EFFECT OF ZINC CONTENTS ON THE MICROSTRUCTURAL EVOLUTION OF A LOCALLY FORMULATED ALUMINIUM-ZINC ALLOY

Salihu B. T.; Verah A. O. and Nasiru M. S.
Mechanical Engineering Department,
College of Engineering, Umaru Ali Shinkafi Polytechnic, Sokoto,
PMB 2356, Sokoto, Sokoto State, salihutbala@gmail.com

ABSTRACT
Aluminium as a very common and important metal in engineering application owing to itsigh strength, low density, corrosion resistant and high electrical and thermal conductivity. It is normally not suitable for application in engineering activities until it is alloyed. Zinc (Zn) is one of the major alloying elements for aluminium alloys. This research investigated the effect of zinc contents on microstructure of aluminium-zinc alloy. Five different categories of the zinc alloys were developed with composition of zinc ranging from 2% to 10%. One of the specimens in each categories was Annealed, while the other was Age-hardened and the remainder left as cast. The specimens were polished, and then etched for observation under the Optical Metallurgical Microscope. The results shown that at low alloy contents, annealing favoured precipitation of spheroidized Zn, while age-hardening produced lenticular and botryoidal structures, which in moderate alloy content, annealing gave widmanstatten precipitate as against age-hardening spheroidized precipitate. The high alloy samples are both modified to dendritic structures and spheroidized precipitate for both annealing and age-hardening. Most of the Al-Zn alloys never contain up to 10%, but it is included in this research to reveal the possibility of obtaining Al-10%Zn alloy. The research significance is mostly in the area of materials science, which guide and direct materials scientists on the nature of microstructures.

Keywords: Aluminium, Zinc, Alloy, Annealing, Age-hardening, Etching, Microscope.

INTRODUCTION

Aluminium is a silvery white, light weight metal with density of 2.7g/cm3, which is approximately one-third of the density of steel (7.83 g/cm^3) (Barrirero, 2019) and Abdulwahab *et al.*, 2012). Aluminium resists the kind of progressive oxidization that causes steel to rust away. The exposed surface of aluminium combines with oxygen to form an inert aluminium oxide film only a few ten-millionths of an inch thick, which blocks further oxidation (Cheng *et al.*, 2020 and Ebhota *et al.*, 2016). And, unlike iron rust, the aluminium oxide film does not flake off to expose a fresh surface to further oxidation. If the protective layer of aluminium is scratched, it will instantly reseal itself. The thin oxide layer itself clings tightly to the metal and is colorless and transparent—invisible to the naked eye. The discoloration and flaking of iron and steel rust do not occur on aluminium (Cheng *et al.*, 2020 and Davis, 2001).

Due to its desirable chemical, physical and mechanical properties, aluminium is the second most widely used metal. It is alloyed with elements like Si, Mg, Cu, Mn, Zn, Sn, Fe, etc. (Chen *et al*,. 2021, Chen *et al.*, 2020, Mario *et al.*, 2019; Barrirero et al., 2019). Aluminium is easily recyclable, lightweight, relatively soft, durable, highly workable, high electrical conductivity, which make its alloy an excellent engineering material (Hong et al., 2021 and Georgantzia *et al*., 2021).

It is equally attracted by its various unique properties; such as appearance, strength-to-weight ratio, excellent thermal properties, such as high strength-to-weight ratios, high thermal conductivity, good corrosion properties, excellent workability properties and good mechanical behaviour (Ann e*t al.*, 2021; Georgantzia *et al.*, 2021 and Abdulwahab *et al*, 2011).

Aluminium has been identified as an important and useful engineering material with wide range of applications in transportation, packaging, construction, electronics, aerospace among others (Cheng *et al.*, 2020, Deekshant and Kaushal, 2020 and Eda and Ali, 2015). They are widely used for different applications in industries and marine environment because of their excellent properties mentioned above (Hong *et al.*, *2021*, Georgantzia *et al.*, 2020, Popoola *et al.*, 2012).

