Effects of Silicon and Deformation Ratio on the Mechanical Behavior of Nickel Aluminum Bronze (NAB) Alloy

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ABSTRACT

The increasing demand for new materials to meet the challenges of adequate resistance to deformation and corrosion in various architectural and industrial sectors especially in marine environment has necessitated the development of metal matrix composites. This paper aim at investigating the influence of silicon and deformation on the mechanical properties of the nickel aluminum bronze (NAB) alloy. Materials for the NAB alloy were sourced locally; sand casting method was used to develop six different compositions with varied weight (0%, 2%, 4%, 6%, 8%, and 10%) percent of silicon addition. The developed material was subjected to 0%, 2%, 4%, 6%, 8% and 10% cold deformation (rolling). The mechanical properties of the NAB alloy were studied using hardness, tensile strength, and elongation tests. The results showed that the hardness of the NAB alloy increased significantly with increase in the silicon content, similarly with the increase in deformation ratio, the hardness also improved. The tensile strength and elongation also showed an increase with increase in silicon content and deformation ratio. Increasing the silicon content and deformation ratio led to improved mechanical properties of the NAB alloy. The findings show that further modifications in the silicon content and deformation ratio have insignificant effect on the mechanical properties of the NAB alloy.

Key words: Deformation, NAB Alloy, Mechanical Behaviour

INTRODUCTION

In recent times, researcher's attention has moved from the use of single phase and binary or dual phase in the development of materials for engineering applications for the development of non-ferrous alloys among this alloys are the multi-phase Nickel Aluminum Bronze (NAB) alloy. These alloy have been found to exhibit high corrosion cavitation resistance due to its ability to develop a protective layer on the substrate, rich in aluminum and copper oxides, that is firmly adhered to the base material, and hence, providing low corrosion in natural water [1].

NAB alloy being a copper base alloys has minimum of 74.5% copper and containing 8.5- 11.5% aluminum, 3-5% iron and 3-6% nickel as the major alloying metals [3]. Nickel Aluminium Bronze (NAB) is an excellent engineering material for maritime application due to its selective mechanical properties and relatively excellent corrosion resistant. However, NAB is susceptible to porosities due to dissolved gasses absorbed during its casting processes and adversely affects the mechanical properties [3]. Its casting is also found to be difficult due to the possible occurrence of casting defects such as shrinkage and porosity [12]. Research however has shown that the creation of risers design, gating system and the quality of moulding sand affects the quality of the casting [8]. These risers are basically used to suppress the shrinkage defects. While Ravi and Talapatra in their research reported that the production of quality casting is dependent on a proper gating system [9]. Wiengwiset had earlier established a relationship between the optimum proportion for the bentonite and water for the recycled moulding sand for improvement of iron castings (Wiengwiset, 2012). Therefore, casting quality is dependent on the proper design and preparation of the sand mould and the moulding sand.

The most widely used NAB alloy is $CuA_{l10}Fe_5Ni_5$ alloy in cast condition [1], with a well-defined complex microstructure of α and β solid solution phases together with different forms of the intermetallic κ phases which present different chemical compositions. It have been observed that this multiphase system is prone to corrosion failure, because there is an important effect of electrolyte composition leading to a change from passive to localized corrosion due to the different corrosion susceptibility of the individual phases [4]. This non-homogeneous distribution of phases at room temperature has been found to be formed during the solidification of the melt, resulting in phases with different amounts of alloying elements [5] [6].

NAB alloy has also been found yielding to the improvement on the mechanical properties of the cast product when subjected to heat treatment. Its amenability to heat treatment and welding has made the material to find wide applications in the engineering sector [2]. The purpose of this research is to investigate the effect of silicon as an additive in the NAB alloy for sole improvement of its mechanical properties. It also delves into the impact of mechanical deformation at room temperature (35^{o}C) with the aim of further amplifying the engineering properties.

