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(Research Article)

Effect Of Zinc Addition on the Microstructure and Mechanical Properties of 6063 Aluminum Alloy

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Abstract

This research work entails addition of Zinc metal to the 6063 aluminium alloy series. The Zinc addition ranged from a percentage of 1% - 5% at an interval of 0.5%. Charge calculations were made and the aluminium alloy and Zinc were melted in a crucible furnace. Permanent mold casting was utilized with dimension of 150 mm * 15 mm. The 6063 aluminium – Zinc alloy was machined to standard tensile dimensions of G.D 5 mm, G.L 40 mm, external diameter 8 mm, two opposite external length of 30 mm; hardness dimensions of 20 mm * 20 mm * 20 mm; and impact dimensions of length 60 mm, diameter 10 mm, notch at 30mm with 3mm depth. The aluminium- zinc alloys were heat treated to 300 °C and 400 °C; and held at a soaking time of 2 hours, allowed to cool in the furnace and another series of aluminium - zinc alloy was not heat treated.

The specimens were destructively tested and the homogenized 400 °C aluminium-zinc alloy possessed the greatest strength of 237 MPa, a hardness value of 113 HV, a maximum percentage elongation of 22.5% and a maximum impact energy of 70.5 J. Thus, the alloy can be used for applications requiring high strength and hardness coupled with low ductility.

Keywords: Aluminium – Zinc Alloy; Hardness; Impact Energy; Strength

1 Introduction

One of the key challenges of the 21st century will be the creation of materials with the ability to operate under different services or loading applications in different media such as space, air, or sea. The materials-community is uniquely positioned to play a central role in addressing these problems by fundamentally changing the materials process used by the society [1]. For this to happen, materials experts must begin to consider the environmental impacts of their design choice and will require additional analytical tools to quantify those broader implications [2]. This paper addresses the need to show that a material can withstand service/loading application under different environmental conditions using Aluminium 6063 alloy as a case study. Materials Engineers must integrate the tetrahedron of properties, processing, structure and performance of materials to create reliable manufactured or fabricated goods of great performance [3]. Of importance to their individual natures, however, is the synergistic manner in which they interact and influence one another. Clearly, the performance of an aluminium structured passenger car reflects the processing or way it was manufactured, which in turn influences the atomic and electronic structure of the constituent materials and the properties each exhibit [4].

The first important structural applications of aluminium were found in passenger hydrofoils. These were highly sophisticated vessels and the know-how developed during this technological experience formed a precious base for subsequent developments [5]. The use of aluminium combined with the use of water-jet propulsion made it possible to

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create a new category of vessels, the so-called high-speed ferries, single-hulled boats or more often catamarans, made entirely of aluminium [6]. In structural load-bearing components, 82% of a Boeing 747 aircraft and 70% of a Boeing 777 aircraft is aluminium. Aluminium usage in automobiles and in light trucks has been increasing steadily. As early as 1990, there were no aluminium-structured passenger cars in production anywhere in the world, but in 1997, Audi A8 and Plymouth Prowler amongst others came into existence, with weight savings of up to 47% over steel vehicles, such cars use less fuel, create less pollution, and are recyclable. As a result new alloys and new design and manufacturing methodologies had to be developed [7]. For example, welding and adhesive bonding procedures had to be refined, structural frame work had to be remolded and new tooling designs for the formation of aluminium was made. Because of these new technologies, the desired environmental savings were realized without any drop in performance or safety [8].

The scope of this work is limited to the following: Casting of 6063 aluminium alloy with varying percentage of zinc metal from 1% - 5% followed by heat treatment. Also included in this study is the determination of mechanical properties like ultimate tensile strength, hardness, impact strength and microstructural analysis. The significance of this study is the need for aluminium to be used in various applications where strength and hardness is required. Aluminium 6063 which when alloyed with zinc by the casting process and further heat treated improves the strength of the composite as would be proved by the results obtained in the experiment. The aim of the present work is to improve the mechanical properties of the aluminium 6063 alloy by alloying with zinc from a composition of 1% -5%. Aluminium - zinc alloys has been proven to be useful industrially in such areas which include: component parts of automobiles (in engines or carburetors) internal casement of airplanes [9]. Aluminium 6063 alloy is well known to be used in the architectural design of windows, doors and zinc is known to be used in galvanizing, coating and surface finish [10]. The alloying of zinc with aluminium 6063 alloy would find application in architecture, automobile, airspace, engines, research and can be used in any other application where necessary. The results obtained after the experimentation would determine the usage of this composite alloy in different environmental conditions.

2 Experimental Procedure

The 6063 aluminium alloy material used was obtained from Nigerian Aluminium Extrusion Company (NIGALEX) at Apapa, Oshodi, Lagos. The chemical composition of the alloy was analyzed at Aluminium Rolling Mill, Ota-Ogun State and is given in the table (1) below.

Table 1 Chemical composition of 6063 Aluminium Alloy

Element	**Si**	**Fe**	**Cu**	**Mn**	**Mg**	**Na**
% composition	0.66665	<0.24315	0.01643	0.02103	0.45346	0.00614
Element	Ti	B	Sn	Pb	Zn	Al
% composition	0.00895	0.00064	0.00390	-0.00380	0.01415	98.52

The Zinc metal was purchased from a metal merchant at Iyana Ipaja, Lagos. The Chemical analysis of the zinc metal was analyzed at the Chemistry Department, Faculty of Science, University of Lagos and given in the table (2) below.

Table 2 Compositional Analysis of Zinc metal

Element	**Zn**	**Fe**	**Cu**	**Cr**	**Mn**	**Pb**	**Ni**
% composition	89.331	4.040	0.015	0.468	0.371	0.010	0.045

The Crucible furnace used in the experiment was heated to a temperature of 800^{o}C in which the 6063 aluminium alloy were charged into the furnace and melted. This was done in order to reduce the weighed quantity of 6063 aluminium alloy in kilograms (Kg) to small size ranges ready to be casted with the zinc metal. The melted 6063 aluminium alloy were weighed to the required size together with the zinc metal and charged into the crucible furnace. A permanent mold was obtained from the metallurgical workshop and this was used for the casting operation.

The melted 6063 aluminium and zinc metal were heated and obtained in molten form after heating in the crucible furnace as shown in Figure 3. The molten alloy is then removed from the furnace and stirred to remove any form of impurities such as slag before being poured rapidly into the permanent mold and allowed to solidify. After solidification of the molten metal composite, cooling occurs and the cast is removed from the permanent mold.

Table 3 Percentage Alloy and Weight Composition of Specimens

S/n	Aluminium 6063 alloy (%)	Zinc (%)	Aluminium 6063 alloy (g)	Zinc metal (g)
X	100	0.0	200	0
IX	99.0	1.0	194	6
VIII	98.5	1.5	191	9
VII	98.0	2.0	188	12
VI	97.5	2.5	185	15
V	97.0	3.0	182	18
IV	96.5	3.5	179	21
III	96.0	4.0	176	24
II	95.5	4.5	173	27
I	95.0	5.0	170	30

The as-cast materials after fettling were machined to standard tensile test piece, impact test piece and hardness test piece. The larger diameter end of the impact test piece was cut off for spectrometer analysis. As the specimens were being machined, the tendency of the cutting tool to damage due to overheating was reduced by the use of cutting fluids.

The heat treatment used for this project is homogenization heat treatment. This involves setting the furnace temperature to 300 ^oC, 400 ^oC. Therein the samples are held at a soaking time of 2 hours. They were cooled in the furnace till the next day and then removed for determining their mechanical properties. The heat treatment process was carried out at Metallurgy laboratory, University of Lagos.