Aluminium is a silvery white, light weight metal with density of 2.7g/cm^3) which is approximately one-third of the density of steel (7.83 g/cm^3) (Barrirero, 2019 and Abdulwahab *et al.*, 2012). Aluminium resists the kind of progressive oxidization that causes steel to rust away. The exposed surface of aluminium combines with oxygen to form an inert aluminium oxide film only a few ten-millionths of an inch thick, which blocks further oxidation (Cheng *et al.*, 2020 and Ebhota *et al.*, 2016). And, unlike iron rust, the aluminium oxide film does not flake off to expose a fresh surface to further oxidation. If the protective layer of aluminium is scratched, it will instantly reseal itself. The thin oxide layer itself clings tightly to the metal and is colorless and transparent—invisible to the naked eye. The discoloration and flaking of iron and steel rust do not occur on aluminium (Cheng et al., 2020 and Davis, 2001).

Aluminium has some valuable properties on which the application is based on. The low density of 2.7g/cm3, the high mechanical strength achieved by suitable alloying and heat treatments, and the relatively high corrosion resistance of the pure metal, which does not require protection of the metal. High thermal and electrical conductivity, reflectiveness, high ductility and resultant low working cost, magnetic neutrality, high scrap-value, are some valuable properties of aluminium, and the non-poisonous and colourless nature of its corrosion products facilitates its use in the chemical and food-processing industries (Barrirero, 2019 and Maxim *et al.*, 2015). One cubic meter of aluminium weighs 2698.54kg (168.48 lb/ft3) as compared to copper, 8967.41kg (559.87 lb/ft3) and iron, 7865.76kg (491.09 lb/ft3). Such light weight, coupled with the high strength of some aluminium alloys (exceeding that of structural steel), permits design and construction of strong and lightweight structures that are particularly advantageous for transportation equipment like space vehicles, aircraft, all types of land and water-borne vehicles (Barrirero, 2019). Furthermore, various treatments of the metal produce valuable features considered when the applications of aluminium and its finishes are considered (Barrirero, 2019 and Maxim *et al.*, 2015).

Maxim *et al.*, (2015), stated that aluminium is a relatively soft metal in pure state, with yield strength of only 34.5N/mm2 and a tensile strength of 90N/mm2. Improved strengths and ductility can be achieved through the development of wide range of alloys making it suitable for various applications today. The alloys are more sensitive to corrosion owing to the addition of some quantities of heavy metals like copper, zinc, and nickel, which has heightened the need for protective surface treatment against corrosion. These applications can be seen ranging from thin foil materials for packaging, drink containers, and electrical purposes, to building industry and aircraft and armoured vehicles. Consideration is now geared towards corrosion resistant alloys for various applications. The aluminium-zinc alloys have been known for many years, but hot cracking of the casting alloys and the susceptibility to stress-corrosion cracking of the wrought alloys curtailed their use. Aluminium-zinc alloys containing other elements offer the highest combination of tensile properties in wrought aluminium alloys (Davis, 2001).

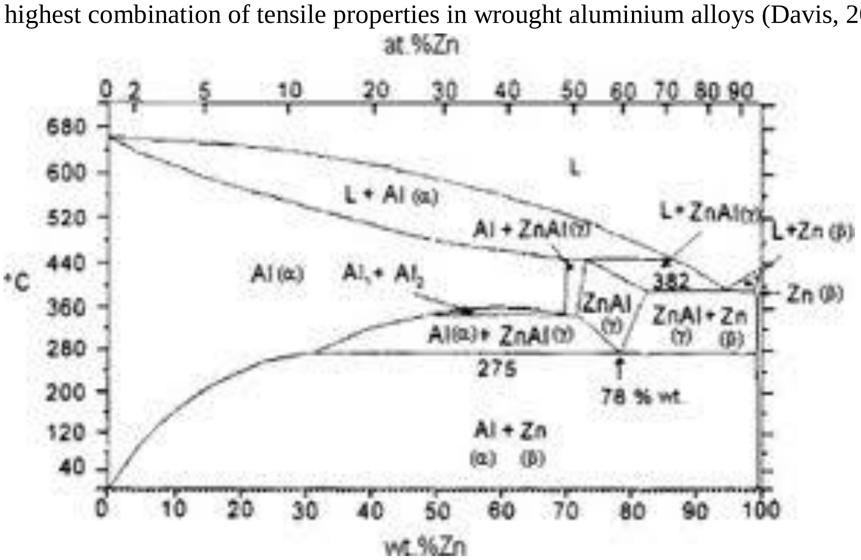


Fig.1:Al-Zn Phase Diagram showing the various phases formed
Source: Van Horn (1967)

