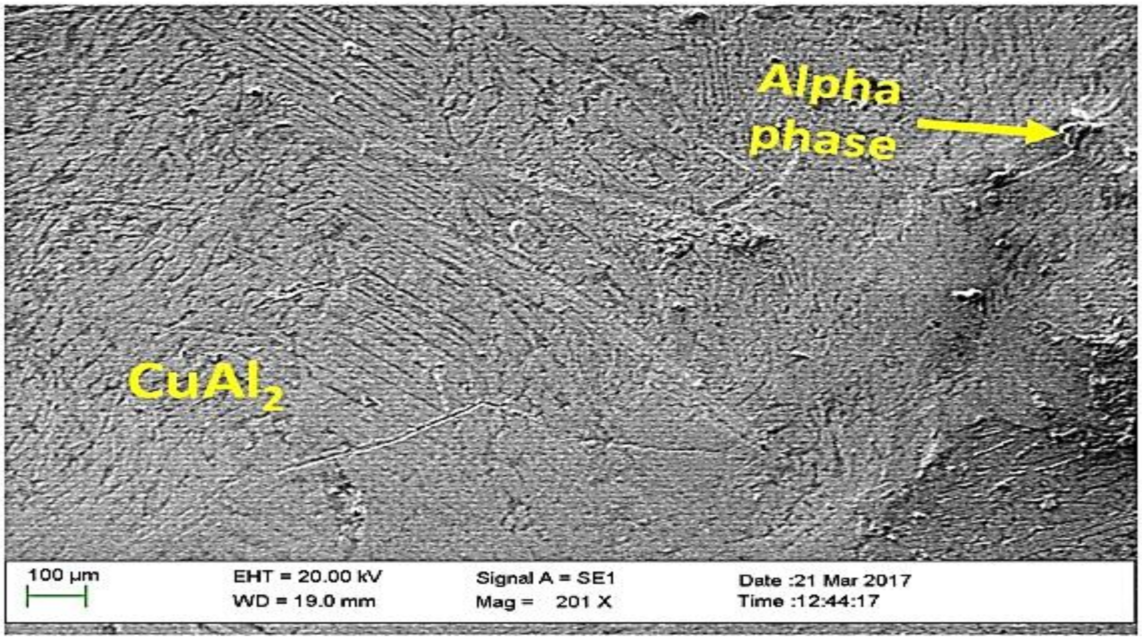

Figure 2. Scanning electron micrograph (SEM) of copper-12% aluminium alloy.

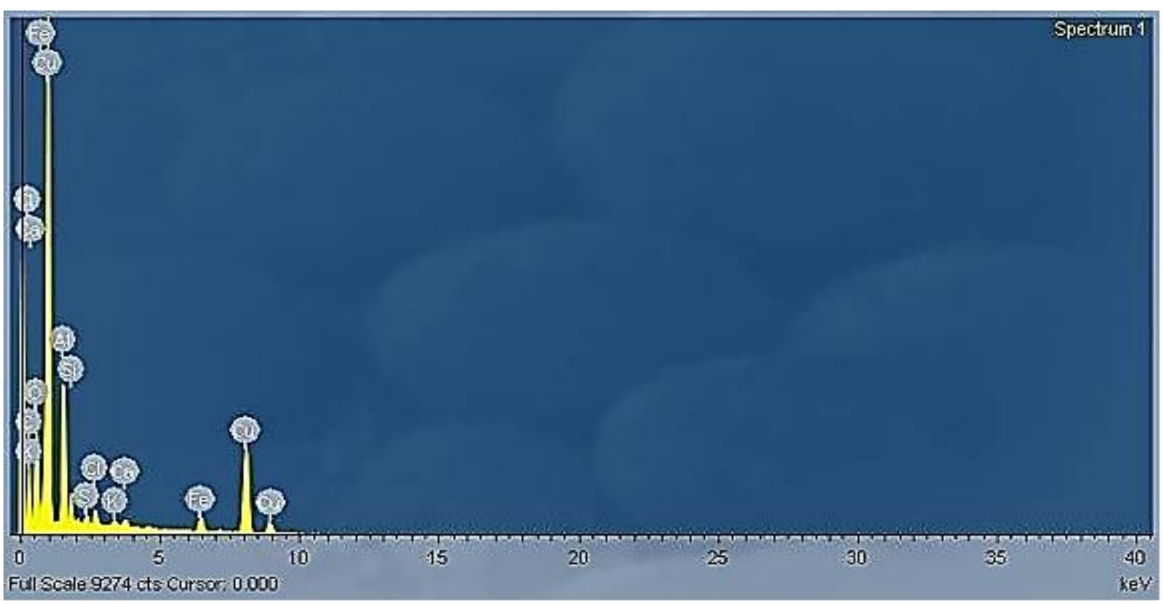

Figure 3. Energy dispersive spectrum (EDS) of copper-12wt % aluminium alloy.