The use of a file was utilized to provide an initial flat surface and subsequent grinding took place on the rotary grinding wheel using silicon carbide abrasive papers of various grades. Water was used to avoid overheating and grinding on each paper progressed until the scratches produced by previous grinding operations were completely removed.

The purpose of polishing was to remove the surface scratches in order to obtain a mirror surface. A polishing powder was utilized as well as water to reduce heat generated from the rotating wheel.

In order to reveal the structure, the specimens were etched in a solution containing Sodium Hydroxide NaOH for 30seconds and then washed with water and allowed to dry. The etched surface was viewed under the metallurgical microscope and the photographs were taken.

The samples were machined according to standard for tensile and impact specimens for mechanical analysis of tensile strength, impact strength and hardness.

TENSILE TEST- This was carried out on an Instron Universal tester,3369 model at the Engineering Materials Development Centre, Km 4 Ondo Road, Akure, Nigeria.

IMPACT V-NOTCHED TEST – The cast samples were tested using the Avery impact testing machine. This was carried out at the stress-strain analysis laboratory, Mechanical Department, University of Lagos.

HARDNESS TEST – The hardness test was done using a Leco Micro hardness tester model at the Engineering Materials Development Centre, Km 4 Ondo Road Akure, Nigeria.

3 Results and Discussion

3.1 Tensile Test Results

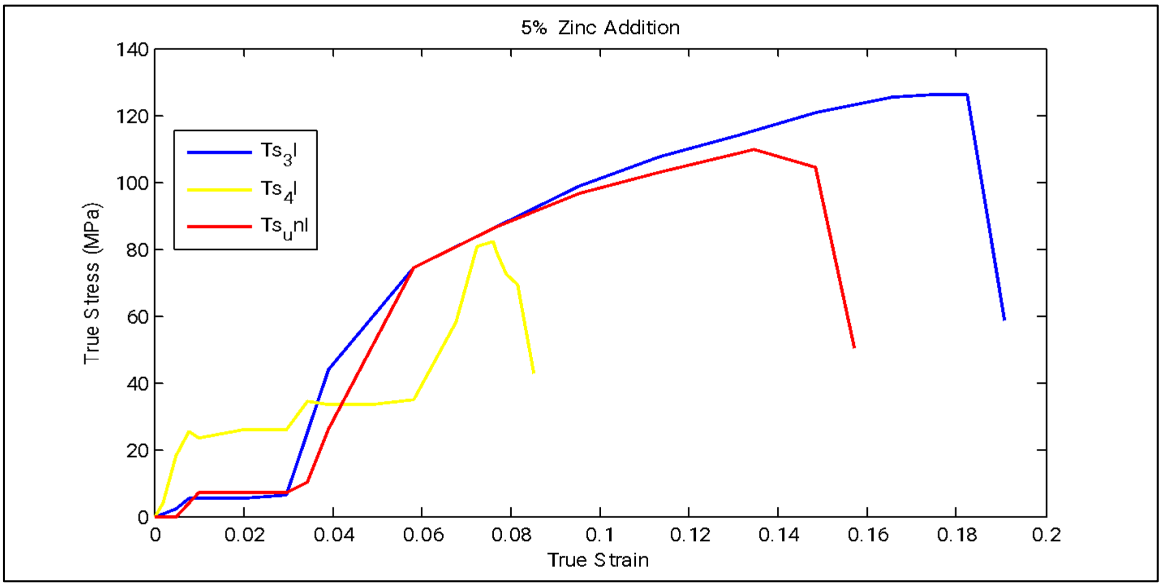


Figure 1 True Stress Vs True Strain for 5% Zinc Addition

From Figure 1; the true stress vs. true strain shows that the homogenized 300 °C alloy undergoes sufficient plastic deformation before fracture indicating the largest ductility with maximum UTS of 125.08 MPa.

From Figure 2; the unhomogenized alloy possesses the highest UTS of 164.16 MPa while that of the Homogenized 300 °C alloy possesses the largest plastic deformation before fracture thereby making it more ductile.

From Figure 3; the homogenized 400 °C alloy has the maximum UTS of 275.39 MPa while the homogenized 300 °C alloy undergoes sufficient plastic deformation.

