Effect of zinc amount on microstructure and mechanical properties of aluminium alloy AA2014

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Abstract

In this work, the mechanical properties of aluminium alloys Al-2014 with variation of zinc concentration (1% to 2.5%) were achieved using experimental method. The influences of zinc concentration on mechanical properties of aluminium alloy Al-2014 have been studied. The ultimate tensile strength value of the composite aluminium alloys has increased with the increase of Zn percentage from 1wt% to 1.5wt% and thereafter decrease with the further addition of 2.5wt%. It was observed that ultimate tensile strength (387.38 MPa) value has been the maximum at 1.5 wt% Zn addition. The strain values for different percentage of Zinc addition vary in the range of 17.62 to 24.48%. The Minimum ultimate tensile strength was obtained 315.85 N/mm^2 at 1.5 wt% Zn addition. The Hardness was improved when concentration of Zinc increased, maximum hardness (115 HV) was obtained in Al-2014 with 2.5% Zinc concentration. Because of fine precipitates and fine grains structure, the cast aluminium alloy with 1.5wt% is associated with plastic deformation and high temperature, due to precipitates formation at high temperature along the grain boundaries. Fine recrystallized grains and increase of grain boundaries was found in the cast aluminium alloy with 1.5wt% Zn predict higher tensile strength.

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Keywords: Aluminium alloy, Tensile strength, Residual stress, Microstructure.

1. Introduction

An alloy is a mixture of metals or a mixture of a metal and another element. Alloys are made by mixing two or more elements, at least one of which is a metal. This is usually called the primary metal or the base metal, and the name of this metal may also be the name of the alloy.

The unique combinations of properties provided by aluminium and its alloys make aluminium one of the most versatile, economical, and attractive metallic materials for a broad range of uses—from soft, highly ductile wrapping foil to the most demanding engineering applications. Aluminium alloys are second only to steels in use as structural metals. Aluminium has a density of only 2.7 g/cm3, approximately one-third as much as steel (7.83 g/cm3). The influence of the Si content of the aluminium alloys on their wear resistance has been well documented and eutectic alloys are reported to have better wear resistance than those of hypoeutectic and hypereutectic composition. Manganese is also able to change the morphology of the iron-rich phases from platelets to a more cubic form or to

globules. These morphologies improve tensile strength, elongation, and ductility [1]. Up to 12 wt. % copper the strength of the alloy can increase through precipitation hardening, with or without the presence of Mg; Hardening is achieved through the precipitation of Al2Cu or Al2CuMg intermetallic phases during ageing which leads to strengths second only to the highest strength 7xxx series alloys [2]. The microstructure, tensile, and tensile–creep behavior of a series of Mg–Zn alloys ranging from 0 to 4.4 wt.% Zn have been analyzed. The microstructures consisted of equiaxed hexagonal-close-packed grains with fine precipitates preferentially located at grain boundaries. Some of the microstructures contained fine laths within the equiaxed grains. The finest grain sizes were observed for a Zn composition of 4 wt.%. Tensile experiments were performed at room temperature and 150°C while creep experiments were conducted at 150°C for applied stresses between 30 and 50 MPa [3].

The grain refinement of the extruded Mg-Zn-Mn alloy by variation of Zn concentration have been analyzed and they found that the mechanical properties of extruded Mg-Zn-Mn alloy enhanced when percentage of Zn increased. The ultimate tensile strength

