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Mechanical Delineation of Copper-12wt% Aluminium Alloy with Titanium Granules Composite

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ABSTRACT
Performance enhancement of copper alloys has attracted significant research attention for industrial applications because of their unique properties. In this work, mechanical (tensile strength and hardness) and structural behaviours of copper-12wt% aluminium alloy modified with titanium were evaluated. The metallographic microstructure of the alloy was also investigated by scanning electron microscopy to complement observations from the implemented characterisation techniques. The results of the mechanical tests revealed that the addition of titanium granules composite into copper-12wt% aluminium alloy significantly improved the tensile strength and hardness by 307.1% and 146.8% respectively. Percentage elongation had a downtrend as titanium content increased in the alloy. The analyses of the microstructure show precipitations of smaller kappa-phases and the presence of a large globular intermetallic compound, which is responsible for the improvement of the alloy's mechanical properties.

KEYWORDS*: Copper, Aluminium, Titanium, Mechanical properties, Microstructure*

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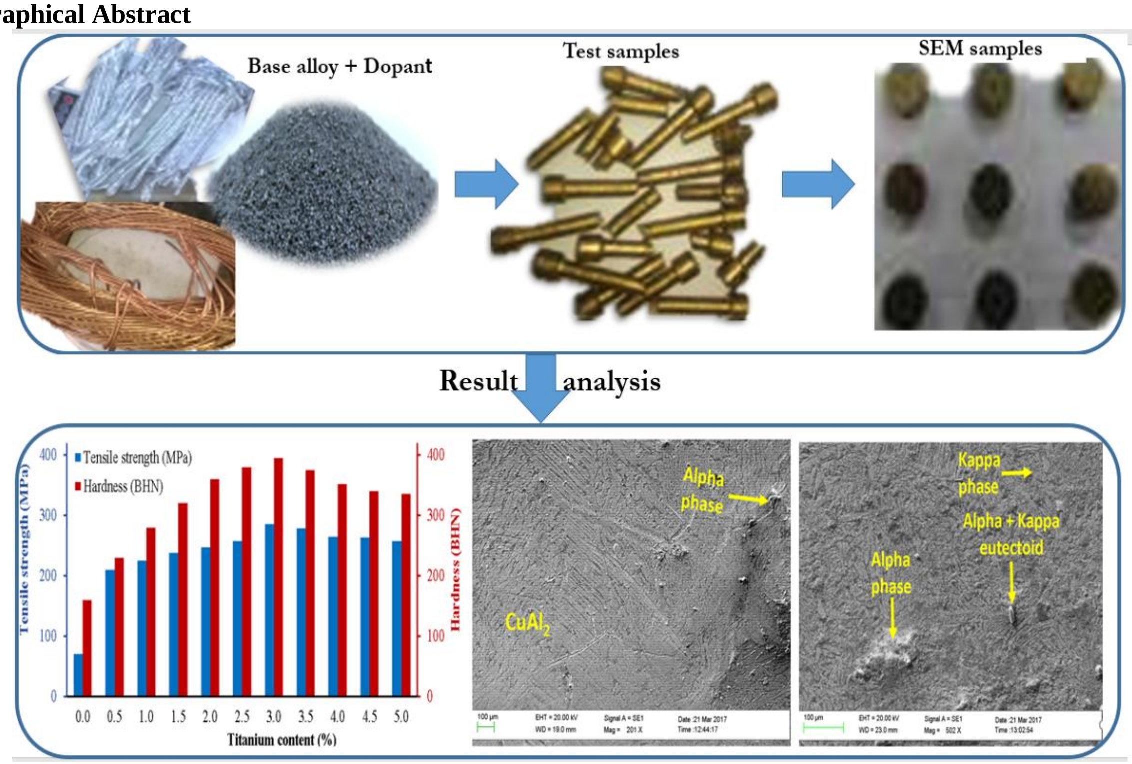
Graphical Abstract



I. INTRODUCTION

Lightweight engineering materials such as aluminium bronze with improved mechanical properties for high-performance applications are in global demand for weight-reduction in the transport sector and other engineering industries [4]. Also, the desired mechanical properties (lightweight, 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 [11]. Despite some of the desirable characteristics of aluminium bronze composites, its abysmally deficient responses in certain applications necessitate mechanical property enhancement [2, 11]. Therefore, researchers have been developing novel approaches to address these issues. Uyime et al. [1] 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. [7]. 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. [10] 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 [3-11], have studied the microstructure and mechanical properties of copper alloys. However, there is an inadequacy of published works on the modification of copper-12wt% aluminium alloy with titanium granules composite. In this work, microstructure and mechanical behaviours of copper-12wt% aluminium alloy modified with titanium granules composites have been studied. The mechanical characteristics of these alloys provide valuable insights into its application. Metallographic analyses were also carried out to assess the effect on the microstructure.