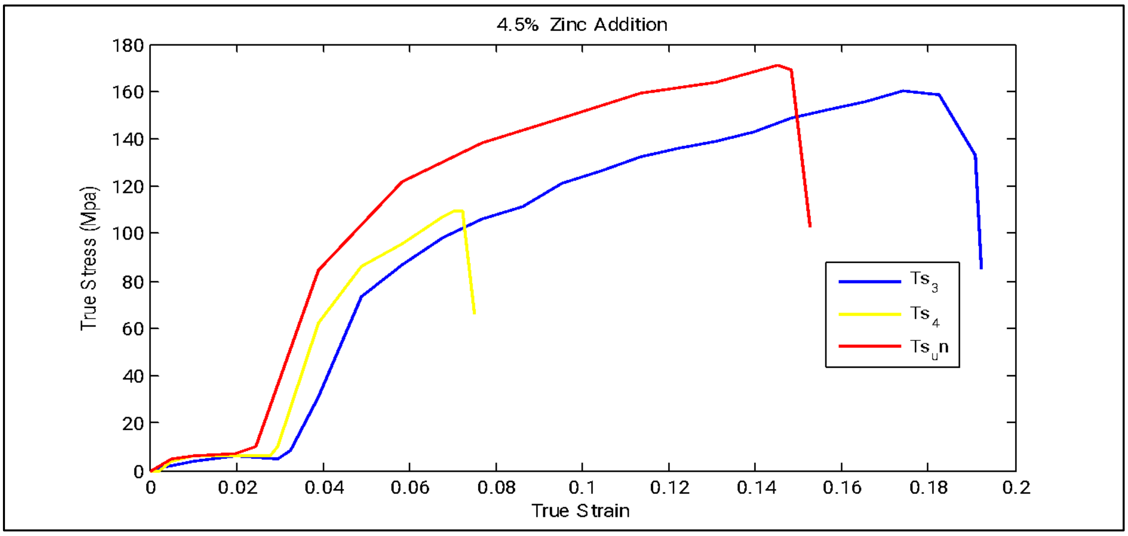


Figure 2 True Stress Vs True strain for 4.5% Zinc Addition

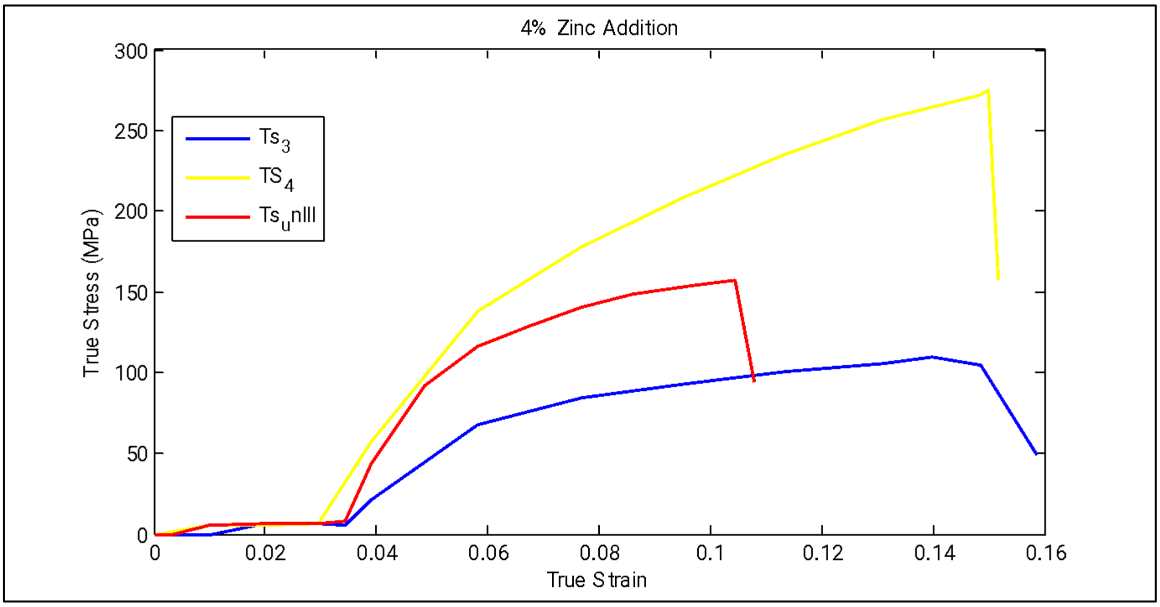


Figure 3 True Stress Vs True strain for 4% Zinc Addition

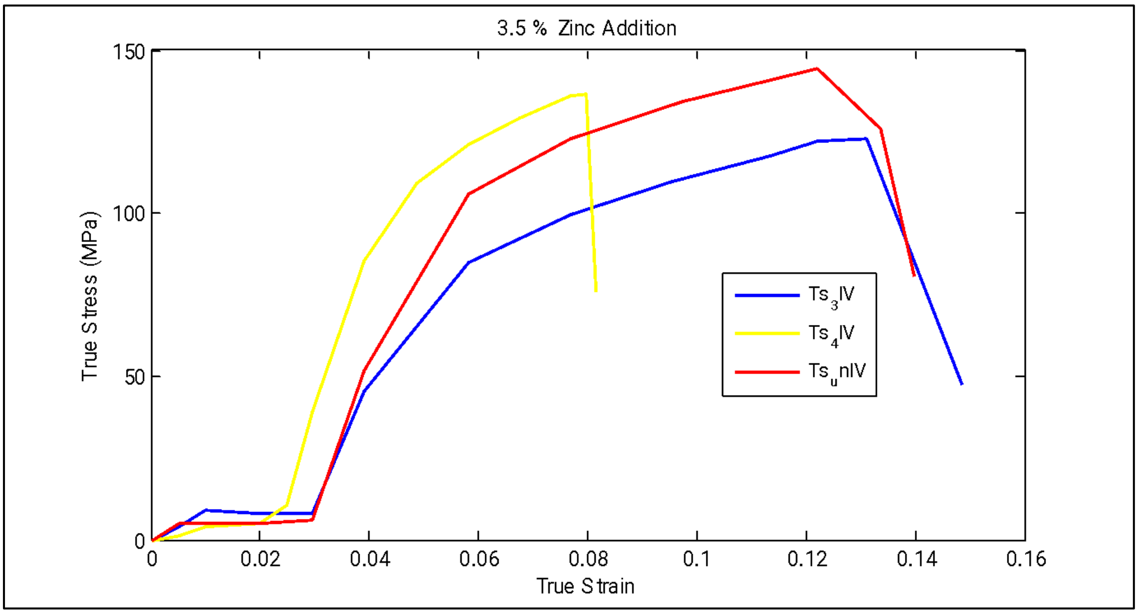


Figure 4 True Stress Vs True strain for 3.5% Zinc Addition

From Figure 4; the unhomogenized alloy has the greatest UTS of 144.84 MPa and undergoes sufficient deformation while the homogenized 400 °C alloy has the largest deformation.

From Figure 5; the homogenized 400 °C alloy has the least deformation and the highest UTS of 172.82 MPa while the homogenized 400 °C alloy undergoes sufficient plastic deformation.

From Figure 6; the unhomogenized alloy has the maximum UTS of 143.51 MPa and undergoes sufficient plastic deformation.

From Figure 7; the homogenized 400 °C alloy undergoes the least deformation with a UTS of 124.76 MPa while the homogenized 300 °C alloy undergoes sufficient plastic deformation.

From Figure 8; the homogenized 300 °C alloy has the maximum UTS of 122.72MPa and undergoes sufficient plastic deformation as shown.