are increased by 54.7 MPa and 69.7 MPa respectively, when 3% of Zn added. When the percentage of Zn was less than 3, then the anti corrosion property of extruded Mg-Zn-Mn alloy may be effectively improved [4]. The presence of additional elements in the Al-Si alloys allows many complex intermetallic phases to form. Copper is a potent precipitation-strengthening agent in aluminium. Cu additions up to about 5% lead to alloys with high strength and good toughness when subject to natural or artificial aging. The addition of Cu increases considerably the strength of Al–Si alloys, due to precipitation of dispersed Al_2Cu (θ) phase during aging [5]. The microstructure and the mechanical properties of Al- alloy of 3003 by variation of Zn percentage and they found that high density particles prcipitates inside the grains and only a few precipitates at the grain boundary. Zinc has a strong influence on the tensile strength of the Al 3003 alloy. The highest ulyimate tensile strength was found with 1.5 % of Zn concentration but lowest elongation. 1.8 % of Zn content in Al 3003 present the most balanced mechanaical properties and has great impact on the corrosion resistance of Al 3003 alloy. The 3003Al+1.5Zn alloy has the highest ultimate tensile strength, but the elongation of this alloy is the lowest [6]. The addition of copper as main alloying element (mostly range 3–6 wt. %, but can be much higher), with or without magnesium as alloying constituent (range 0–2 %), allows material strengthening by precipitation hardening, resulting in very strong alloys. Also the fatigue properties are very good for this series. Copper tends to precipitate at grain boundaries, making the metal very susceptible to pitting, intergranular corrosion and stress corrosion [7]. Increase in Mg content results formation of new phases in microstructure as indicated by some black phases present on copper bearing phase in Al-6% Cu alloys. Thus addition of magnesium results in an increase magnesium containing phase and therefore increases hardness. With increasing amount of deformation, hardness continues to increase for different magnesium addition. Also, the higher the magnesium content, the greater the hardness. Deformation causes an increase in hardness than non-deformed homogenized alloy due to changes in dislocation density. Deformation increases the number of dislocations by interactions of dislocation during deformation and other defects, which cause an enhancement of hardness values [8]. The mechanical properties of aluminium alloy Al-Si-Mg by variation of magnisium (Mg) concentration have been investigated and they found that the tensile strength of Al-alloy increased and percentage elonagtion decreased when Mg concentration increases. Intermetallic compund $Al_8Si_6Mg_3Fe$, Mg_2Si, and Al_5FeSi detected in the microstructure and observed from the SEM images were identified with XRD evaluation [9]. The ultimate tensile strength of the alloy improved as compared to LM 12, the solidifications temperature for Al- Alloy reduces and this is an important factor to consider which temperature the heat treatment not should exceed. When increase the silicon content then the melting point of aluminium alloy is decreases whereas fluidity was increases [10-11]. The effect of Mg/Si ratio and Cu content on the stretch formability of aluminium alloys of the series 6xxx by using scanning electron microscopy (SEM), hardness tests, forming limit diagram measurements and tensile tests. It was found that the formability of Al–Mg–Si alloys decreases due to a decrease in the work hardening and strain-rate

hardening capability, with the increase of Mg/Si ratio. It also has been investigated that with the addition of Cu improved the work hardening capacity, but slightly decreases the strain-rate hardening potential [12]. In this work, our aim is to improve the mechanical properties of Al 2014 by variation of zinc content.

2. Materials and Method

In order to prepare the die and carry out the casting process first of all a wooden pattern of desired dimensions was prepared. Later on die was prepared with the help of machining process as shown in the Fig. 1. It consists of Upper plate, Base plate, slot for tensile specimen, lever etc. The material use for making die is mild steel.
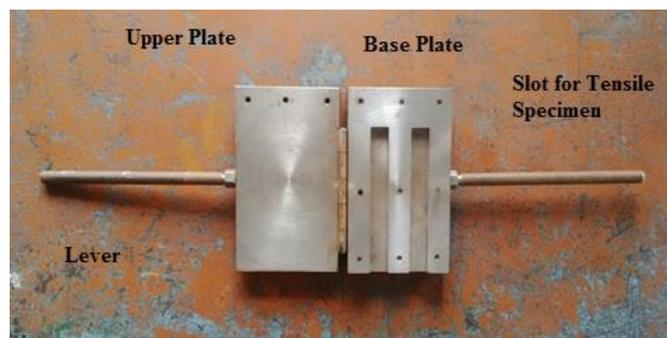
Figure 1: Mild steel die

For casting process different metals such as alumimium, copper, magnesium, silicon, iron, manganese, nickel, zinc lead, tin, titanium was melted one by one according to their melting points i.e. metal with higher melting point was melted first and so on. A specimen (casted product) was obtained by the combination of all these metals as shown in Fig.2.

Figure 2: Casting of aluminum alloys

The chemical composition of casted aluminum alloys as shown in table 1.