EXPERIMENTAL PROCEEDURE

The major raw materials for the cast NAB alloy are copper, aluminum, nickel and iron. The copper and aluminum are locally sourced from scraps of refrigerating pipes/electric motor engine coils and scraps of aluminum tins. Thus, these two major materials were cut into smaller pieces to enhance speedy melting of the pieces before being fed into the crucible pot and melted in an oil fired pit furnace. The Silicon, magnesium and iron were added in their powder form stirred and then poured into prepared mould cavities to produce 30cm x 16ᴓ sample material for the study. Six (6) different composition samples of X_0, X_1, X_2, X_3, X_4 and X_5 were sand cast with varied percentages of silicon contents at 0%, 2%, 4%, 6%, 8% and 10% respectively. After the casting and fettling, the materials were subjected to deformation (cold rolling) at 0%,2%, 4%, 6%, 8% and 10% (weight percent) on each of the developed samples after which stress relieve annealing at 450^{o}C for 60minutes holding time was achieved.

The spectrometric analysis of the developed NAB alloy shown in Table 1 was determined prior to the mechanical property evaluation. A digital micro Vickers Hardness Tester HVS-1000Z: model 550 was used in evaluating the micro-hardness under an applied load of 4.904N over a dwell time of 15 seconds at room temperature. An average reading at four different points per sample was observed, these factors were maintained all through the samples readings for correlation purposes. A computer numeric control (CNC) tensile testing machine was adopted in conducting and evaluating the strength and percentage elongation of the developed NAB alloy.

Table 1: Chemical Composition of the Developed NAB Alloy

Element	**Cu**	**Al**	**Fe**	**Na**	**Ni**	**Si**	**Cl**	**Zn**	**S**	**Mg**	**Mn**
Sample X0	78.06	11.7	3.02	1.68	3.29	0.48	0.24	0.56	0.03	0.25	0.31
Sample X1	78.12	11.73	3.06	1.45	3.27	0.66	0.21	0.59	0.08	0.22	0.35
Sample X2	77.91	10.8	3.12	1.44	3.71	0.68	0.21	0.4	0.05	0.25	0.35
Sample X3	78.14	10.81	3.09	1.78	3.77	0.71	0.25	0.59	0.04	0.25	0.32
Sample X4	78.11	10.66	3.11	1.77	3.71	0.73	0.22	0.58	0.07	0.22	0.34
Sample X5	78.11	10.83	3.07	1.71	3.75	0.75	0.27	0.68	0.07	0.2	0.32

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Samples Designations and Interpretation

- The first subscript indicates the percentage of silicon addition while the second represent the degree of deformation the materials was subjected to: Note: X_{0-0}, X_{1-0}, X_{2-0}, X_{3-0}, X_{4-0} and X_{5-0} are the reference materials
- Samples X_{0-0}, X_{0-1}, X_{0-2}, X_{0-3}, X_{0-4} and X_{0-5} represents samples without silicon (Si) addition (0% Si) and with deformation ratio of 0%, 2%, 4%, 6%, 8% & 10% respectively
- Samples X_{1-0}, X_{1-1}, X_{1-2}, X_{1-3}, X_{1-4} and X_{1-5} represents samples with 2% Si addition with deformation ratio of 0%, 2%, 4%, 6%, 8% & 10% respectively
- Samples X_{2-0}, X_{2-1}, X_{2-2}, X_{2-3}, X_{2-4} and X_{2-5} represents samples with 4% Si addition with deformation ratio of 0%, 2%, 4%, 6%, 8% & 10% respectively
- Samples X_{3-0}, X_{3-1}, X_{3-2}, X_{3-3}, X_{3-4} and X_{3-5} represents samples with 6% Si addition with deformation ratio of 0%, 2%, 4%, 6%, 8% & 10% respectively
- Samples X_{4-0}, X_{4-1}, X_{4-2}, X_{4-3}, X_{4-4} and X_{4-5} represents samples with 8% Si addition with deformation ratio of 0%, 2%, 4%, 6%, 8% & 10% respectively
- Samples X_{5-0}, X_{5-1}, X_{5-2}, X_{5-3}, X_{5-4} and X_{5-5} represents samples with 10% Si addition with deformation ratio of 0%, 2%, 4%, 6%, 8% & 10% respectively.