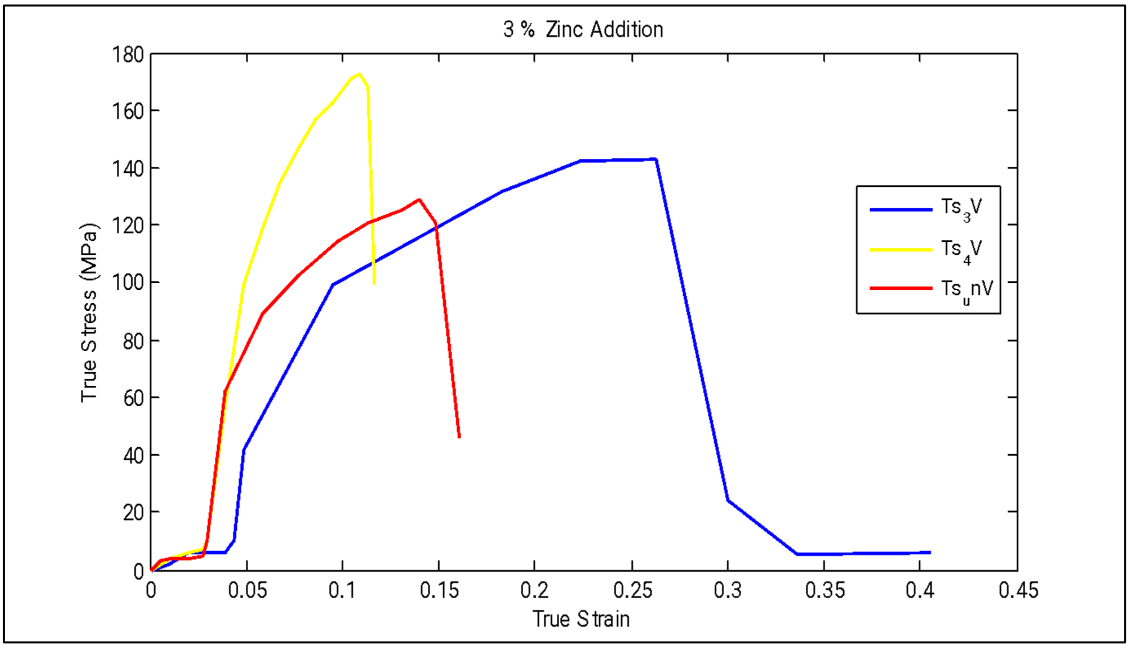


Figure 5 True Stress Vs True strain for 3% Zinc Addition

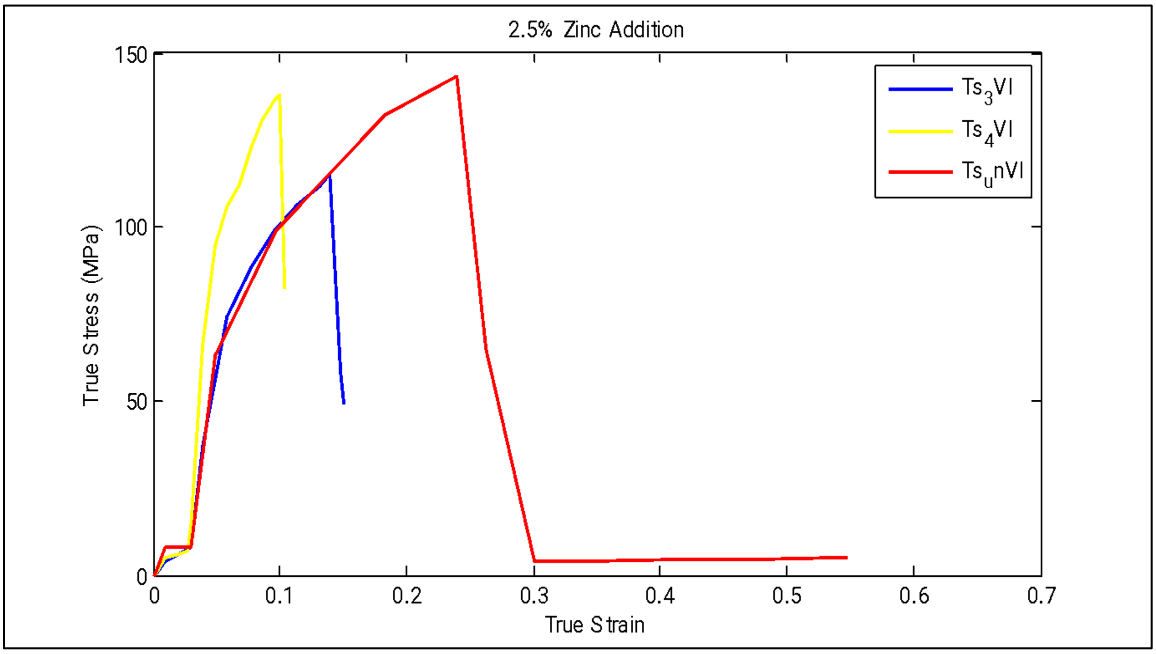


Figure 6 True Stress Vs True strain for 2.5% Zinc Addition

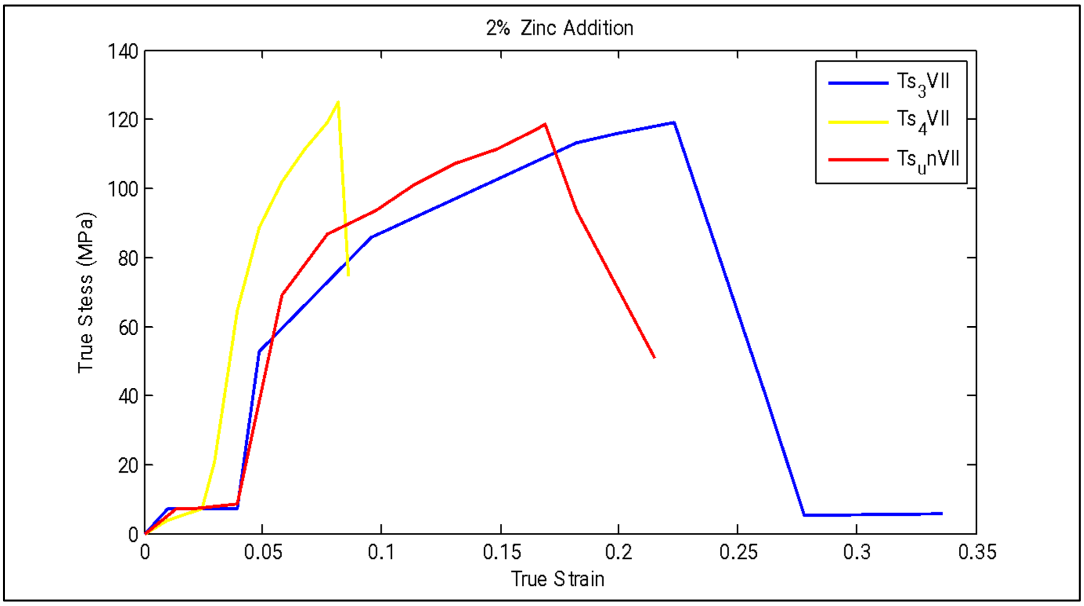


Figure 7 True Stress Vs True strain for 2% Zinc Addition

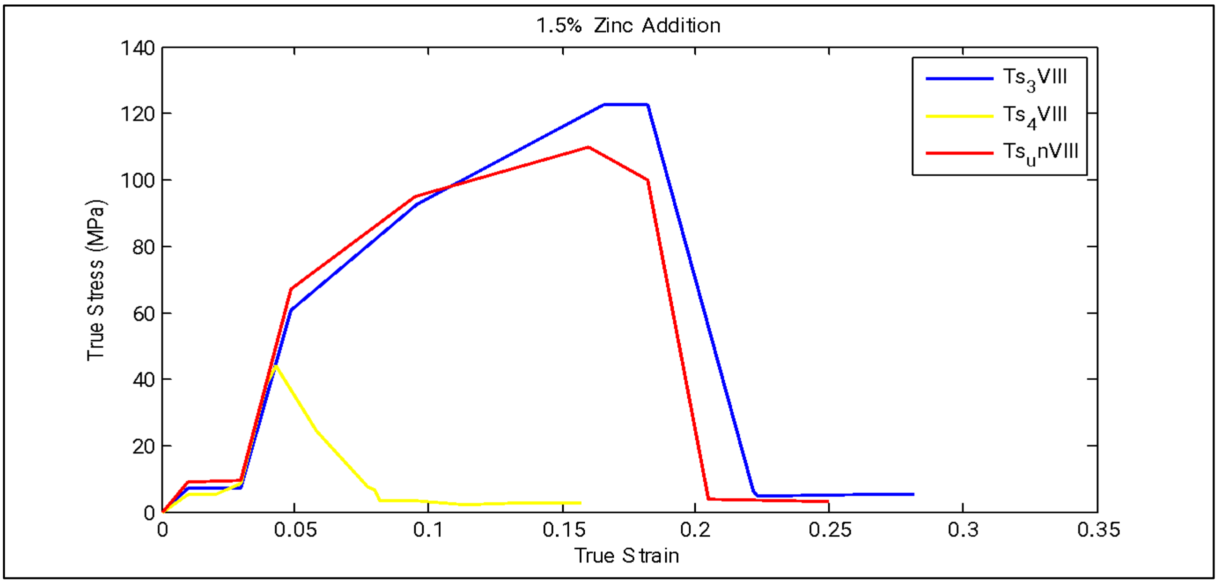


Figure 8 True Stress Vs True strain for 1.5% Zinc Addition

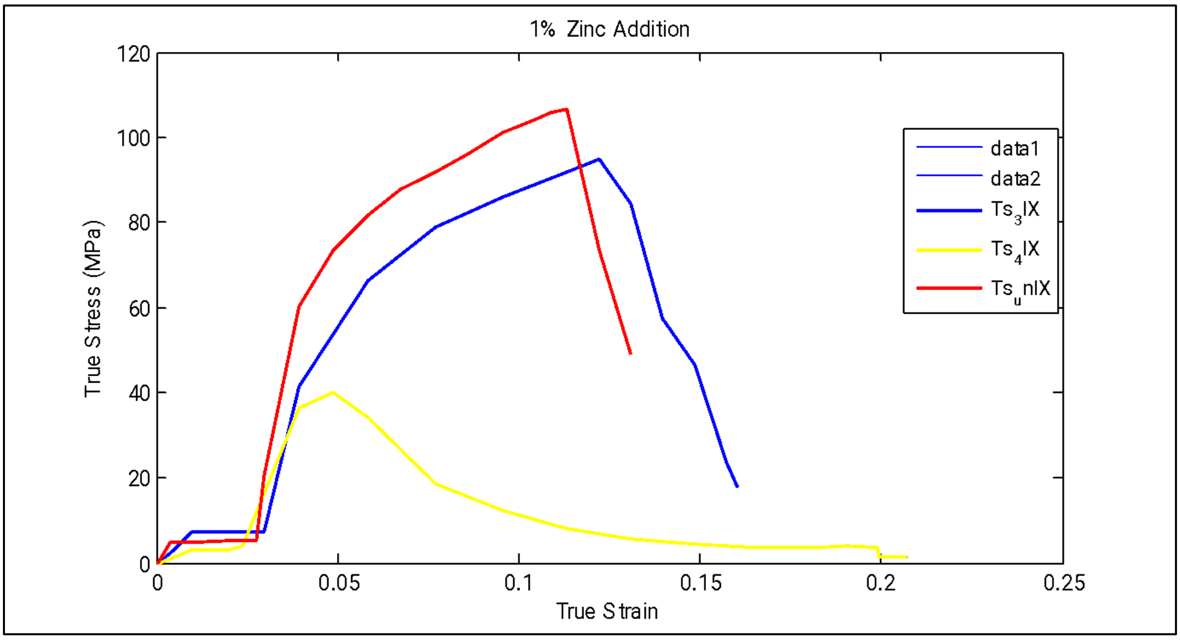


Figure 9 True Stress Vs True strain for 1% Zinc Addition

From Figure 9; the unhomogenized alloy has the maximum UTS of 106.4 MPa while the homogenized 400 °C alloy undergoes sufficient plastic deformation.

From Figure 10; the homogenized 300 °C alloy has the maximum UTS of 134.52 MPa and undergoes the highest plastic deformation.

