Effect Of Macro Additions Of Zinc And Nickel On The Mechanical And Microstructural Properties Of A Modified 7xxx Aluminium Alloy

Andrew Idoko Haruna, Innocent Uduehi Abhulimen

ABSTRACT: There has been large interest in combining the light weight of aluminium with varied excellent mechanical properties that a metal should poses for various industrial applications. This interest has led to vigorous researches in improving the mechanical properties of aluminium.This paper therefore investigatesthe effect of macro additions of zinc and nickel on the mechanical and microstructural properties of a modified 7xxx aluminium alloy. In this investigation, a corresponding relationship has been established between the microstructure and the properties of aluminium. Using the process of stir casting, Zinc was added to Al2.5Mg7Ni and Al2.5Mg2Ni to cast samples which were later homogenized at 550 ^{o}C and tempered (T6). Mechanical properties including, tensile strength, tensile elongation, hardness and fracture strength were investigated. Result shows that cast samples containing 15wt%Zn and 2wt%wtNi exhibited superior tensile strength (128.5MPa) and (0.0419) which is attributed to the presence and even distribution of Mg2Si and NiAl3 intermetallic, in the microstructure of the as-cast material. Solution treatment at 550^{o}C led to a good combination of tensile strength and elongation (111.72MPa and 10%). Increase in Nickel content led to a stabilization of the material structure but did not impart strength and ductility. T6 tempering of solution treated samples did not give any increase in the mechanical properties. Microstructure of cast structure shows the presence of three intermetallic including NiAl3, AlFeSi and Mg2Si in the α-aluminium matrix.

KEYWORDS: hardening, intermetallic, mechanical properties, stir casting and tempering.

1. INTRODUCTION

Aluminium and its alloys have a wide variety of industrial applications due to its low weight and high resistance to corrosion. In general, apart from steel, Aluminium is rated to have a widest range of usage in the family of metals.But due to its low mechanical resistance, the usage of aluminium could be limited in engineering applications. Recently, specific industrial processes have been developed and as a result an improvement in the aluminium mechanical resistance has become mandatory, thereby initiating researches in the study of new aluminium-based alloys [10]. In the designing of wrought, high-strength aluminium alloys, some of the most important factors and attributes to be considered are chemical composition and processing parameters and the resulting effects of the microstructure on mechanical and corrosion properties [13]. Recently, investigations have alloyed aluminium with Ni and Ti principally, giving rise to aluminium alloys with good mechanical properties [1-2]. However, because of the limited solubility of nickel in aluminium, there exist a reinforcement effect which is due to the formation of AlxNiy intermetallic phases in the aluminium matrix and this provokes a significant increase in the mechanical properties of the alloy. The addition of nickel as a reinforcement material allows the generation of a new type of aluminium-based alloys with high potential of development and applications, which offers high mechanical resistance besides other numerous advantages over the conventional aluminium alloys[3-7]. The effect of nickel and magnesium addition in the microstructure and properties of Al-(4-5)Fe-1V-1Si alloys have been investigated, Results show that addition of magnesium and nickel changed the morphology of both primary and eutectic phases. The authors concluded that the presence of Magnesium impacts a limited solution-hardening effect and promote the strengthening of the Al alloy through work hardening.[12] Also, further work revealed that the Mg addition, however, increases the strain corresponding to the formation of a stable microstructure and the saturated strength value [14]. Alloys of Al-Zn-Mg systems have a combination of high fracture toughness and resistance to stress corrosion cracking that renders them very useful in aerospace applications. Thus, the balance of properties of 7xxx alloys can be optimised by microstructural modifications via alloy compositional changes and heat treatment variations [8 and 11]. An understanding of how compositional variations affect the characteristics of coarseintermetallic particles in 7xxx alloys, and how coarse intermetallic particles are detrimental, especially to the toughness of the alloy has been investigated [9]. The aim of this study is to understand the effect of macro additions of zinc and nickel on the mechanical and microstructural properties of a modified 7xxx aluminium alloy. This also includes a study into the microstructural characterization of heat treated aluminium alloy and an investigation into the effect of artificial aging conditions on metallographic, tensile strength and hardness of aluminium alloys

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2. EXPERIMENTAL PROCEDURE

The wrought aluminium alloy used for this study was obtained from NigalexOshodi Lagos; with designation 6000 series of 40kg mass. In addition, zinc, magnesium and nickel were gotten from same source.