Table 1: Chemical composition of aluminium alloy AA2014 by variation of Zn percentage

Alloy	Si	Mg	Cu	Mn	Fe	Zn	Cr	Al
AA2014	0.8	0.6	4.2	1.2	0.3	0.25	0.1	Bal
AA2014+1%Zn	0.8	0.6	4.2	1.2	0.3	1	0.1	Bal
AA2014+1.5%Zn	0.8	0.6	4.2	1.2	0.3	1.5	0.1	Bal
AA2014+2%Zn	0.8	0.6	4.2	1.2	0.3	2	0.1	Bal
AA2014+2.5%Zn	0.8	0.6	4.2	1.2	0.3	2.5	0.1	Bal

3. Results and Discussions

3.1 Tensile Strength

Tensile test results of Al-2014 with variation of Zinc percentage (1%, 1.5%, 2% and 2.5%) are shown in Table 2-3.and Fig.3-4. The aluminium alloy Al 2014 + 1.5%Zn has the highest ultimate tensile strength, but the elongation of this alloy is the low as compare to base material. The Al-2014+1.5%Zn alloy has the most balanced mechanical properties. The addition of 1.5% Zn to Al-2014 aluminium alloy could greatly enhance the tensile strength of the alloy, but results in a decrease of elongation of the alloy. The addition of 2% and 2.5% Zn could not only enhance the tensile strength of Al-2014 alloy but also prevents a remarkable decrease of the elongation. The difference in the tensile strength of the four alloys could be explained by different strengthening mechanisms. It is well known that there are several common strengthening mechanisms including strain strengthening, solid-solution strengthening, grain refining strengthening and precipitation or particle strengthening.

Table 2: Mechanical properties of cast aluminium alloy 2014

Material	Tensile strength (MPa)	Strain (%)	Hardness (HV)	Residual Stress (MPa)
Al-2014	327.43	24.48	97	68

Table 3: % Improvement of mechanical properties of al-2014 by variation of Zn

Material	Tensile strength (MPa)	% stress Improvement	Hardness (HV)	% Hardness Improvement	Residual stress (MPa)	% Residual stress decrement
Al-2014 with 1% Zn	363.67	11.06	104	9.47	41	39.7
Al-2014 with 1.5% Zn	387.38	18.30	112	17.89	35	48.52
Al-2014 with 2% Zn	339.87	3.79	98	3.15	54	20.58
Al-2014 with 2.5% Zn	315.85	-3.53	115	21.05	61	10.29

In this work, all the alloys were fabricated through the casting process, and there was no much difference in the grain size of the four alloys but Al-2014+1.5% Zn has a fine grain structure as compare to other casted alloys. The strain strengthening and grain-refining strengthening should not cause the difference in tensile strength. In addition, the solid-solution hardening is limited in the Al-2014 based alloys due to the low solubility of the alloying elements. Therefore, the strength difference of the all four alloys should be mainly related to the precipitation/particle strengthening mechanism. The quantity and types of dispersoids change with the addition of Zn element, and the tensile strength changes accordingly. The enhanced tensile strength due to Zn addition should be closely related to a precipitation strengthening. The ultimate tensile strength value of the composite aluminium alloys has increased with the increase of Zn percentage from 1% Zn to 1.5%Zn and thereafter decrease with the further addition of Zn%. It was observed that highest ultimate tensile strength of 387.38 MPa was observed at 1.5% Zn addition, whereas minimum tensile strength of 315.85 MPa was observed at 2.5% Zn content. The strain values for different percentage of Zinc addition vary in the range of 17.62 to 22.86%. The % improvement of tensile strength, and % strain of casted aluminium alloy of Al-2014 with variation of Zinc (1 to 2.5%) in comparison to base Aluminium alloy Al-2014 as shown in table 5. The maximum % improvement (18.30%) of tensile strength was observed at 1.5% of zinc content, whereas % decrement (-3.53 %) of tensile strength was observed at 2.5% of zinc content as shown in table 3.
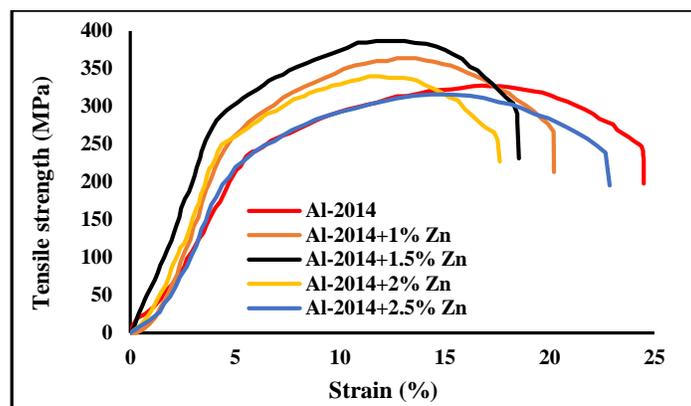
Figure 3: Comparison of aluminium alloyAl-2014 with variation of Zn percentage
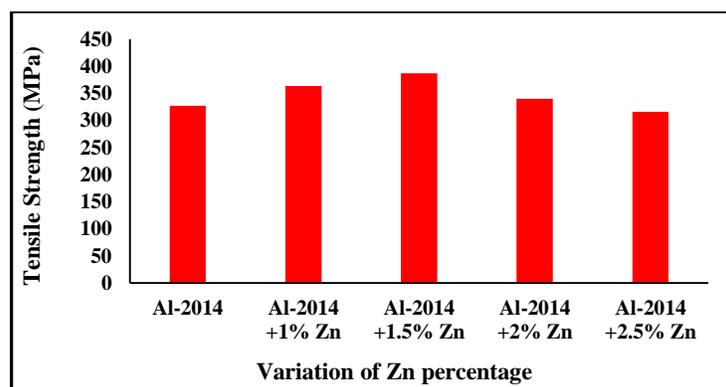
Figure 4: Comparison of ultimate tensile strength of Al-2014 with variation of Zn