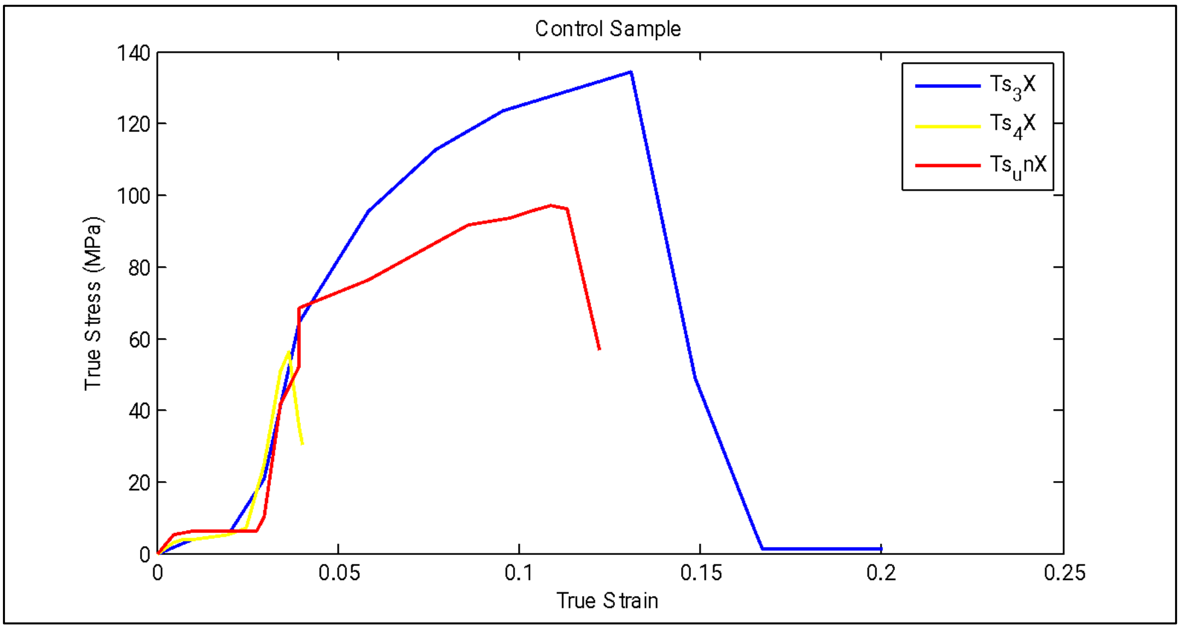


Figure 10 True Stress Vs True strain for control sample - 100% Al alloy

3.1.1 Ultimate Tensile Strength Graph

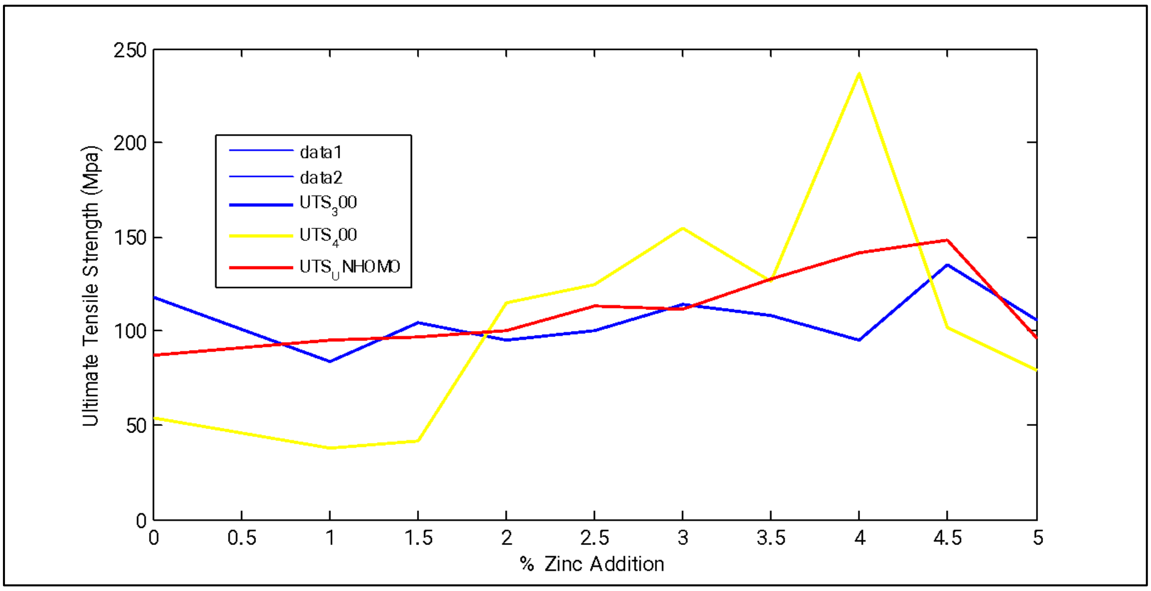


Figure 11 Comparison of UTS for Homogenised and Non-Homogenised Alloys

UTS: From Figure 11; the homogenized 400 °C alloy possesses the highest UTS of 237 MPa from an increasing percentage zinc addition of 4% while that of unhomogenized alloy shows an increasing UTS from a corresponding percentage increase in zinc addition with a maximum UTS of 148 MPa and homogenized 300 °C shows a fluctuating increase in strength from a corresponding percentage increase in zinc at a maximum UTS of 135 MPa.