Table 1. Spectrophotometric result of Aluminium alloy used in the study

Elements	Fe	Si	Mn	Cu	Zn	Ti	Mg	Pb	Sn	Al
Composition	0.395	0.540	0.148	0.197	0.097	0.017	0.098	0.014	0.002	**98.28**

Theprocess started with the preparation of the charge containing required quantities of different elements like Al, Zn, Ni and Mg. Cutand weighed pieces were charged in a graphite crucible and melted employing an oil-fired furnace. Care was taken to ensure that the lower melting elements like Al be added at latter stages of melting with a view toreduce losses through vaporization. The melt was stirred manually for some time to facilitate dissolution of thealloying elements. After cleaning the melt surface, pouring was carried out in preheated P.O.P moulds in the form of **180 x 100 x 30** mm rectangular bars. A total of twenty four samples were cast with varying amount of zinc and nickel and are designated as shown in the table below:

Table 2. Materials designation and percentage weight composition of elements in the as-cast samples

Materials designation	R11	R12	R21	R22	R31	R32	R41	R42
Zn(%wt)	5	5	10	10	12.5	12.5	15	15
Ni(%wt)	2	7	2	7	2	7	2	7
Mg(%wt)	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Al(%wt)	90.5	85.5	85.5	80.5	83	78	80.5	75.5

The samples were divided into three groups; Some were kept as-cast, the second set were homogenized in a muffle furnace at 550^0 C and was held for 4hrs, while the last set were T6 tempered (homogenized at 550^0 C quenched and tempered at 250^0 C). The materials were further designated according to the various groupsas follows
:

Table 3.

Materials designation	R11	R12	R21	R22	R31	R32	R41	R42
Composition	Al5Zn2Ni	Al5Zn7Ni	Al10Zn2Ni	Al10Zn7Ni	Al12.5Zn2Ni	Al12.5Zn7Ni	Al15Zn2Ni	Al15Zn7Ni
As-cast	R11A	R12A	R21A	R22A	R31A	R32A	R41A	R42A
Homogenized	R11H	R12H	R21H	R22H	R31H	R32H	R41H	R42H
T6 Tempered	R11T	R12T	R21T	R22T	R31T	R32T	R41T	R42T

All samples were subjected to the following mechanical test: Tensile test using an Instron grade tensometer. Hence, the Ultimate tensile strength, fracture strength, and ductility were calculated Vickers hardness test was carried out at the Engineering Materials Development Institute (EMDI), Akure, Ondo State. The model of the machine used is Leco AT_{700} digital Micro Hardness Tester and the applied load used was 490.3mN (approximately 50kgf). Each sample was placed on the anvil of the tester and the load was applied with a dwell time of 10 seconds. Several readings were taken for each of the sample and the average values were calculated from two closely related values. Microstructural evaluation using an optical metallurgical microscope was also conducted at Engineering Materials Development Institute (EMDI), Akure, Ondo State.

3. RESULTS AND DISCUSSION

A summary of the tensile strength(MPa), Tensile Elongation and hardness values of AlZnMg alloy modified with Nickel in the as-cast, homogenized and T6 tempered forms are presented in Table 4. shown below.

Table 4.