RESULTS AND DISCUSSION

A. Effect of Silicon and Deformation Ratio on the Hardness Property of NAB Alloy

The study evaluates the effect of Si and deformation ratio on the micro hardness of NAB alloy. In order to accurately measure micro-hardness value, the sample were prepared from the developed NAB alloy and tested at different concentrations and deformation ratio. Figure 1 shows the hardness variation of the developed alloy subjected to micro-hardness Vickers harness testing equipment. The experimental results obtained indicate that there is a significant difference in the obtained hardness values of 130.5Hv as the least value of micro-hardness observed for sample X_{0-0}, representing the as-cast material without silicon addition and deformation ratio while it peak value of 181.8Hv at sample X_{0-5} indicating the effect of deformation ratio on the alloy. Similar trends were observed for samples with silicon ratio. However, the highest hardness value of 262.4Hv was observed for sample X_{3-5} (which contains 6% Si addition at 10% deformation; this is closely followed by hardness value of 257.9Hv for sample X_{4-3} indicating 8% Si additions at 6% deformation ratio. The Results established that a significant difference exist in the mechanically deformed samples as compared to the un-deformed samples. Further increment in the hardness value was also associated to the deformation ratios of the cast samples. These values are improvement over results reported by Uyime (2012) and Kavinjr (2019) [12] [13].

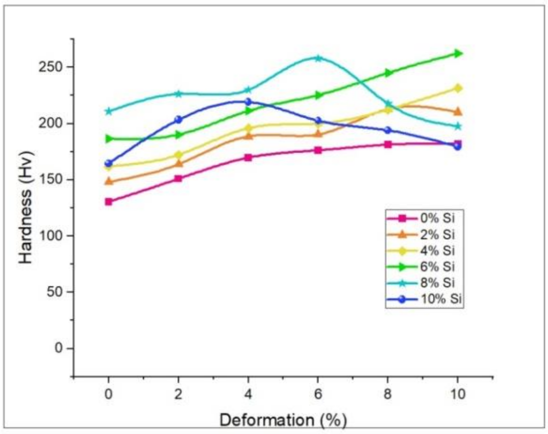

Fig. 1: Variation of hardness with respect to Deformation Ratio

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From the results in Fig 1, it can be deduced that silicon addition beyond 4% and 6%deformation ratios for samplesX_{5-2} and X_{4-3} respectively exhibits minimal effect and a decline in the hardness value of the alloy. However, samples X_2 and X_3 alloy show a linear progression in its hardness response to both silicon and deformation above 10% ratios. The indentations as shown in Figure 1(b) confirm the proof of hardness values displayed. The geometry is a display of the effect of silicon on the reference sample of (i) X_{0-0} without silicon (0% Si), (ii) X_{1-0} with 2% silicon, (iii) X_{2-0} with 4% silicon, (iv) X_{3-0} with 6% silicon, (v) X_{4-0} with 8% silicon and (vi) X_{5-0} with 10% silicon reinforcement.

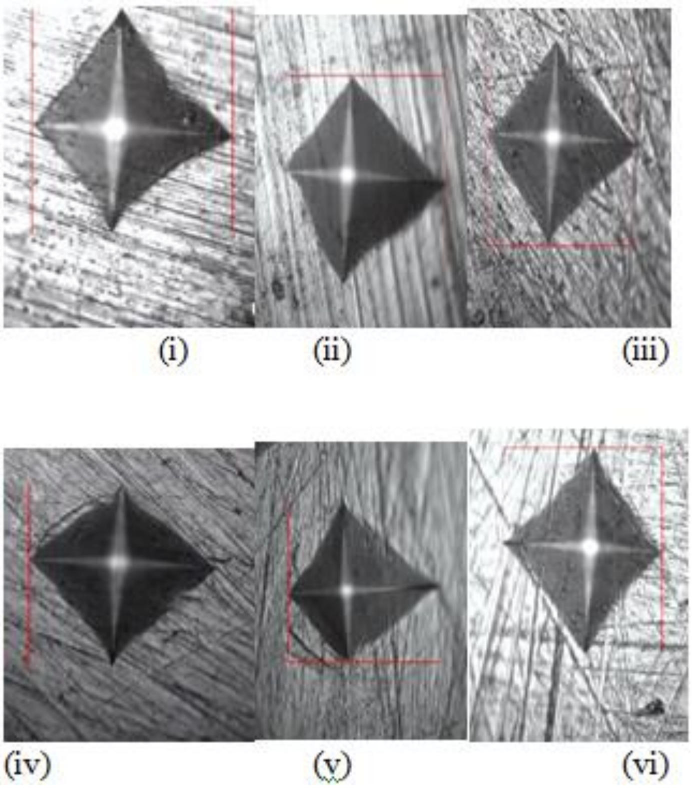

Fig. 1(b): Display of micro-hardness indentation geometry of the NAB alloy with respect to silicon variation