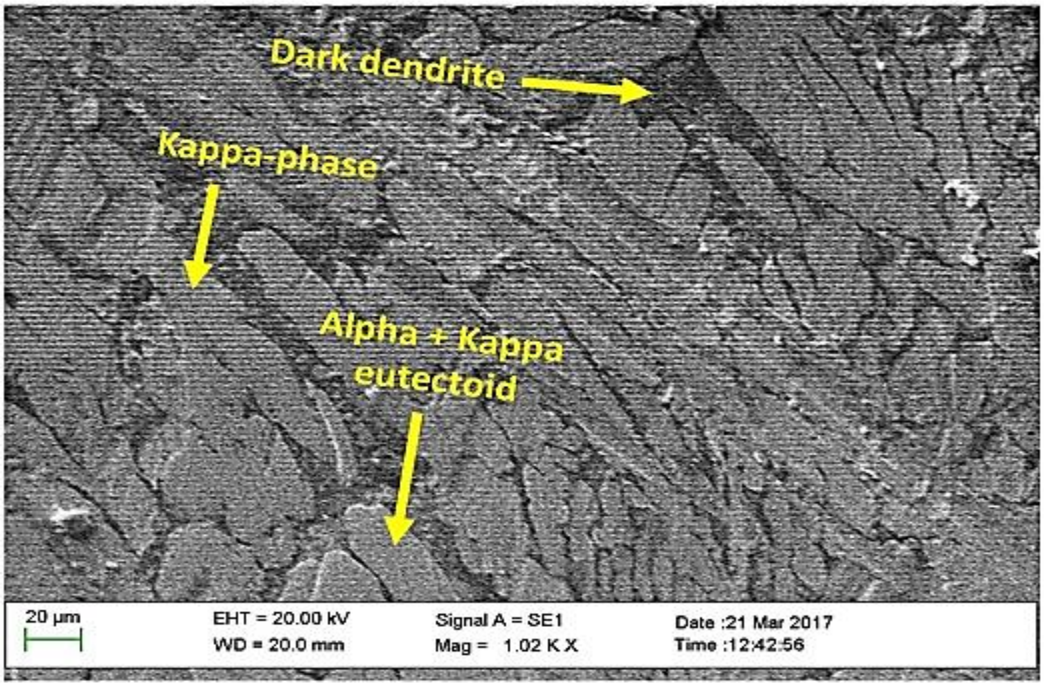

Figure 4. Scanning electron micrograph of copper-12wt% aluminum + 3wt% titanium alloys.

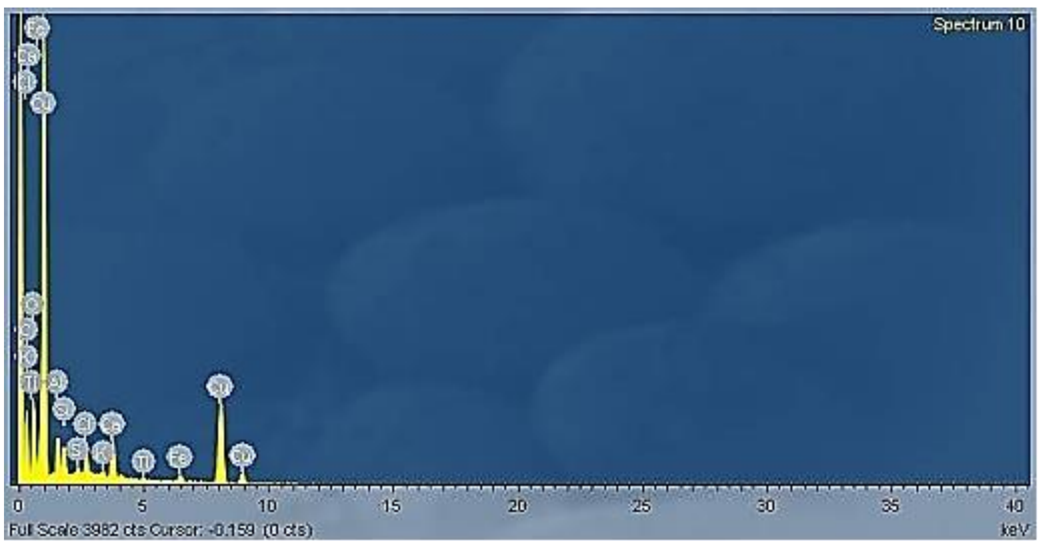

Figure 5. Energy dispersive spectrum (EDS) of copper-12wt%Aluminum + 3wt% Titanium alloys.

4.0. Conclusion

A study was undertaken to modify the structure of a copper-12wt% aluminum alloy with titanium granules composite, and the results led to the following conclusions. The inoculation of copper-12wt% aluminum with titanium content significantly improves the alloy's mechanical properties. The addition of titanium to the copper-12wt% aluminum alloy dramatically boosted tensile strength and hardness, while decreasing percentage elongation. The mechanical properties such as tensile strength and hardness of the alloy increased as titanium content increased up to 3.0wt%, with peak values of 285MPa and 395 BHN observed. However, further additions of titanium content brought a decrease in both properties. The increment in the mechanical properties of the alloy was as a result of the precipitation of the kappa phase and a large globular phase within the microstructure. However, an increase of coarse intermetallic compounds caused by excess titanium content from 3.5wt% to 5.0wt% affected the mechanical properties of the alloy negatively. Our observations are in agreement with those of Łabanowski and Olkowski

(2014). on the mechanical responses of alloys. The developed alloy can be used to improve the service life of alloy components in sub-sea constructions, including propeller shafts.

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