3.2 Hardness Test

The average Vickers hardness for the four casted aluminium alloys of Al-2014 with different zinc content are shown in Fig.5 18. Zinc is the only material that is having greatest impact of all alloying elements on the strength and hardness of aluminium cast alloys. Zn improves the machinability of aluminium alloys by increasing the hardness, making it easier to generate small cutting chips and fine machined finishes [13-14].

The tensile strength and fracture point locations of the casted aluminium alloys depends on the hardness distributions and casting defects. When the casted aluminium alloys were defects free then the tensile strength of the casted aluminium alloys were dependent on the micro-hardness distribution of the aluminium alloys
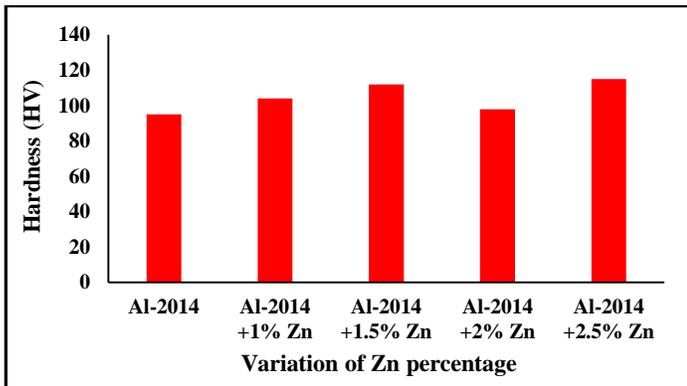
Figure 5: Hardness of aluminium alloy with variation of zinc content

The hardness value of the composite aluminium alloys has increased with the increase of Zn percentage from 1% Zn to 2.5%Zn except 2%Zn content. It was observed that highest hardness of 115 HV was observed at 2.5% Zn addition, whereas minimum tensile strength of 98 HV was observed at 2% Zn content. The % improvement of hardness of casted aluminium alloy of Al-2014 with variation of Zinc (1 to 2.5%) in comparison to base Aluminium alloy Al-2014 as shown in table 3. The maximum % improvement (21.05%) of hardness was observed at 2.5% of zinc content, whereas minimum % improvement (3.15 %) of hardness was observed at 2% of zinc content as shown in table 3.

3.3 Residual stress measurement by cosα method

A mini portable X-ray diffraction apparatus (pulstec μ-X360) used for analyzing the residual stresses of the casted aluminium alloy by variation of zinc content. The X-ray incident angle was set 35º and ± 5 oscillation was applied. The X-ray incident time was 4-5 min throughout this process for each sample. Under these conditions, a diffracted beam from the workpiece surface has captured the images of the casted aluminium alloys plates at 50μm resolution, the size of the beam spot was approximately 2.5 mm for 1.2 mm pinhole collimator.