Aluminium-Zinc alloy identified as 7xx.x, usually contain 6.2% to 7.5% Zn. Zinc is the principal alloying element. Other alloying elements such as copper and magnesium may be specified. The 7xx.x aluminium-zinc-magnesium alloys are notable for their combinations of good finishing characteristics, good general corrosion resistance, and the capability of developing high strength through natural aging without heat treatment (Ahmet et al., 2007). According to Dmitri (2006), addition of Zn up to 8% to aluminium in combination with magnesium or magnesium-copper allows to strengthen the alloys by precipitation hardening heat treatment (Wrought aluminium-zinc-magnesium alloys (7xxx), Cast aluminium alloy (713.0). Increases susceptibility of the alloys to Stress corrosion cracking. 7xx.x alloys are used mostly where (Toschi, 2018 and Lu *et al.*, 2015):

i. Heat treatable/sand and permanent mould cast (harder to cast)
ii. Excellent machinability/appearance
iii. Furniture/garden tools/office machines/farm/mining equipment
iv. Representative alloys: 705.0, 712.0
v. Approximate ultimate tensile strength range: 30-55 ksi

The aim of the research was to investigate the effects of zinc contents on the microstructure of Al-Zn alloy developed locally. This aim will be achieved through the development of five Al-Zn alloys with zinc contents ranging 2, 4, 6, 8 and 10% using sand casting and annealed some, age some and the remainder left as cast, after which their microstructures were observed. The scope of the research was observed the microstructures of the samples under the scanning electron microscope.

METHODOLOGY

Five different sets of Al-Zn alloys were produced with composition range from 2%, 4%, 6%, 8%, and 10% by weight of zinc and casted using sand mould in block form. Each block was cut into three cubes, out of which some were annealed, others age-hardened and the remaining left as cast. They are grinded, polished and etched and mounted on the scanning electron microscope for observation.

Table 1: The Al-Zn Alloys specimens Designations

Compositions of alloying elements	Annealed	Age-Hardened	Normal Cast
2%	AZ1	HZ1	CZ1
4%	AZ2	HZ2	CZ2
6%	AZ3	HZ3	CZ3
8%	AZ4	HZ4	CZ4
10%	AZ5	HZ5	CZ5

From the table 1, the coding are as defined on the headers of each column, such as AZ1 is annealed Al-2%Zn alloy, HZ1 is age-Hardened Al-2%Zn alloy, CZ1 is as cast Al-2%Zn alloy, and that other in the next row to the end. Such that AZ5 is annealed Al-10%Zn alloy.

Charge Calculations

In each of the five different samples of the various alloying elements of the following compositions; 2% 4%, 6%, 8%, and 10% of the cast produced, the following calculations were adopted.

The following assumptions were made for various Al-Zn Alloys production:

Aluminium losses = 12%; zinc losses = 0%

For the production of Al-2%Zn alloy the calculation is as follows:

Aluminium = $\frac{12}{100}$ x 98 = 11.76kg losses; zinc = $\frac{0}{100}$ x 2 = 0kg losses

Adding these values of losses to the actual compositions of both Aluminium and zinc, it gives

Aluminium = 98 + 11.76 = 109.76kg; zinc = 2 + 0 = 2kg

Total = 100 + 11.76 = 111.76kg

The calculations follow the same pattern for 4%, 6%, 8% and 10%, which yielded the tables shown below:

Table 2: Calculated values of Al-Zn alloys Charges

Elements involved	Compositions of alloying elements (kg)				
	2%	4%	6%	8%	10%
Aluminium	109.76	107.52	105.28	103.04	100.80
Zinc	2.00	4.00	6.00	8.00	10.00
Total	111.76	111.52	111.28	111.04	110.80

The piece of aluminium cables were bought at Bello way in Sokoto State, it is the base metal in which other metals will be added to produce the various alloy for the experimental observations. It has face centered cubic (FCC) crystal structure and a composition of 99.98%Al+0.01%Fe+0.01%Si.

Zinc powder was obtained from Ceman Ventures Nigeria Limited, Kano, Kano State. It is the alloying element with hexagonal closed pack (HCP) crystal structure. It is used because it has hexagonal closed pack (HCP) crystal pattern and a composition of 99.84%Zn+0.07%Pb+0.07%Cd+0.2%Fe.