3.1.2 Hardness Test Graph

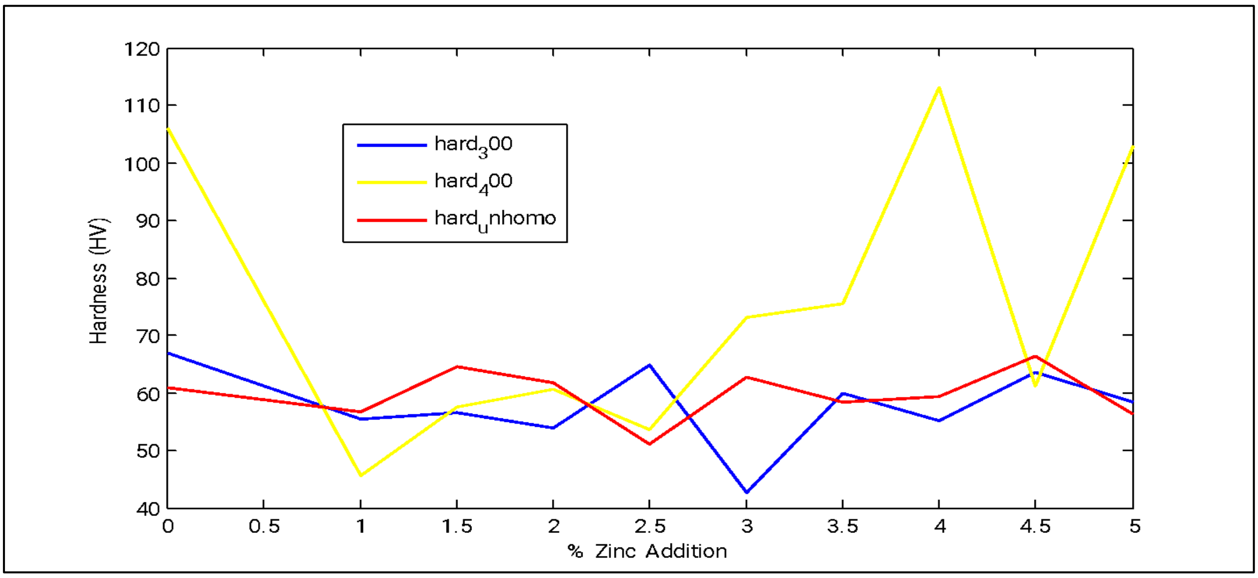


Figure 12 Comparison of Hardness for Homogenised and Non-Homogenised Alloys

Hardness: From Figure 12; four readings were taken for each specimen and the average found and plotted against percentage zinc addition as shown. The Homogenised 400 °C alloy possess the highest hardness value of 113HV (Vickers Hardness- HV) followed by the homogenized 300 °C alloy with a hardness value of 66.8HV and the Unhomogenized alloy with a maximum hardness value of 66.3HV all with an increasing percentage of zinc addition.

3.1.3 Impact Strength Graph

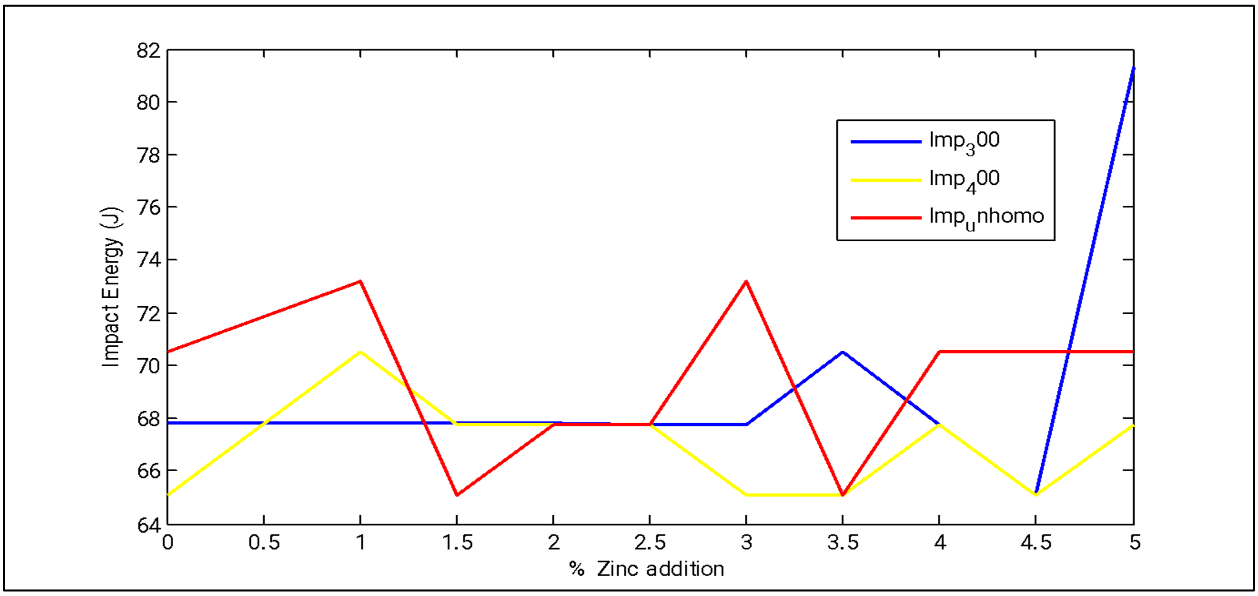


Figure 13 Comparison of Impact Strength for Homogenised and Non-Homogenised alloys

Impact: From **Figure 13;** the Homogenized 300 °C alloy shows maximum impact energy of 81.35 J with an increasing zinc addition also the Unomogenized alloy shows a maximum impact energy of 73.21 J while that of Homogenized 400 °C alloy shows a maximum impact energy of 70.5 J

3.1.4 Ductility Graph

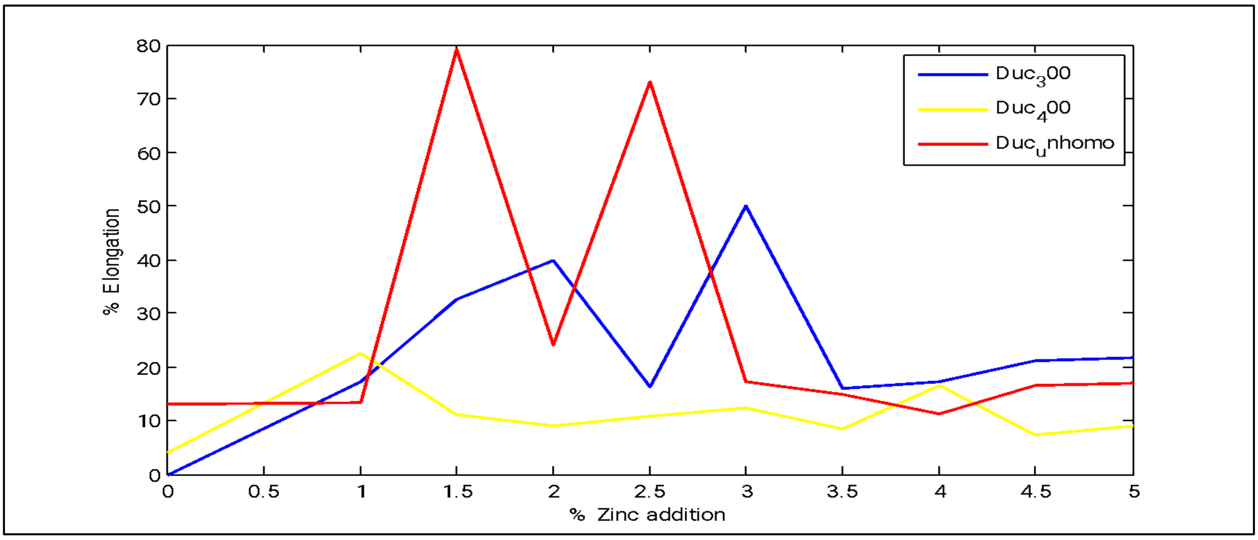
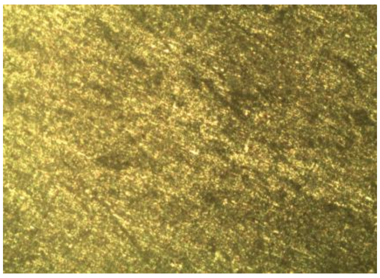
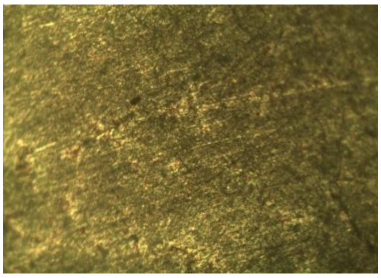