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 titanium particles (Kermel Chemical Reagent Co. Ltd. Hebei, Tianjin, China), were added in concentrations of 0.5wt% to 5.0wt% before permanent die casting technique was used for casting of the eleven samples.

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 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 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.

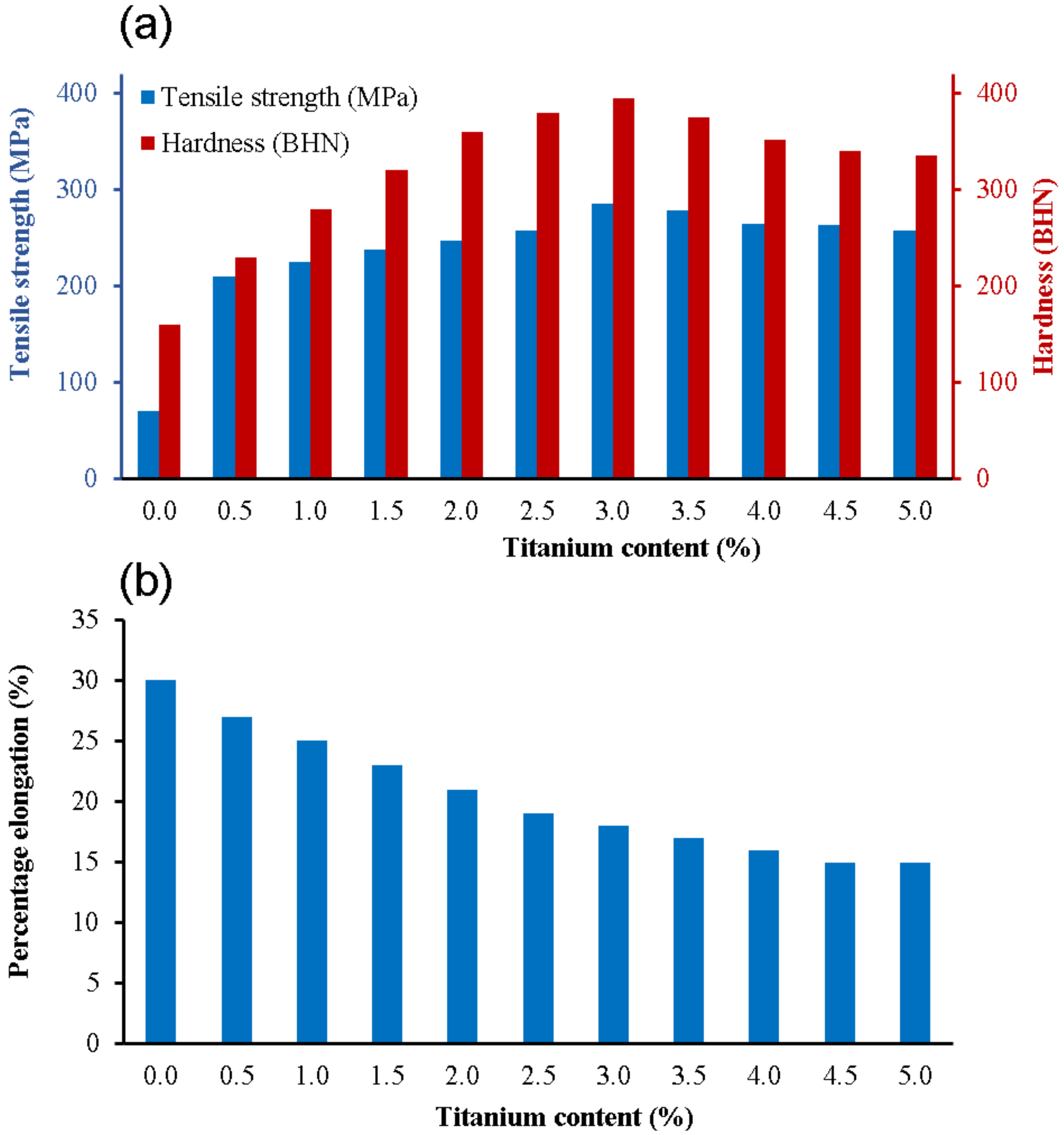


Fig 1. Alloy mechanical properties.