Mechanical Tests	As-cast	Homogenized	T6 tempered
	R11A	**R11H**	**R11T**
Tensile Strength(MPa)	30.74	39.64	22.5
Tensile Elongation	0.0316	0.0314	0.152
Hardness(HV)	127.2	152.8	111.4
	R12A	**R12H**	**R12T**
Tensile Strength (MPa)	59.0	39.83	32.699
Tensile Elongation	0.148	0.172	0.1085
Hardness (HV)	243.1	162.3	146
	R21A	**R21H**	**R21T**
Tensile Strength(MPa)	48.49	48.78	99.14
Tensile Elongation	0.08	0.0576	0.0676
Hardness(HV)	166.7	175.8	87.8
	R22A	**R22H**	**R22T**
Tensile Strength(MPa)	51.37	98.69	89.67
Tensile Elongation	0.0285	0.0367	0.0498
Hardness(HV)	113.1	115.4	133.9
	R31A	**R31H**	**R31T**
Tensile Strength(MPa)	78.35	102.52	103.42
Tensile Elongation	0.0301	0.067	0.0632
Hardness(HV)	126.7	104.6	91.7
	R32A	**R32H**	**R32T**
Tensile Strength(MPa)	61.22	60.56	57.36
Tensile Elongation	0.0286	0.0367	0.0338
Hardness(HV)	134.9	115.4	126.6
	R41A	**R41H**	**R41T**
Tensile Strength(MPa)	128.5	111.72	33.56
Tensile Elongation	0.0419	0.1	0.028
Hardness(HV)	127.1	91.1	97
	R42A	**R42H**	**R42T**
Tensile Strength(MPa)	62.85	12	32.47
Tensile Elongation	0.059	0.173	0.0299
Hardness(HV)	144.8	85.7	99.2

The fracture strength and ductility for the as-cast, homogenized and tempered samples with variations in zinc and nickel contents can also be seen from the graphs shown below in figures 1.0 -1.5. In figure 1.0, for the as-cast samples, it was observed that the fracture strength increases with increase in zinc content for both Al-2wt%Ni and Al-7wt%Ni samples to a maximum of 69.955MPa and 28.39MPa respectively. Hence,Al-2wt%Ni having a more superior fracture strength.Homogenization as seen in figure 1.1, however shows a reverse behaviour of Al-7wt%Ni to the as-cast sample. Tempering on the other hand on figure 1.2 of both samples shows an increase in the fracture strength with increase in zinc content to a peak value before decline with further increase in zinc content. In figure 1.3, the tensile strain of the as-cast samples decrease with increase in zinc content with a maximum strain of 0.23 and 0.08 respectively at 10wt%Zn content. Homogenization of Al-2wt%Ni show a steady increase in tensile strain to a maximum value of 1.0 at 15wt%Zn whereas strain values of Al-7wt%Ni does not show any specific trend. Tempering of both materials lead to uniform decrease in tensile strain with increase in zinc content. These results show that homogenization favours tensile strain while tempering does not.

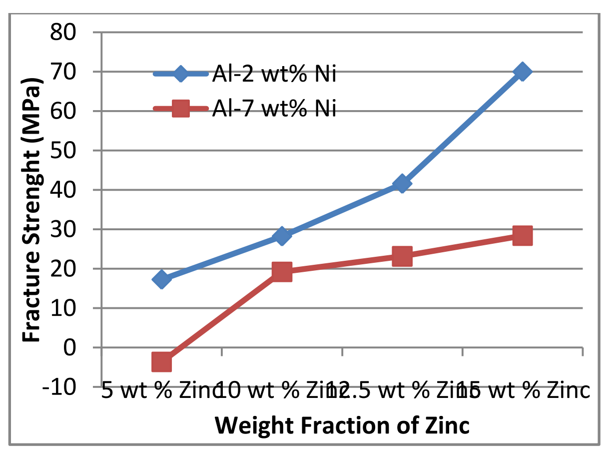


Figure 1.0: Variation of fracture strength withincrease in zinc content of homogenized samples

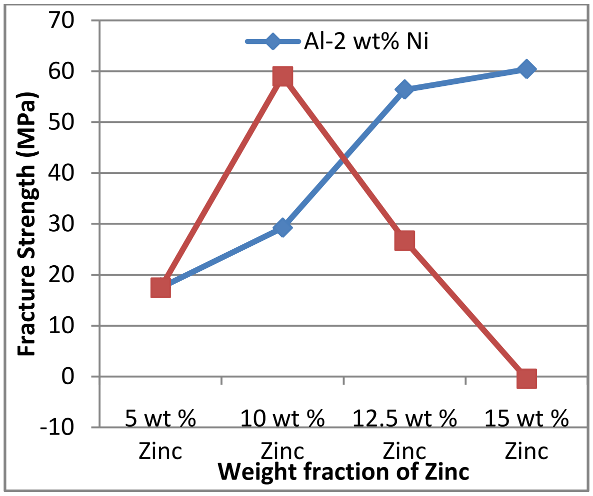


Figure 1.1: Variation of fracture strength with increase in zinc content of homogenizedsamples