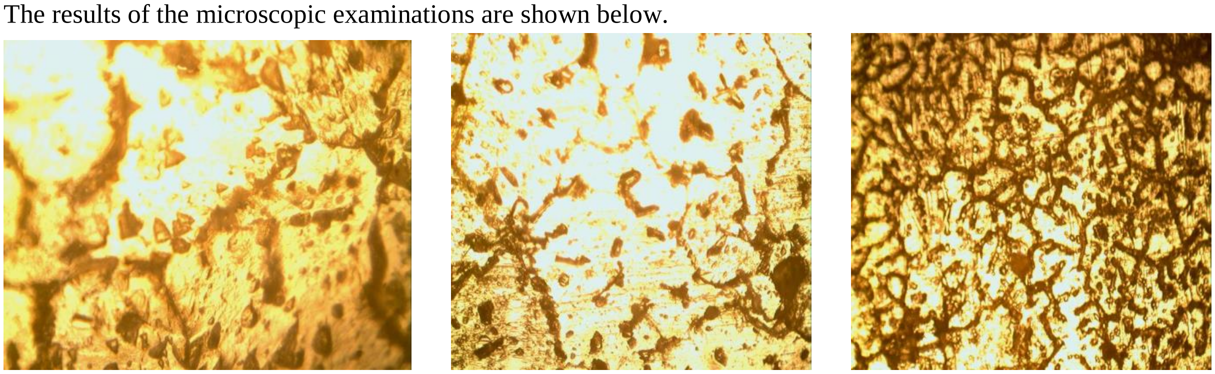
The various alloys compositions were prepared by melting and mixing the aluminium and the zinc in according the charge calculation values shown in Table 2. The melts were casted using sand mould and cut into small blocks.

To study the microstructure, small blocks were used, produced by jet polishing with different grades of sand papers, with the chemical solution consisting of 20% nitric acid and 80% methanol at a temperature of 25°C. A mean size of structural elements was determined based on the measurements of at least 200 mean diameters. At least three blocks of each state were studied to obtain statistically significant results.

The microstructure homogeneity as well as the distribution of particles of crystallized secondary phases were estimated by SEM using JSM-6490LV model of SEM at an accelerating voltage of 20 kV.

RESULTS AND DISCUSSIONS

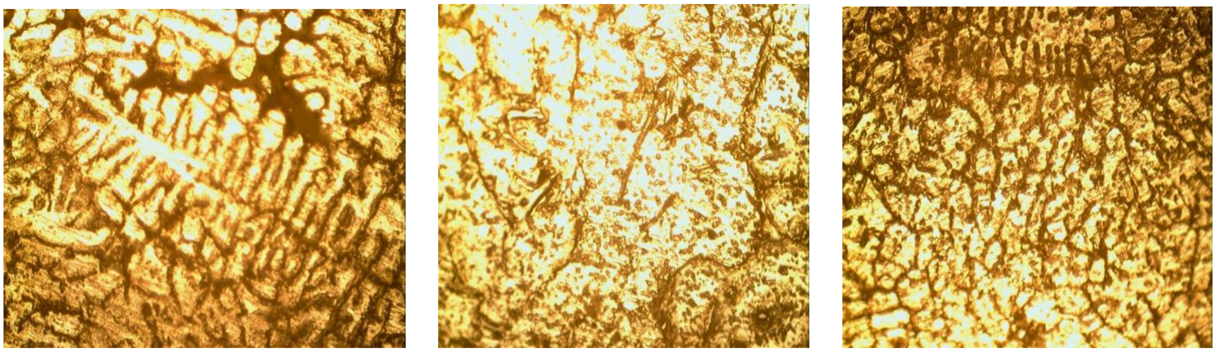
The results of the microscopic examinations are shown below.