Figure 14 Comparison of % Elongation for Homogenised and Non-Homogenised alloys

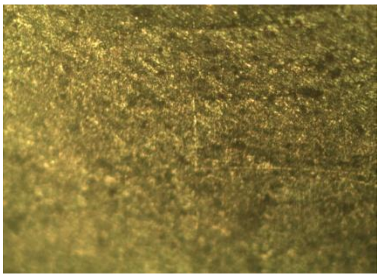
3.1.5 Microstructural Analysis



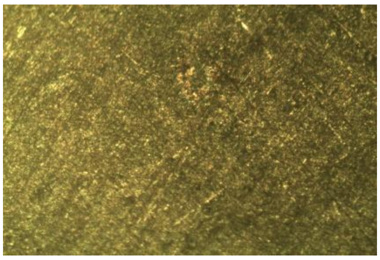
5% Zn Addition



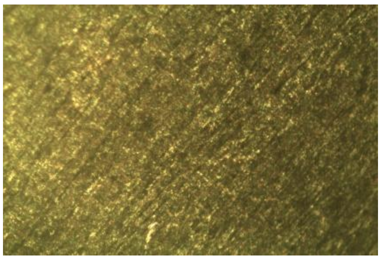
4.5% Zn Addition



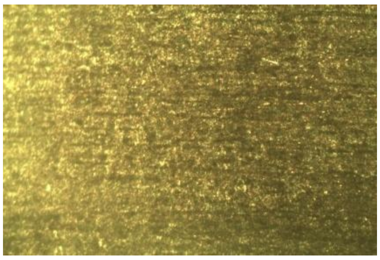
4% Zn Addition



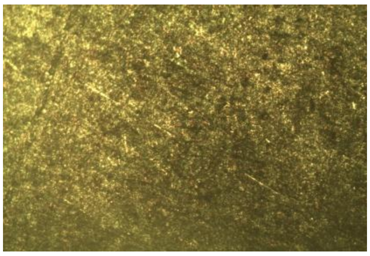
3.5% Zn Addition



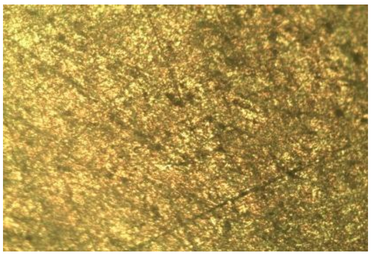
3% Zn Addition



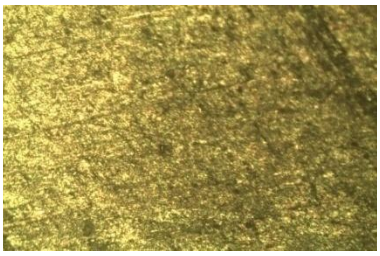
2.5% Zn Addition



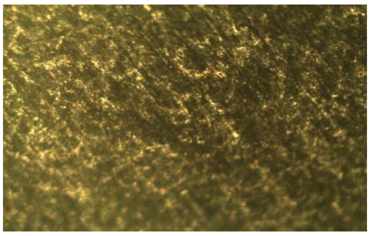
2% Zn Addition



1.5% Zn Addition



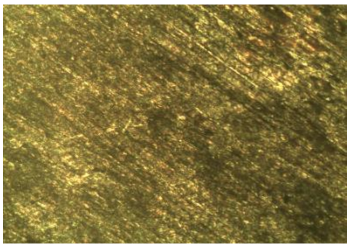
1% Zn Addition



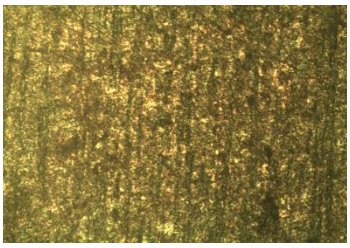
0% Zn Addition

Figure 15 (I) – (X) micrograph of homogenized Alloy 300oC at 100X

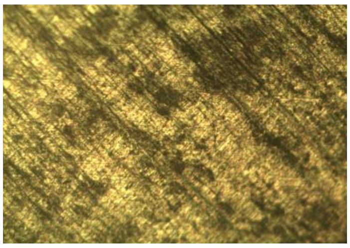
- In Figure 15 (I), this shows 5% zinc addition indicating a uniform distribution of both phases and Mg2Si crystals having coarse grains.
- In Figure 15 (II), this shows 4.5% zinc addition indicating a uniform distribution of both phases.
- In Figure 15 (III), this shows 4% zinc addition indicating a fine and uniform distribution of both phases.
- In Figure 15 (IV), this shows 3.5% zinc addition indicating a fine and uniform distribution of both phases and a change in orientation of the crystals.
- In Figure 15 (V), this shows 3% zinc addition indicating a fine and uniform distribution of both phases.
- In Figure 15 (VI), this shows 2.5% zinc addition indicating a very fine and uniform distribution of both phases.
- In Figure 15 (VII), this shows 2% zinc addition indicating a uniform distribution of both phases.
- In Figure 15 (VIII), this shows 1.5% zinc addition indicating a fine and uniform distribution of both phases and a change in orientation of the crystals.
- In Figure 15 (IX), this shows 1% zinc addition indicating a uniform distribution of both phases change in orientation of the crystals.
- In Figure 15 (X), this shows no zinc addition indicating a coarse grain structure.