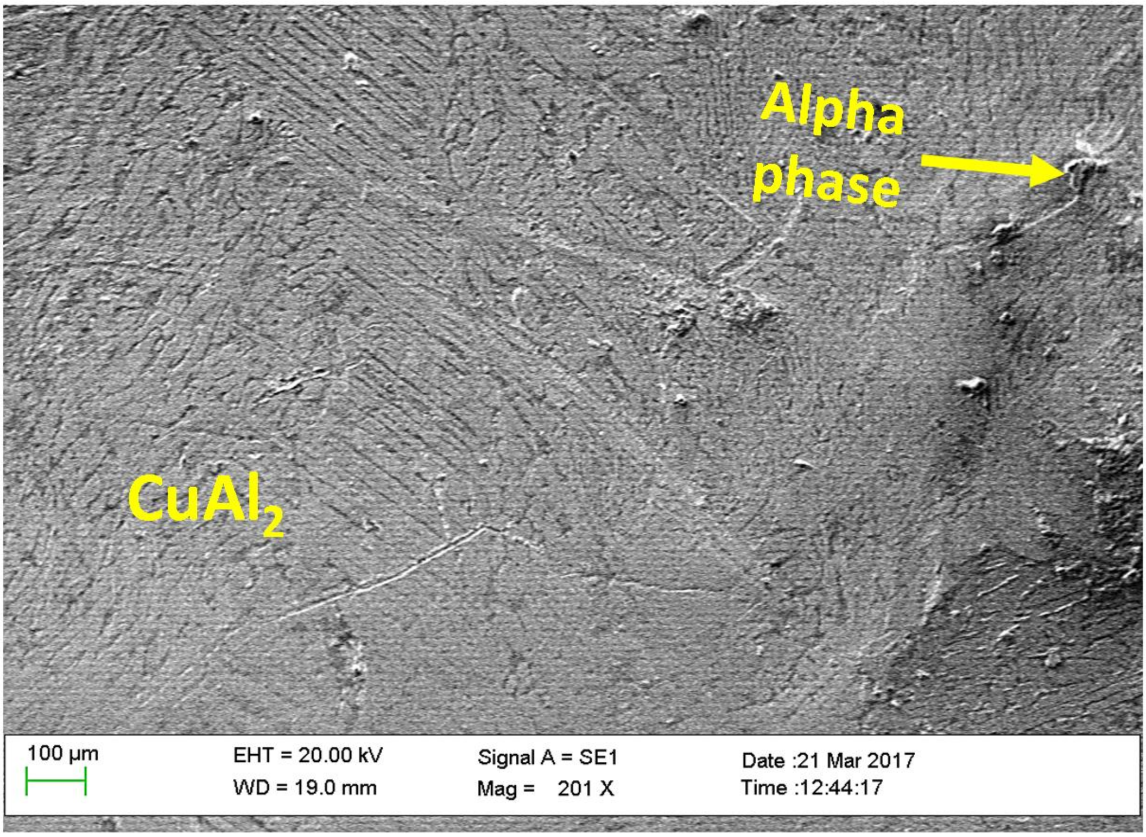


Fig 2. Scanning electron micrograph (SEM) of copper-12% aluminium alloy.