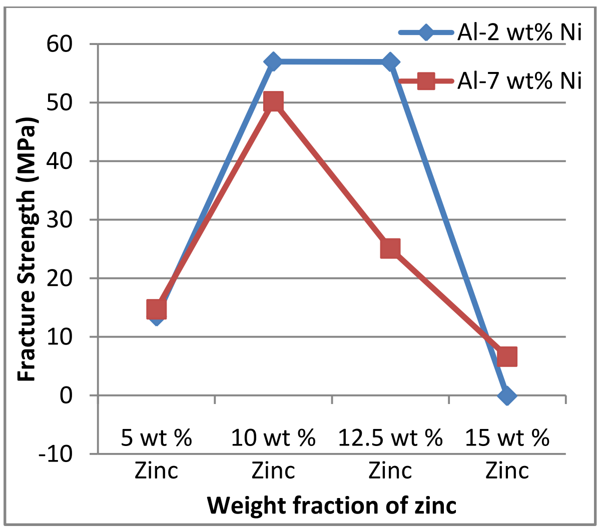


Figure 1.2: Variation of fracture strength with in zinc content of tempered sampleswith increase in zinc content

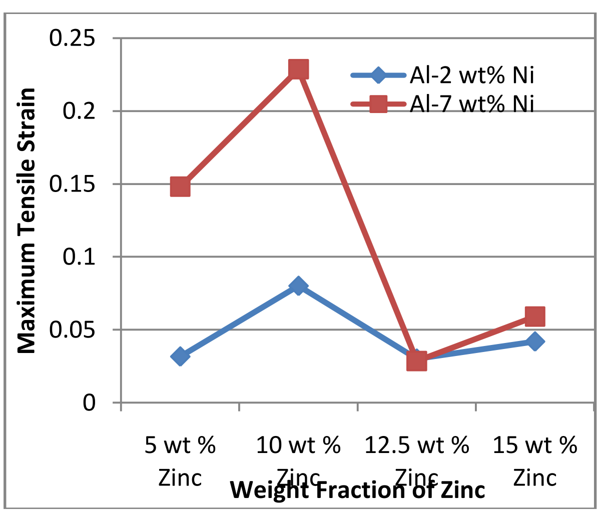


Figure 1.3: Variation of maximum tensile strain with increase in zinc content of as-cast samples

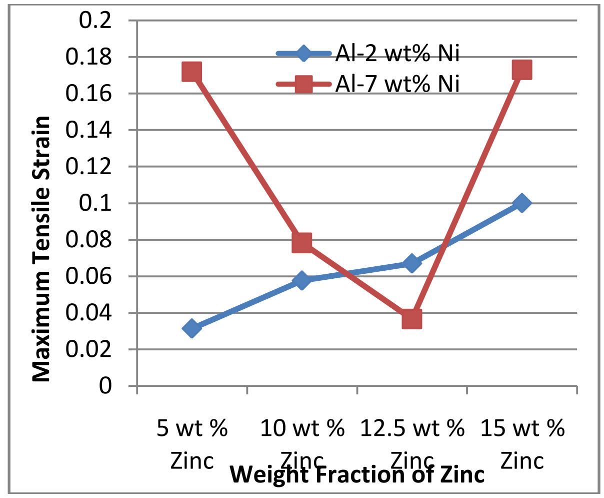
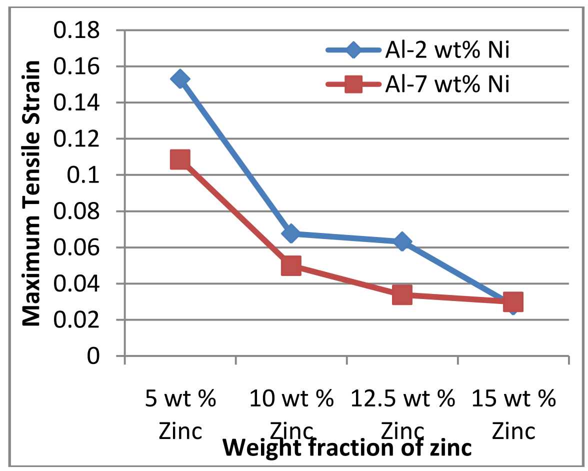