For residual stress determination, the cosα method was described [15]. The translation from the diffractometer space to the sample

inherently more complex due to the 2D planar geometry of the measurement and can be expressed as

$$q_s = \begin{bmatrix} \cos\eta \, \sin\psi_0 + \sin\eta \, \cos\psi_0\cos\alpha \\ \cos\eta \, \sin\psi_0 \sin\phi_0 + \sin\eta \, \cos\psi_0\sin\phi_0\cos\alpha + \sin\eta \, \cos\phi_0\sin\alpha \\ \cos\eta \, \cos\psi_0 + \sin\eta \, \sin\psi_0\cos\alpha \end{bmatrix}$$

(1)

The strain projection along (η, α) coordinates can be written as in terms of scattering vector and strain component as

$$\varepsilon_\alpha = q_i q_j \varepsilon_{ij}$$

$$\varepsilon_{ij} = \frac{1+\nu}{E}\sigma_{ij} - \delta_{ij}\frac{\nu}{E}\sigma_{kk}$$

(2)

So, the strain projection may be written as

$$\varepsilon_\alpha = \frac{1+\nu}{E}q_i q_j \sigma_{ij} - \frac{\nu}{E}\sigma_{kk}$$

(3)

Now, defining two parameters a_1 and a_2 for linear determination of σ_{11} and σ_{22}

$$a_1 = \frac{1}{2}[(\varepsilon_\alpha - \varepsilon_{\pi+\alpha}) + (\varepsilon_{-\alpha} - \varepsilon_{\pi-\alpha})]$$

(4)

$$a_2 = \frac{1}{2}[(\varepsilon_\alpha - \varepsilon_{\pi+\alpha}) - (\varepsilon_{-\alpha} - \varepsilon_{\pi-\alpha})]$$

(5)

After re-expressing of equations (26) and (27) to lead the final relationship for this method.

$$a_1 = \frac{1+\nu}{E}\sin2\psi_0 \, \sin2\eta \, \cos\alpha \, [\sigma_{11}(1+\cos2\phi_0) + \sigma_{22}(1-\cos2\phi_0) + 2\sigma_{12}(\sin2\phi_0)]$$

(6)

$$a_2 = \frac{1+\nu}{E}\sin\psi_0 \, \sin2\eta \, \sin\alpha \, [\sigma_{22}\sin2\phi_0 - \sigma_{11}\sin2\phi_0 + 2\sigma_{12}\cos2\phi_0)]$$

(7)

at $\phi_0 = 0$, the above equations will be

$$a_1 = \sigma_{11}\frac{1+\nu}{E}\sin2\psi_0 \, \sin2\eta \, \cos\alpha$$

(8)

$$a_2 = 2\sigma_{12}\frac{1+\nu}{E}\sin\psi_0 \, \sin2\eta \, \sin\alpha$$

(9)

Thus the term cosα in the equation (30) was the origin of the name for this method

The value of stresses after re-expression maybe written as

$$\sigma_{11} = -\frac{E}{1+\nu}\frac{1}{\sin2\psi_0 \, \sin2\eta}$$

(10)

$$\sigma_{12} = -\frac{E}{2(1+\nu)}\frac{1}{\sin2\psi_0 \sin^2\eta}$$

(11)

Residual stresses (compressive or tensile) will influence the mechanical behavior of the casted aluminium alloys. It can reduce brittle fracture strength, buckling strength and cracking in the aluminium alloys. Residual stress is also influenced the prediction of brittle failure and affect the life time prediction of

the component. Residual stress contributes both negative and positive effect to the casted aluminium alloys. Generally, the tensile residual stress lead to negative effect to the casted aluminium alloys [16-18].
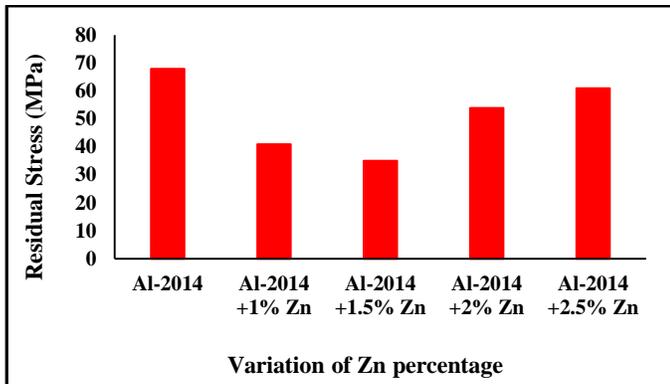
Figure 6: Variation of residual stress to casted aluminium alloys with different Zn content