The bigger and deeper the indentation, the lower the hardness value exhibited, in other words the degree of penetration of the diamond indenter indicate the level of softness of the material. The following hardness value of 130.5Hv, 148.2Hv, 161.8Hv, 186.5Hv, 210.8Hv and 164.5Hv represents the hardness for the respective images in Fig.1b. The deduction extracted from this experimental result indicates that silicon (Si) is an effective reinforcing element and a great refiner of NAB alloy, thus showing an indication that NAB alloy will find greater application in the area where high impact resistance is required.

B. Effect of Silicon and deformation on the Tensile Strength

In this study, NAB alloy samples were subjected to tensile tests at different Si and deformation ratios. The result of the tensile strength compliments the hardness value as shown in Figure 2. The ultimate tensile stress (UTS) of the NAB alloy is found to follow the same trend as exhibited by the hardness. The sample X_{0-0} without Si and deformation displays the least value of strength at 190.72MPa. While samples (X_{4-3}) reinforced with 8% Si and deformed at 6% ratio displays highest UTS value of 590.79MPa although it shows a decline beyond 6% deformation. However, samples X_1 and X_2 at varied degree of silicon addition show a linear progression in strength with respect to deformation ratio above 10%. Samples X_{3-4}, X_{4-3} and X_{5-2} displayed their highest optimization at 560.51MPa, 590.79MPa and 566.98MPa deformation respectively. It could be observed that sample X_{5-2} exhibits high brittleness after 4% deformation.

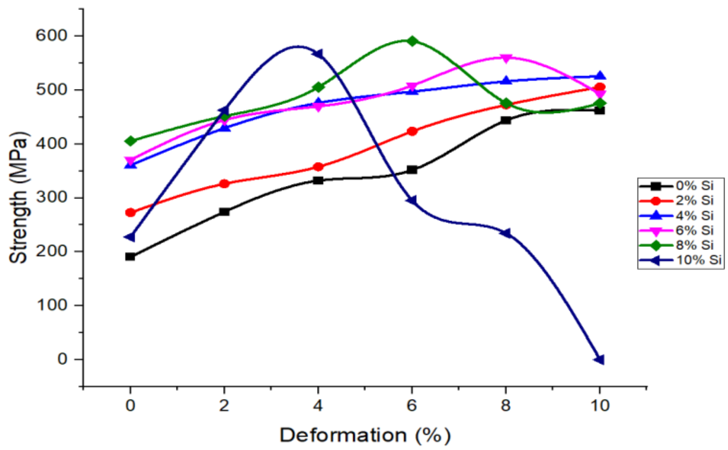

Fig. 2: Variation of stress with respect to percentage deformation

The results showed that increasing the Si content resulted in a greater tensile strength. However, increasing the deformation ratio led to threshold strength where by further increase in the deformation ratio does not result in further increases in strength. The results of this research indicate that the tensile strength of NAB alloy can be improved through variation in the Si and deformation ratio. Additionally, the results provide valuable insights into the effects of Si and deformation ratio on the tensile strength of NAB alloy. This knowledge can be used to develop further applications of NAB alloy in various industries.

C. Effect of Silicon and deformation on the Ductility of NAB Alloy

An attempt to examine the ductility of the samples while in service, the elongation at peak (Figure 3(a)) and at break (Figure 3(b)) were taken into consideration. Further evidence of the impact of silicon and deformation on the NAB alloy was significantly noticed in the ductility trend. Results show significant improvement for the six (6) reference NAB materials. Samples $X_{3-4,}$ and X_{2-4} exhibit its highest value of ductility 46.99% and 43.63% respectively at 8% deformation (fig 3b), this strain level of resistance shows an improvement over the sample without silicon X_{0-0} as it displays the least strain value of 23.69% (Fig. 3b). A fairly consistent and gradual increment was observed for samples X_1 with respect to the % deformed ratio.