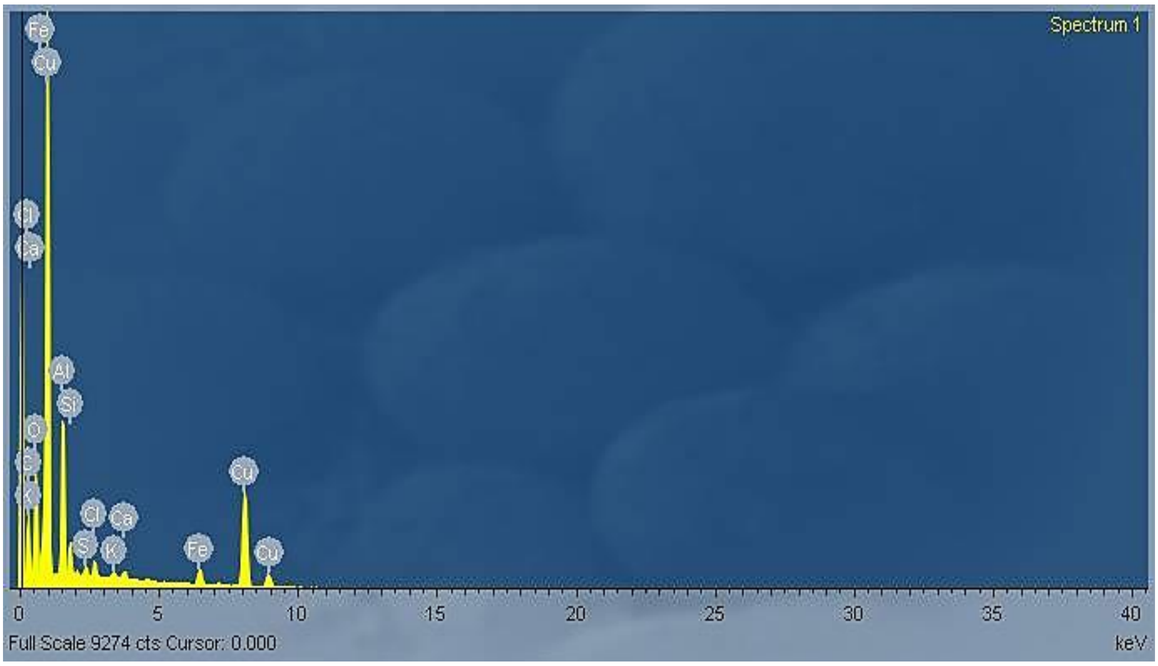


Fig 3. Energy dispersive spectrum (EDS) of copper-12wt % aluminium alloy.

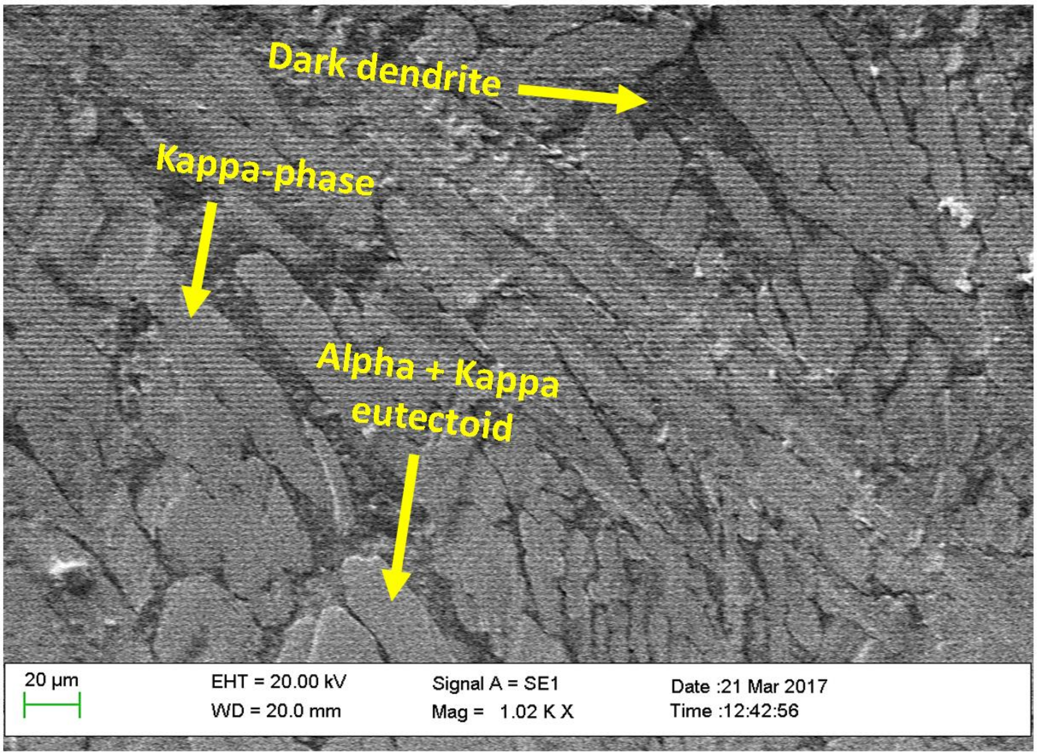


Fig 4. Scanning electron micrograph of copper-12wt% aluminium + 3wt% titanium alloys.