(a) **Annealed Specimen** (b) **Hardened Specimen** (c) **As Cast Specimen**

Micrograph 1: Optical Micrograph of the Al-2%Zn Alloy (X100)

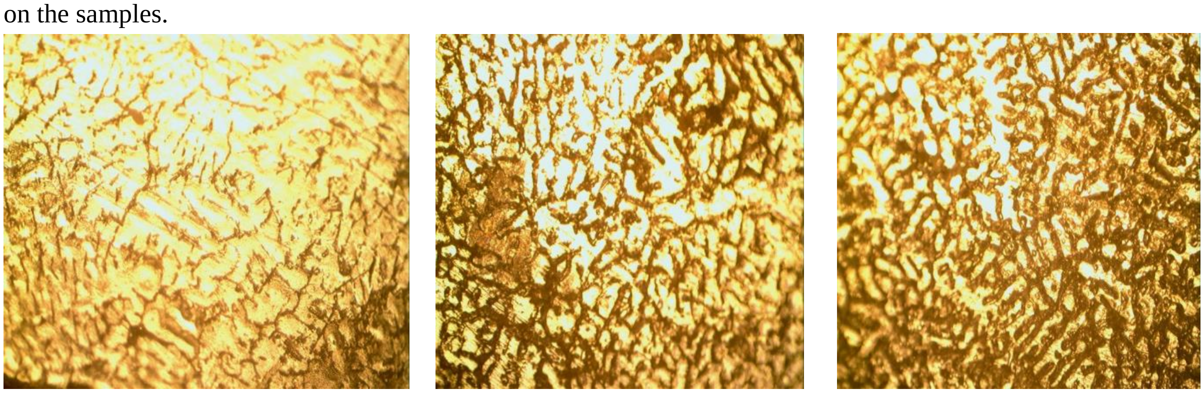
According to Micrograph 1, it can be observed that (a), contains large nodular structures with intermixed lenticular structures, precipitates of Zn spheroidized mostly at bottom to the right side of the graph, (b) shows nodular shapes of the primary Al phase spread in the matrix of Al, botryoidal and lenticular shapes can as well be seen. Spheroidized precipitate of Zn can be seen scattered, but more concentrated at bottom left and right of the micrograph. (c) Show some dark precipitate of Zn spread, in form of fibrous structures, widmanstatten precipitates in mixture with continuous precipitates. White dendritic structures are revealed, with Eutectic phases of Al+Zn. As a result of the two different heat treatments carried out, the microstructures resulted in different patterns.



(a) **Annealed Specimen** (b) **Hardened Specimen** (c) **As Cast Specimen**

Micrograph 2: Optical Micrograph of the Al-4%Zn Alloy (X100)

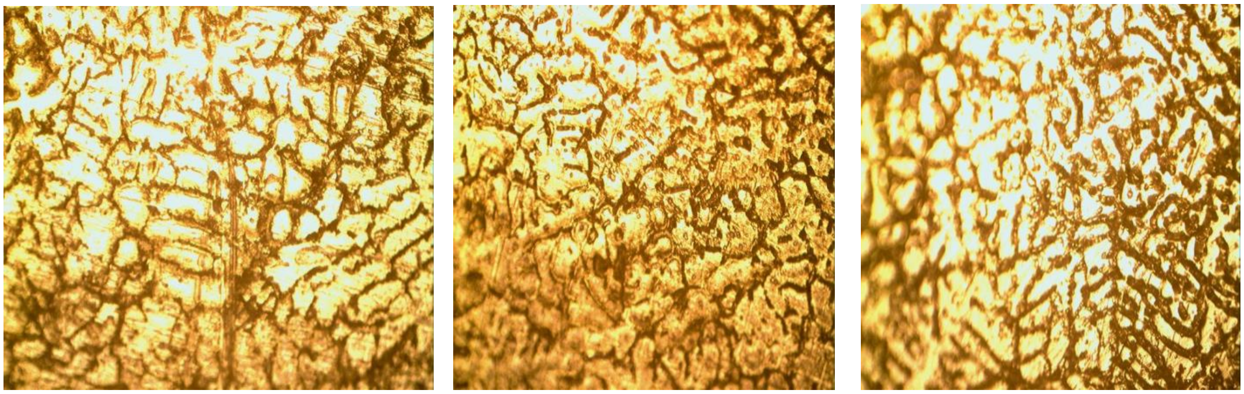
In Micrograph 2, it is shown that (a) Reveals large leaf-like dendritic shape, with other smaller dendritic structures of eutectic phases of Al+Zn, a large dark spheroidized precipitate of the Zn primary phases can be seen, angular fragments can be seen and also massed spheroidized precipitates of Zn on the bottom of the micrograph to the left side. (b) shows long acicular structures on the center intermixed with nodular and botryoidal structures can be seen; (c) reveals several acicular and fusiform structures intermixed within the center and widmanstatten precipitates wide spread on the micrograph. The difference is as a result of the two different types of heat treatments on the samples.