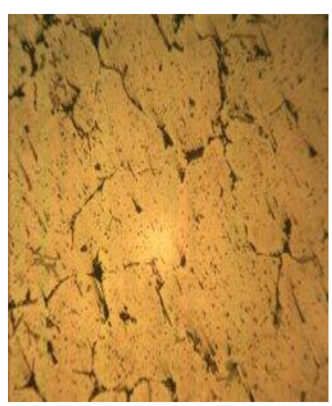
Figure 1.4: Variation of maximum tensile strainFigurewith increase in zinc content of tempered samples



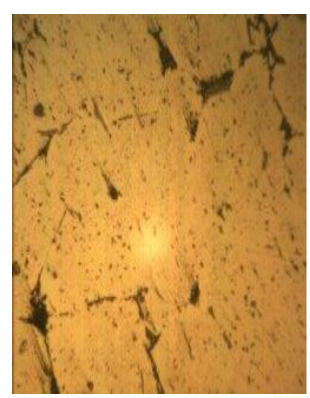
1.5: Variation of maximum tensile strainwith increase in zinc content of homogeniezedsamples

3.1Microstructural Examination

As shown by optical microscopy, figures 2.0 – 2.2 shows the microstructures of the as-cast, homogenized and tempered R41 samples in double magnification (200 and 400) respectively.



R41 AC CAST 200X



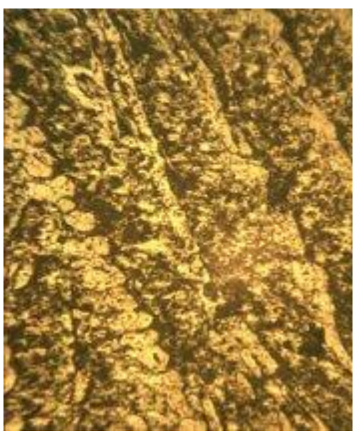
R41 AC CAST 400X

Figure2.0: Microstructures of R41 samples in as-cast conditions

R41 HOMOGENIEZED 200X

R41 HOMOGENIEZED 400X

Figure 2.1: Microstructures of R41 samples in homogenized conditions



R41 T6 TEMPERED 200X

R41 T6 TEMPERED 400X

Figure 2.2: Microstructures of R41 samples in tempered conditions

Microstructure of cast Al-Zn-Ni-Mg alloy shows the presence of intermetallics including $NiAl_3$ (light grey phase), AlFeSi (Dark), Mg_2Si (light brown) and the α-aluminium matrix. It can be observed that the as-cast samples show AlFeSi scattered randomly with Mg_2Si present. The homogenized sample shows AlFeSi littered across the matrix with Mg_2Si sparsely distributed within the matrix. The tempered samples show that $NiAl_3$ and Mg_2Si precipitates are densely populated along the grain boundaries. A comparative analysis of the effect of heat treatment on the hardness, ultimate tensile strength and tensile elongation of Al-2wt%Ni and Al-7wt%Ni samples with varying amounts of zinc content was conducted. This can be seen in figures 3.0 – 3.5