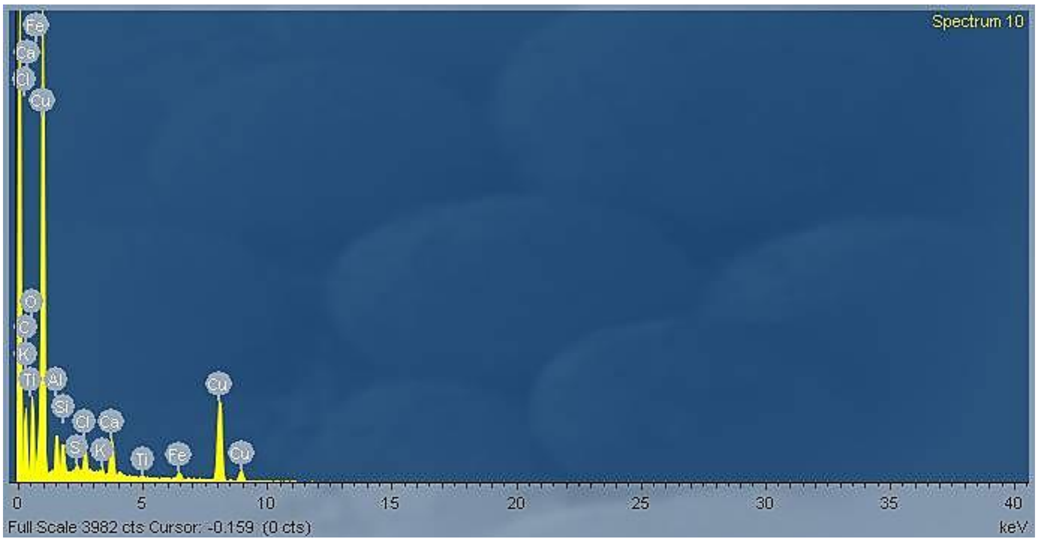


Fig 5. Energy dispersive spectrum (EDS) of copper-12wt%Aluminium + 3wt% Titanium alloys.

III. RESULTS AND DISCUSSION

According to the mechanical analysis, as evident in **Figure 1,** it is obvious that the tensile strength of Copper-12wt% aluminium alloy was increased significantly by increasing titanium granules content within the range of 0.5-3.0wt%. The improvement on the tensile strength was caused by the modification of the microstructure, which led to an increase in grain boundary area and impedes dislocation motion. The addition of titanium granules content into the base alloy formed a fine precipitate of intermetallic particles that inhibit recrystallisation. Tensile strength of copper-12wt% aluminium recorded maximum value at 3.0wt% (285 MPa) of titanium content before rapid decrease due to 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% aluminium 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 ductility of the alloy; thereby improving its hardness.

In addition, the microstructural analysis with a scanning electron microscope (SEM) revealed precipitation of two regions (**Figures 2 – 5**), which are small k-phases and 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 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. [2] on the microstructures of alloys. Łabanowski et al. [10] state that additives suppress the growth of alpha (α) and gamma (γ^2) phase, and instead, cause formation 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.

IV. CONCLUSION

A study to modify the structure of copper-12wt% aluminium alloy with titanium granules composite was conducted, and the following conclusions were drawn from the results of the study.

- The inoculation of copper-12wt% aluminium with titanium content has an outstanding improvement on the mechanical properties of the alloy.
- Addition of titanium to copper-12wt% aluminium alloy significantly increased the tensile strength and hardness, respectively, while the percentage elongation decreased.
- 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 kappa phase and a large globular phase within the microstructure. However, an increase of coarse intermetallic compound 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 Labanowski et al. [5] and K.C Nnakwo, [3] on mechanical responses of alloys. These findings are essential for structural engineering applications. Further comparative investigations are required to substantiate these findings.

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