(a) **Annealed Specimen** (b) **Hardened Specimen** (c) **As Cast Specimen**

Micrograph 3: Optical Micrograph of the Al-6%Zn Alloy (X100)

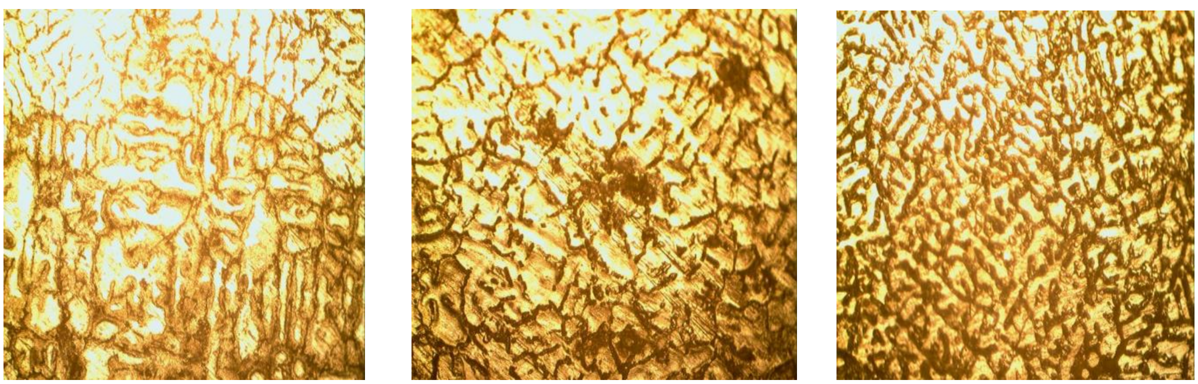
According to the Micrograph 3 above, it can be observed that, (a) Contains fusiform, acicular and nodular eutectic phases, with phases of Al+Zn, with some widmanstatten precipitates of Zn concentrates on the right, (b) shows banded, fusiform, acicular structures, with dark precipitates of Zn spheroidized mostly at the top right and bottom left, also primary phases can be seen on the center top of the micrograph. (c) has dendritic, acicular and fusiform structures , with some botryoidal structures seen. This is owing to the different heat treatment given to the samples.



(a) **Annealed Specimen** (b) **Hardened Specimen** (c) **As Cast Specimen**

Micrograph 4: Optical Micrograph of the Al-8%Zn Alloy (X100)

Micrograph 4 show that (a) is made up of banded structures in mixture of nodular, lenticular, fusiform and angular fragments structures, with widmanstatten precipitates of Zn in Al-matrix, and some fibrous lines on the center part of the micrograph, there are also some white primary phases of Al on the center top of the graph, (b) has nodular and botryoidal structures mixed with angular fragments structures, with small polygonal grains with patches of the eutectoid between the and interspersed with globules of Zn, while (c) Contains acicular, dendritic, and nodular structures of the primary phases can be seen on the micrograph. Dark precipitates of Zn spheroidized in the Al-matrix. As a results of the two different types of heat treatments given to the samples.



(a) **Annealed Specimen** (b) **Hardened Specimen** (c) **As Cast Specimen**

Micrograph 5: Optical Micrograph of the Al-10%Zn Alloy (X100)

The micrographs 5 show that (a) has dendritic, acicular, nodular and banded structures, with interdendritic dark patches of eutectoid phases of Al+Zn, Spheroidized precipitates of Zn can be seen at the bottom of the graph, (b) is made up of widmanstatten precipitates of Zn spread over the microstructure, with a lot of acicular and dendritic structures, with spheroidized precipitates of Zn at the center and top right corner. The bottom is generally dark evidence of concentration of precipitates of Zn, while in (c) acicular, lenticular and angular fragments as well as nodular and botryoidal structures interspersed throughout the graph, with massed precipitates of Zn spheroidized throughout the Al-matrix. These resulted because of the difference in the heat treatment given to the samples.