It was observed that higher residual stress of 68 MPa was observed at base metal Al-2014, whereas minimum residual stress of 35 MPa was observed at 1.5% Zn. The % decrement of residual stress of casted aluminium alloy of Al-2014 with variation of Zinc (1 to 2.5%) in comparison to base Aluminium alloy Al-2014 as shown in table 3. The maximum % decrement (48.52%) of residual stress was observed at 1.5% of zinc content, whereas minimum % improvement (10.29 %) of residual stress strength was observed at 2.5% of zinc content as shown in fig.6.

3.4 Microstructural Analysis

The microstructure of base material Al-2014, Al-2014 + 1% Zn, Al-2014 + 1.5% Zn, Al-2014 + 2% Zn, and Al-2014 + 2.5% Zn were analyzed. Fig. 7 clearly shows that the zinc content in the aluminium alloy Al-2014 has improve the homogenous dispersion of the reinforcement particulates in the matrix, therefore due to fine grain structure, the ultimate tensile strength and hardness of the aluminium alloy was increased when Zn content increased. Very less porosity was observed in the microstructure which is evident from the density value. This figure shows the relationship between the grain size and the zinc percentage. It was found that the grain size decreases when the zinc content increases.

The microstructure of composite Al-alloy with variation of Zn percentage reveal that the zinc reinforcement has both affected the mechanical properties and microstructure. In composite aluminium alloy, as the percentage of Zn increased from 1wt% to 2.5wt%, zinc is observed to have become finer. This suggested that zinc morphology was affected by particle additions. Higher percentage (>2.5wt%) of zinc particles provide growth restriction to zinc making them finer. The morphological changes brought but by particle addition have been substantiated by past researcher [19].
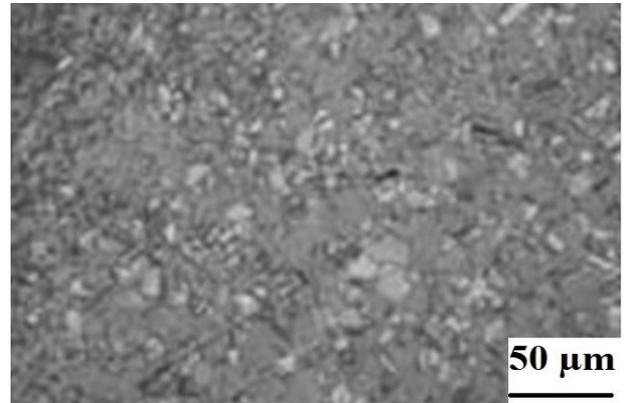