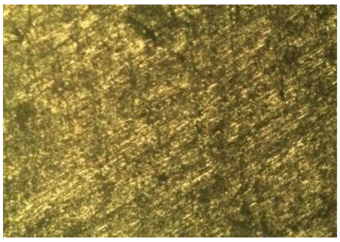
5% Zn Addition



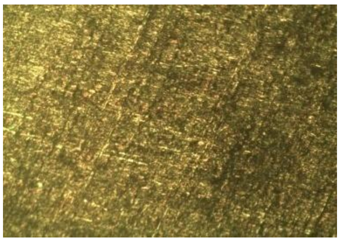
4.5% Zn Addition



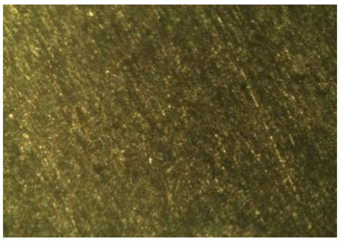
4% Zn Addition



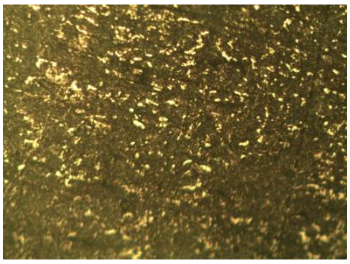
3.5% Zn Addition



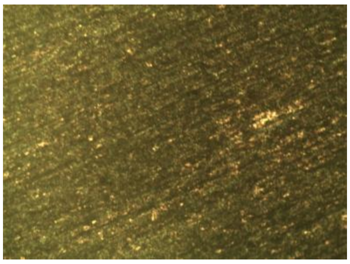
3% Zn Addition



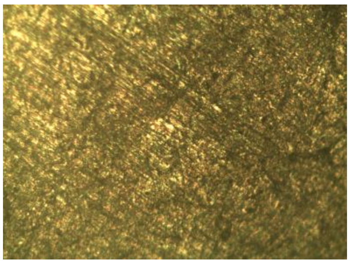
2.5% Zn Addition



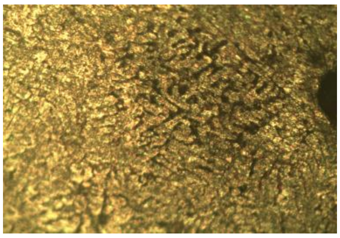
2% Zn Addition



1.5% Zn Addition



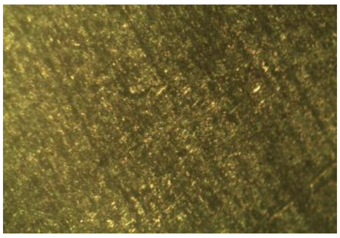
1% Zn Addition



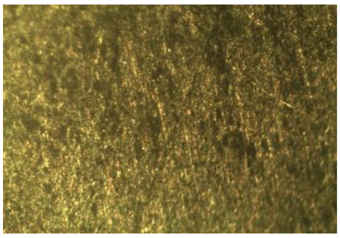
0% Zn Addition

Figure 16 (I) – (X) Micrograph of Homogenized Alloy 400oC at 100X

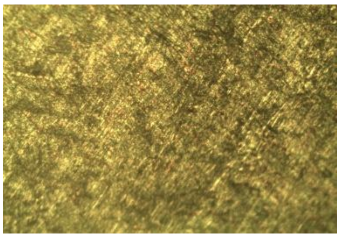
- In **Figure 16** (I), this shows 5% zinc addition indicating a uniform distribution of both phases.
- In **Figure 16** (II), this shows 4.5% zinc addition indicating a uniform distribution of both phases and a change in orientation of the grains.
- In **Figure 16** (III), this shows 4% zinc addition indicating a coarse grain structure and precipitation of impurities.
- In **Figure 16** (IV), this shows 3.5% zinc addition indicating a uniform distribution of both phases.
- In **Figure 16** (V), this shows 3% zinc addition indicating a fine and uniform distribution of both phases and change in orientation of the grains.
- In **Figure 16** (VI), this shows 2.5% zinc addition indicating a uniform distribution of both phases with precipitation of minute impurities.
- In **Figure 16** (VII), this shows 2% zinc addition indicating a coarse grain structure and traces of zinc
- In **Figure 16** (VIII), this shows 1.5% zinc addition indicating a uniform distribution of both phases and change in orientation of the grains
- In **Figure 16** (IX), this shows 1% zinc addition indicating a fine and uniform distribution of both phases.
- In **Figure 16** (X), this shows no zinc addition indicating a coarse grain structure presence of impurities.



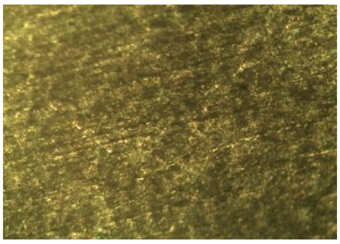
5% Zn Addition



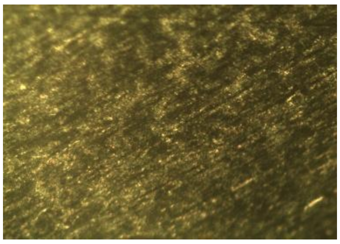
4.5% Zn Addition



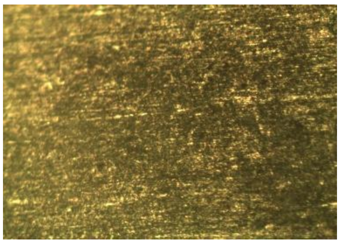
4% Zn Addition



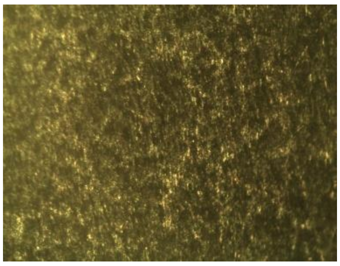
3.5% Zn Addition



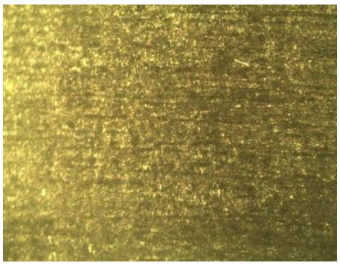
3% Zn Addition



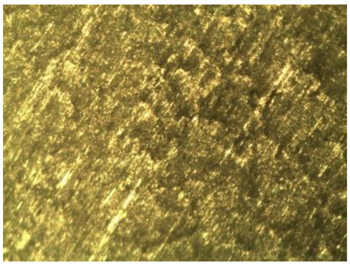
2.5% Zn Addition



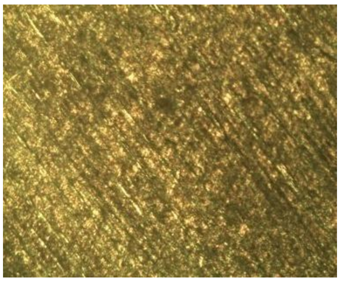
2% Zn Addition



1.5% Zn Addition



1% Zn Addition



0% Zn Addition

Figure 17 (I) – (X) Micrographs of Unhomogenized Alloy at 100X

- In **Figure 17** (I), this shows 5% zinc addition indicating a uniform distribution of both phases.
- In **Figure 17** (II), this shows 4.5% zinc addition indicating a uniform distribution of both phases and change in orientation of the grains.
- In **Figure 17** (III), this shows 4% zinc addition indicating a fine and uniform distribution of both phases and a change in orientation of the grains.
- In **Figure 17** (IV), this shows 3.5% zinc addition indicating a uniform distribution of both phases and traces of impurities.
- In **Figure 17** (V), this shows 3% zinc addition indicating a coarse grain structure and change in orientation of grains.
- In **Figure 17** (VI), this shows 2.5% zinc addition indicating a fine and uniform distribution of both phases.
- In **Figure 17** (VII), this shows 2% zinc addition indicating a uniform distribution of both phases and traces of impurities.
- In **Figure 17** (VIII), this shows 1.5% zinc addition indicating a uniform distribution of both phases.
- In **Figure 17** (IX), this shows 1% zinc addition indicating a uniform distribution of both phases and a change in orientation of the grains.
- In **Figure 17** (X), this shows no zinc addition indicating a fine and uniform distribution of both phases.

4 Conclusion

This study has shown that the Homogenized 400 ^oC alloy solutionized for 2 hours possesses the highest UTS of 237 Mpa with a maximum Hardness value of 113 HV and least percentage elongation of 22.5% and impact energy of 70.5 J.

The Homogenized 300 ^oC alloy solutionized for 2 hours possesses a modest UTS of 135 Mpa with a modest Hardness value of 66.8 HV and an average percentage elongation of 50% and impact energy of 81.35 J.

The Unhomogenized alloy possesses modest UTS of 148 Mpa with least Hardness value of 66.3 HV and highest percentage elongation of 73% and impact energy of 73.21 J.

It can be concluded that when high strength and hardness is required, the Homogenized 400 ^oC should be employed but when high hardness with relatively low strength and ductility is required, the Homogenized 300 ^oC should be employed.

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