From the micrographs shown above it will be seen that:

- Annealing modified the structures of as cast samples from mixtures of fibrous and dendritic structures as well as widmanstatten precipitate of Zn into spheroidized precipitate of Zn, while age-hardening changed them to nodular, botryoidal and lenticular shapes for the 2% samples

- The acicular and fusiform structures as well as the widmanstatten precipitate of the as cast 4% samples is changed to dendritic shape, with spheroidized precipitate of Zn by annealing, while age-hardening modified it to lenticular plus nodular and botryoidal structures.
- The 6% samples with dendritic, plus acicular, fusiform structure are modified by annealing to nodular and widmanstatten precipitate retaining acicular, and fusiform structure, while age-hardening changed it to spheroidized precipitate and also retaining acicular and fusiform structure
- As for the 8% samples, the as cast acicular, plus dendritic and nodular structures, with spheroidized precipitate are modified into lenticular, plus fusiform structures, with widmanstatten precipitates by annealing, retaining nodular structure, while the age-hardening modified it to botryoidal shapes with eutectoid and globules of Zn, retaining nodular as well.
- The 10% as cast sample's acicular, plus lenticular, nodular and botryoidal structures with spheroidized precipitate of Zn are adjusted to dendritic structure, with spheroidized precipitate of Zn retaining acicular and nodular structures, while it is modified to widmanstatten and spheroidized precipitates with dendritic structure, retaining acicular structure.

CONCLUSION

From the results shown above, it can be conclude that at low alloying contents (2% and 4%), annealing favoured the conversion of the structures to spheroidized precipitates, while age-hardening encouraged formation of lenticular and botryoidal structures. As for the medium alloying content (6%), annealing produce widmanstatten precipitates as against the spheroidized precipitate for age-hardening. High alloying content (8 and 10%) indicate that both annealing and age-hardening favoured dendritic structure and spheroidized precipitate formations. As indicated, the effect of zinc on the microstructure is the evolution of precipitates of Zn and eutectic Al+Zn, which may be dangerous to the alloy, but can be controlled by heat treatment.

REFERENCES

Abdulwahab, M., Madugu, I. A., Yaro, S. A., Hassan, S. B., & Popoola, A. P. I. (2011). Effects of Multiple-Step Thermal Ageing Treatment on the Hardness Characteristics of A356.0- type Al-Si-Mg Alloy. Materials and Design, **32(3):** 1159.

Abdulwahab, M., Madugu, I. A. Yaro, S. A. and Popoola, A. P. I. (2012). Effects of Temper Conditions and Step-Quenching-Ageing on the Hardness Characteristics and Yield Strength of A356.0-type Al-Si-Mg Alloy. Silicon. **4:**137-143, DOI 10.1007/s12633-012-9111-5. Received: 20 August 2011 / Accepted: 25 January 2012 / Published online:25 March 2012. Springer Science+Business Media B.V.

Ahmet, T., Mehmet, D. and Sabri, K. (2007). The Effect of Manganese on the Microstructure and Mechanical Properties of Zinc-Aluminium Based ZA-8 Alloy. Journal of Materials Science. **42:**8298.

Anna, K., Vendula, S., Pavel, N., Filip, P., Marcello, C. and Lucyna N., (2021). Effect of Alloying Elements on the Properties of Ti-Al-Si Alloys Prepared by Powder Metallurgy. Journal of Alloys and Compounds, 868, 159251. Science Direct.

Barrirero, J., (2019) Eutectic modification of Al-Si Casting Alloys. PhD. Dissertation. Linköping Studies in Science and Technology Dissertation No. 2014. Nanostructured Materials Department of Physics, Chemistry and Biology (IFM) Linköpings University, Sweden. ISBN 978-91-7519-007-5. ISSN 0345-7524. Printed by LiU-Tryck, Linköping, Sweden.

Cheng, Z., Liang, W., Zilong, Z., Guangsheng, H., Bin, J., Andrej, A. and Fusheng, P., (2020). Effect of the Al–Si Eutectic on the Microstructure and Corrosion Behaviour of the Single-Phase Mg Alloy Mg–4Li. Journal of Magnesium and Alloys. 2020 Published by Elsevier B.V. on behalf of Chongqing University. This is an open access article under the CC BY-NC-ND license. (http://creativecommons.org/licenses/by-nc-nd/4.0/) Peer review under responsibility of Chongqing University. https://doi.org/10.1016/j.jma.2019.08.004

Che, J., Liu, C., Wen, F., Zhou, Q., Zhao, H. and Guan, R. (2020). Effect of Microalloying and Tensile Deformation on the Internal Structures of Eutectic Silicon Phase in Al-Si Alloy. Journal of Materials Research and Technology, 9 (3), 4682 - 4691. Science Direct.