3.2 EFFECT OF HEAT TREATMENT

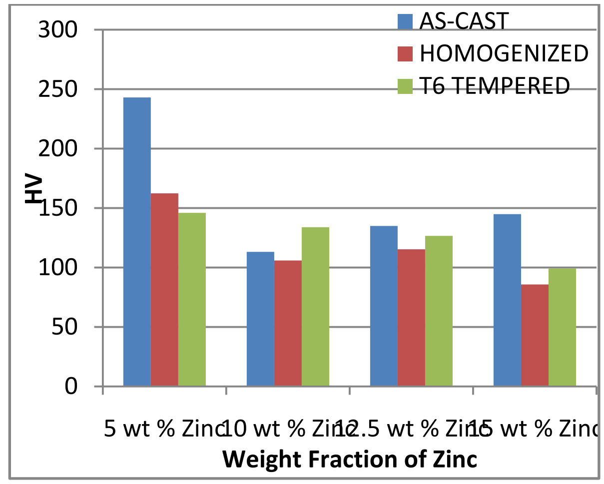


Figure 3.0: Effect of heat treatment on the treatment on the hardness of Al-7wt% Ni with varying amount of Zinc

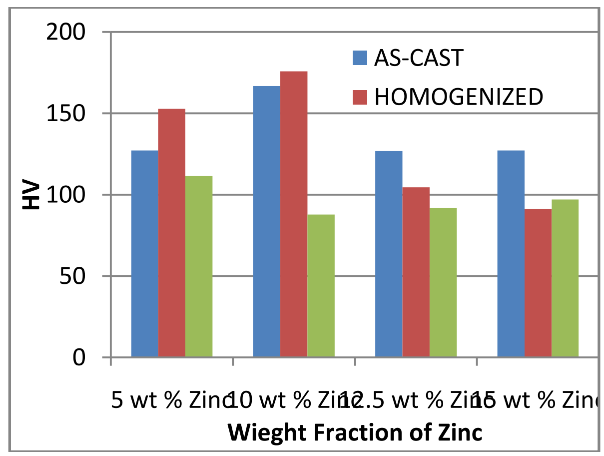


Figure 3.1: Effect of heat hardness of Al-2wt% Ni with varying amountof zinc

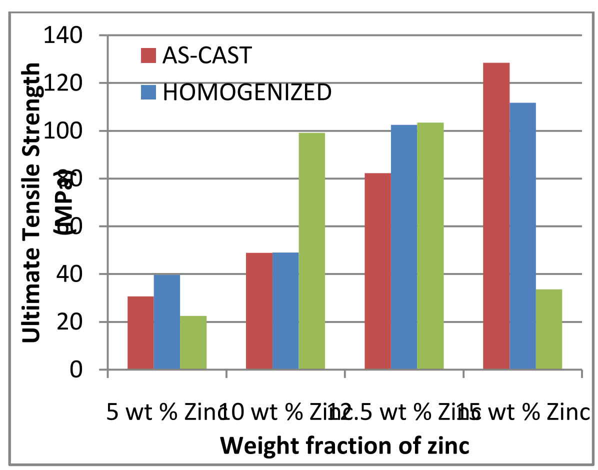


Figure 3.2: Effect of heat treatment on ultimateof Al-2wt% Ni with varying amountof zinc

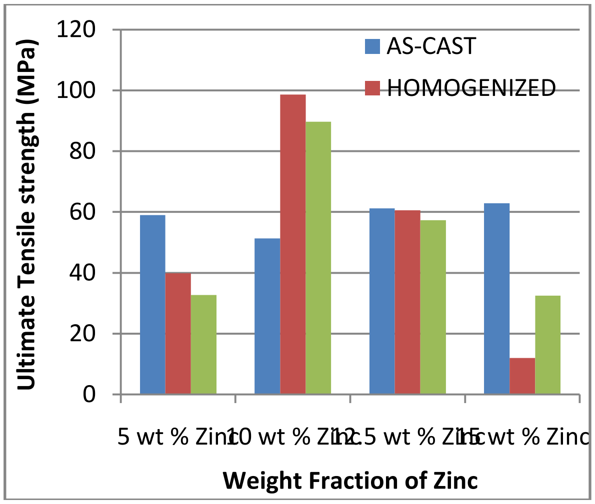


Figure 3.3: Effect of heat treatment on tensile strength ultimate tensile strength of Al-7wt% Niwith varying amount of zinc