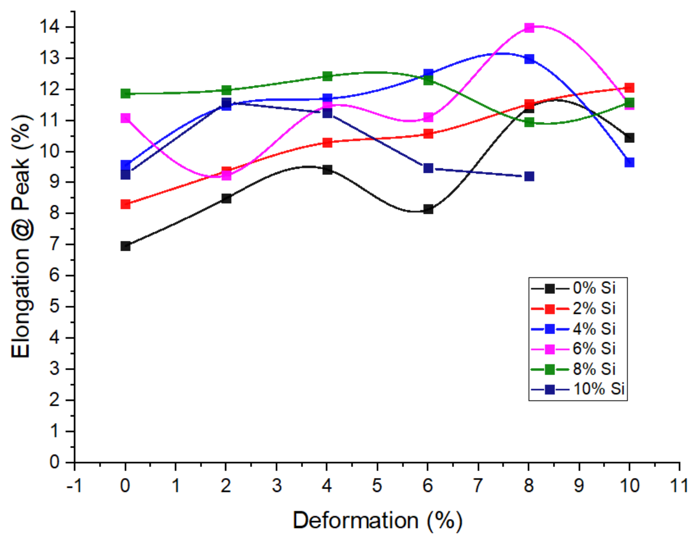

Fig. 3(a): Elongation @ Peak

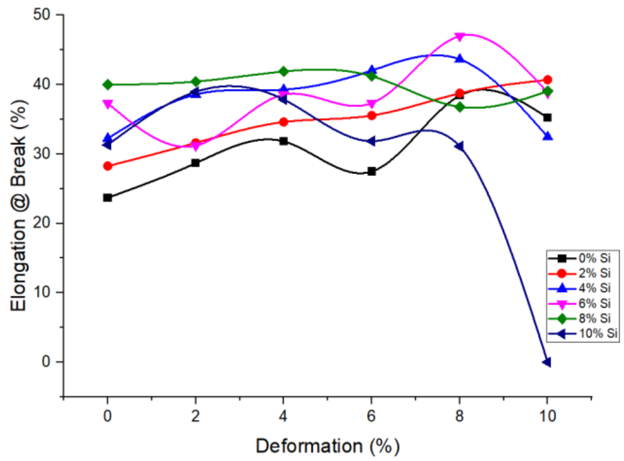

Fig. 3 (b): Elongation at break

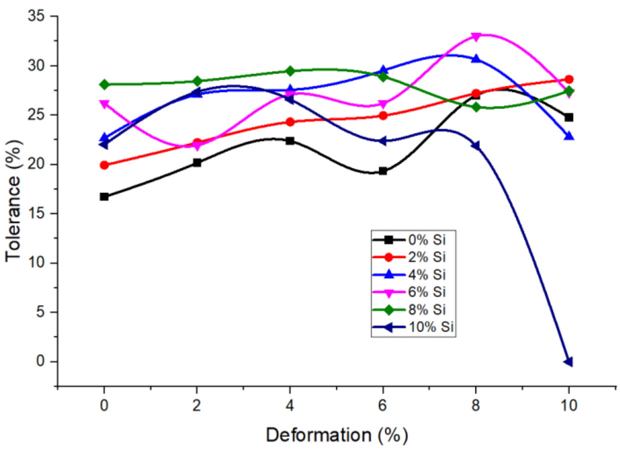

Fig. 3(c): Tolerance of NAB alloy

It was observed that insipte of the noticeable high ductility exhibited by the developed NAB alloy, further ductility or endurance limit prior to failure was also exhibited by all the samples with silicon and deformation ratios (Fig. 3c). Thus, indicating that on attaining a peak stress value, NAB alloy endures the applied load for a relatively longer time with respect to the reference material.

CONCLUSION

The effect of Si and deformation ratio on the hardness, tensile strength and ductility on NAB alloy has been investigated. The presence of Si significantly influenced the mechanical properties. In summary, the overall results of this study show that;

- The increasing levels of Si and deformation ratios had a positive effect on the micro-hardness of the NAB alloys. This work adds to the current understanding of the effect of Si and deformation ratios on the micro-hardness of NAB alloys and contributes to the growing body of knowledge in this field.
- The tensile strength of NAB alloy is affected by both Si and deformation ratio. Increasing Si increases the yield strength and ultimate tensile strength of the alloy, while increasing the percentage deformation increased its yield strength and ultimate tensile strength. Further investigation suggests that the addition of Si improves the ductility of the alloy. The results suggest that Si and deformation ratio have significant impacts on the tensile strength of NAB alloy, and both must be carefully

controlled in order to produce optimum results.

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