Chen, J., Wen, F., Liu, C., Li, W., Zhou, Q., Zhu, W., (2021). The Microstructure and Property of Al-Si Alloy Improved by the Sc Microalloying and Y_2O_3 Nano Particles. Science and Technology of Advanced Materials, 22 (1). Engineering and Structural Materials.

Davis, J. R. (2001). Aluminium and Aluminium Alloys. Light Metals and Alloys. ASM International. Alloying: Understanding the Basics. P351-416. www.asminternational.or. https//doi.org/:10.1361/autb2001p351. Deekshant, V. and Kaushal, K., (2020). Application and use of Different Aluminium Alloys with

Respect to Workability, Strength and Welding Parameter Optimization. Ain Shams Engineering Journal, 12 (1), 1143 – 1152. Science Direct. https://doi.org/10.1016/j.asej.2020.05.013.

Dmitri, K. (2006). Effects of Alloying Elements on Properties of Aluminium. Material Engineering.

Ebhota, W. S., Karun, A. S. and Inambao, F. L. (2016). Investigation of functionally graded aluminium A356 alloy and A356-10%SiCp composite for hydro turbine bucket application. International Journal of Engineering Research in Africa. 26:30-46

Eda, D. and Ali, U. (2015). Aluminum Sheet Production: Heat Treatment of Aluminium and Temper Designations of Aluminium Alloys. Teknik Alüminyum A.Ş. – Türkiye

Georgantzia, E., Gkantou, M. and Kamaris G. S. (2021). Aluminium Alloys as Structural

Material: A Review of Research in Engineering Structures. 2021;227:111372. Article *in* Engineering Structures. https://doi.org/10.1016/j.engstruct.2020.111372. refining, and solidification enthalpies of Al–Ce–Si alloys.

Georgantzia, E., Gkantou, M. and Kamaris, G. S., (2021). Aluminium Alloys as Structural Material: A Review of Research. Engineering Structures 2021;227:111372. ResearchGate. https://doi.org/10.1016/j.engstruct.2020.111372. www.researchgate.net/publication/345062964

Hong, X., Chen, D., Xu, Y., Zhu, H., Zhang, J., Liu, Y., Peng, Y. and Hou, L., (2021). Effect of Different Phosphorus Modifiers on Microstructure and Properties of Al-Si Alloy. IOP Conference Series: Earth and Environmental Science, 692 (2), 032053. Published under license by IOP Publishing Ltd.

Lu, T., Wu, J., Pan, Y., Tao, S. and Chen, Y. (2015). Optimizing the tensile properties of Al–11Si–0.3Mg alloys: Role of Cu addition. Journal of Alloys Compound. **631:** 276–282,

Mario, D., James, A. K. and Prakash, S. (2019). Modification of Al-Si Alloys by Ce or Ce with Sr. Aluminum: New Alloys and Heat Treatment. JOM, Vol. 71, No. 1, 2019. https://doi.org/10.1007/s11837-018-3192-6

Maxim, M., Andrey, M., Vil, K., Alexander, K., Georgy, R., Nariman, E. and Ruslan, Z. V. (2015). Enhanced Mechanical Properties and Electrical Conductivity in Ultrafine-Grained Al 6101 Alloy Processed via ECAP-Conform. Metals 2015, 5, 2148-2164; https://doi.org/10.3390/met5042148. ISSN 2075-4701. www.mdpi.com/journal/metals/

Popoola, A. P. I., Fayomi, O. S. I., Abdulwahab, M. (2012). Degradation behaviour of Aluminium in 2M HCl/HNO3 in the presesnce of Archis hypogeae Natural Oil. International Journal of Electrochemical Science. **7:** 5817-5827,

Toschi, S. (2018). Optimization of A354 Al-Si-Cu-Mg Alloy Heat Treatment: Effect on Microstructure, Hardness, and Tensile Properties of Peak Aged and Overaged Alloy. Metals, **8:** 961. doi:10.3390/met8110961. www.mdpi.com/journal/metals.

Van Horn, K. R. (1967). Solid Solubility of elements in aluminium. Volume 1, American Society for Metals Cleveland, Ohio, in Mondolfo, L. F. (1976). Aluminium Alloys: Structures and Properties. Butter-Worth, London.