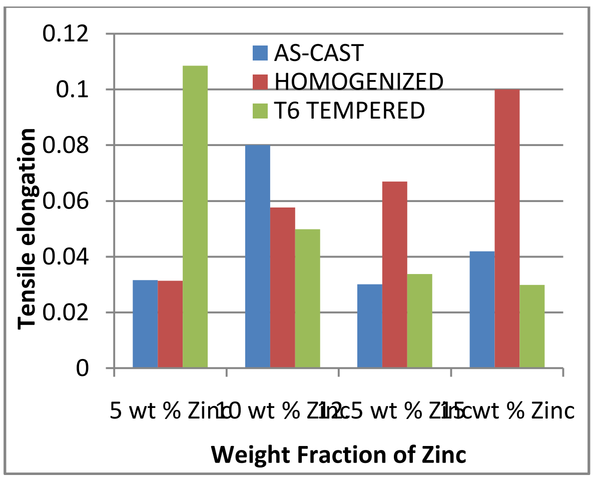


Figure 3.4: Effect of heat treatment on tensile elongation of Al-2wt% Ni with varying amount of zinc

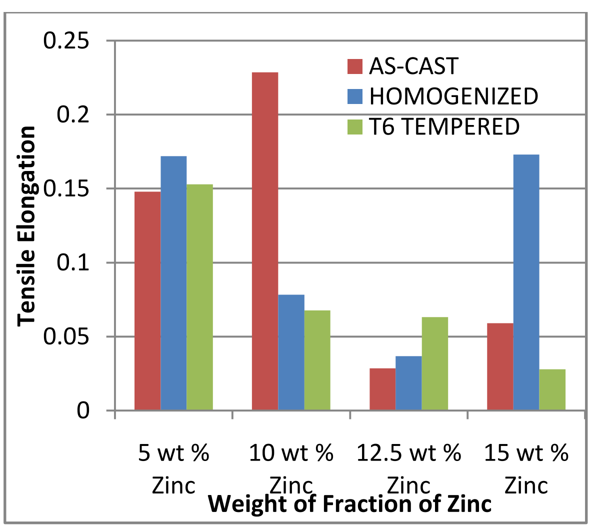


Figure 3.5: Effect of heat treatment on tensileelongation of Al-7wt% Ni with varying amountof zinc

Comparative results of all samples show that R41 sample containing 15wt%Zn and 2wt%Ni exhibit the superior tensile strength (128 MPa) and elongation (0.0419). This may be attributed to the even distribution of intermetallics of $NiAl_3$ and Mg_2Si in the Microstructure. These intermetallics are dissolved in the dendritic structure of the cast such that they are not easily identifiable. Solution treatment of the sample lead to a breakdown of the structure with increase in volume fraction of precipitates in the surface littered all over the grains. This may be the reason for the good combination of strength and ductility (111.72 and 10% respectively). However T6 Tempering led to a structure that is detrimental to both strength and ductility.This is unusual and may be a question of experimental inadequacy rather than mere evolution of properties due to structural disruption. Hardness values of the R41 sample are 127.1HV, 91.1HV and 97HV for as-cast, homogenized and tempered conditions respectively. These are appreciable values and may be attributed to the presence of well dispersed hard AlFeSiintermetallics in the α-Al matrix as seen in the photomicrographs. It can be stated emphatically here that increase in the amount of nickel did not improve the mechanical properties but rather stabilized the structure of the alloy giving rise to moderate tensile strength values.

4. 4. CONCLUSION

From results obtained from this research work, the following deductions can be drawn:
Increase in zinc content has a marked influence on the mechanical properties of the aluminium alloys. Intermetallics of $NiAl_3$,AlFeSi and Mg_2Si are formed and precipitated in the α-aluminium matrix. Tensile strength tends to be dependent on the amount of AlFeSi and $NiAl_3$intermetallics in the matrix Solution treatment of these alloys did not lead to remarkable change in their mechanical properties, which may be as a result of deformations in the structure of the material. T6 tempering did not give any appreciable result as expected. This was attributed to experimental errors which may be associated with the machine.Increase in Nickel content stabilized the structure of the alloys but produces moderate mechanical properties.

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