(a)
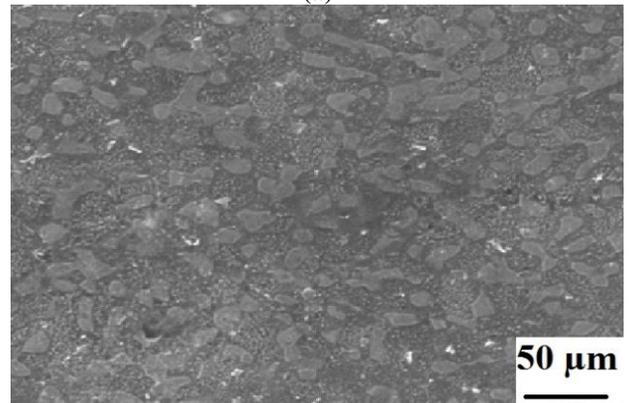
(b)
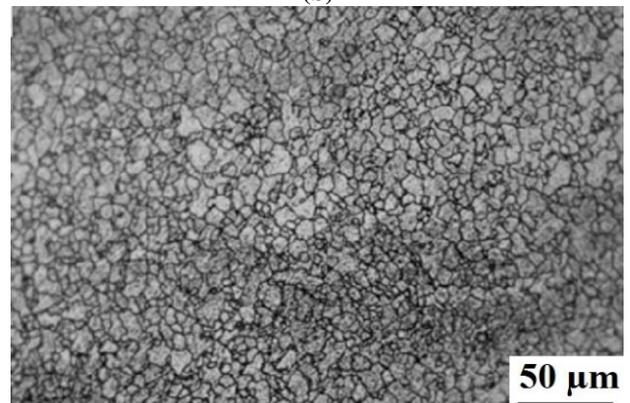
(c)
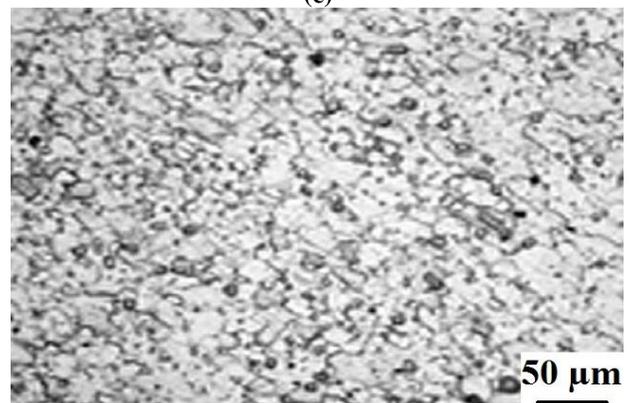
(d)
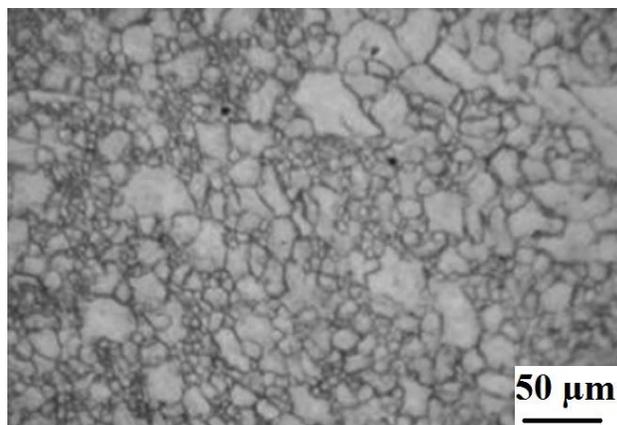
(e)

Figure 7: SEM images of casted aluminium alloys (a) Al-2014, (b) Al-2014 +1% Zn (c) Al-2014+ 1.5% Zn , (d) Al-2014+2% Zn, (e) Al-2014 +2.5% Zn

4. Conclusions

The mechanical properties of aluminium alloys Al-2014 with variation of zinc concentration are achieved using experimental method. The influences of zinc concentration on mechanical properties of aluminium alloy Al-2014 have been studied. Based on Mechanical testing, the following conclusion can be drawn.

➢ The ultimate tensile strength value of the composite aluminium alloys has increased with the increase of Zn percentage from 1wt% to 1.5wt% and thereafter decrease with the further addition of 2.5wt%.

➢ It was observed that ultimate tensile strength (387.38 MPa) value has been the maximum at 1.5 wt% Zn addition.

➢ The strain values for different percentage of Zinc addition vary in the range of 17.62 to 24.48%.

➢ The Minimum ultimate tensile strength was obtained 315.85 N/mm^2 at 1.5 wt% Zn addition.

➢ Hardness was improved when concentration of Zinc increased, maximum hardness (115 HV) was obtained in Al-2014 with 2.5% Zinc concentration.

➢ Because of fine precipitates and fine grains structure, the cast aluminium alloy with 1.5wt% is associated with plastic deformation and high temperature, due to precipitates formation at high temperature along the grain boundaries.

➢ Fine recrystallized grains and increase of grain boundaries was found in the cast aluminium alloy with 1.5wt% Zn predict higher tensile strength.

References

[1] Singh M., Prasad B.K., Mondal D.P., Jha A.K., Dry sliding wear behaviour of an aluminium alloy-granite particle composite, Tribology International, 2001, 34(8), p. 557-567.

[2] A. Zhu, B. M. Gable, G. J. Shiflet, E. A. Jr. Starke, Trace element effects on precipitation in Al–Cu–Mg–(Ag, Si) alloys: a computational analysis, Acta Materialia 52, 3671–3679, 2004.

[3] C.J. Boehlert, K. Knittel, the microstructure, tensile properties, and creep behavior of Mg–Zn alloys containing 0–4.4 wt.% Zn, Materials Science and Engineering A 417 (2006) 315–321.

[4] Yin Dong-Song, Zhang Er-Lin, Zeng Song-Yan, Effect of Zn on mechanical property and corrosion property of extruded Mg-Zn-Mn alloy, transactions of the indian institute of metals 18 (2008), 763-768.

[5] Muzaffer Zeren and Erdem Karakulak, "Study on hardness and microstructural characteristics of sand cast Al–Si–Cu alloys", Bull. Mater. Sci., Vol. 32, No. 6, December, pp. 617–620. © Indian Academy of Sciences, 2009.

[6] Zhu Mei-Jun, Ding Dong-Yan, Gao Yong-Jin, Chen Guo-Zhen, Li Ming, Mao Da-Li, Effect of Zn content on tensile and electrochemical properties of 3003 Al alloy, Trans. Nonferrous Met. Soc. China 20(2010) 2118−2123.

[7] H. N. Girisha, K. V. Sharma, Effect of magnesium on strength and microstructure of aluminium, copper, magnesium alloys, International Journal of Scientific Engineering and Research, 3 (2), 2012.

[8] N. Nafsin, H. M. M. A. Rashed ,Effects of Copper and Magnesium on Microstructure and Hardness of Al-Cu-Mg Alloys, International Journal of Engineering and Advanced Technology (IJEAT) ISSN: 2249 – 8958, Volume-2, Issue-5, June 2013.

[9] Musa Yıldırım, Dursun Özyürek, The effects of Mg amount on the microstructure and mechanical properties of Al–Si–Mg alloys, Materials and Design 51 (2013) 767–774.

[10] Vipin Kumar, Husain Mehdi, Arpit Kumar, Effect of Silicon content on the Mechanical Properties of Aluminium Alloy, International Research Journal of Engineering and Technology, 2(4), 1326-1330, 2015.

[11] Husain Mehdi, Shivam Sharma , Mohd Anas, Naman Sharma, The Influences of Variation of Copper Content on the Mechanical Properties of Aluminium alloy, International Journal of Material Science Innovations, 3(3), 2015, 74-86.

[12] Hao Zhong, Paul A. Rometsch, Lingfei Cao, Yuri Estrin, "The influence of Mg/Si ratio and Cu content on the stretch formability of 6xxx aluminium alloys", Publication Materials Science & Engineering A, Publisher Elsevier, 2016, pp 688-697.

[13] J.E. Hatch, Aluminium: Properties and Physical Metallurgy, American Society for Metals, Materials Park, OH, 1984, p. 135.

[14] ASM Handbook,Properties and Selection: Nonferrous Alloys and Special-Purpose Materials, L.A. Abel, R.T. Kiepura, P. Thomas, H.F. Lampman and N.D. Wheaton(Eds.), ASM International, Materials Park, OH, Vol. 2, 1990, p. 1328.

[15] Sasaki T, Hirose Y, Sasaki K, Yasukawa S,Adv X-ray Anal **40** (1997) 588.

[16] D. J. Buchanan and R. John. 2014. Residual stress redistribution in shot peened samples subject to mechanical loading. Materials Science & Engineering: A. 615: 70-78.

[17] N. S. Rossini, M. Dassisti, K. Y. Benyounis and A. G. Olabi. 2012. Methods of measuring residual stresses in components. Materials and Design. 35: 572-588.

[18] Albertini, G.; Bruno, G.; Dunn, B.D.; Fiori, F.; Reimers, W. & Wright, J.S. Comparative neutron and X-ray residual stress measurements on Al-2219 welded plate. Mater. Sci. Eng.: A, 1997, 224(1-2), 157-165. doi:10.1016/S0921-5093(96)10546-3.

[19] J.T. Berry:AFS Trans., 1970, vol. 78, pp. 421–428.