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Influence of Zn content on mechanical properties of aluminum alloy AA6061

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Abstract

In this work, the mechanical properties of aluminum alloys Al-6061 with variation of zinc concentration were achieved using experimental method. The influences of zinc concentration on mechanical properties of aluminum alloy Al-6061 have been studied. Based on Mechanical testing, the following conclusion can be drawn. The ultimate tensile strength value of the composite aluminum alloys has increased with the increase of Zn percentage from 1wt% to 4wt% and thereafter decrease with the further addition of 5wt%. It was observed that ultimate tensile strength (244.9 MPa) value has been the maximum at 4wt% Zn addition. The strain values for different percentage of Zinc addition vary in the range of 6.8 to 8.1%. The Minimum ultimate tensile strength was obtained 198.1N/mm^2 in base aluminum alloy Al-6061. By addition of more zinc, the solidifications temperature for aluminum alloy AL-6061 reduces and this is an important factor to consider. Hardness was improved when concentration of Zinc increased, maximum hardness was obtained in Al-6061 with 4% Zinc concentration. The alloying elements such as Zn and Mg existing in cast aluminum alloy and make precipitation reaction and form a strong precipitate of $MgZn_2$ to give a higher strength. Fine recrystallized grains and increase of grain boundaries was found in the cast aluminum alloy with 4wt% Zn predict higher micro-hardness and tensile strength. Because of fine precipitates and fine grains structure, the cast aluminum alloy with 4wt% is associated with plastic deformation and high temperature, due to precipitates formation at high temperature along the grain boundaries.

Keywords: Aluminum alloys, Zinc percentage, Tensile strength, Hardness

1. Introduction

Aluminum is one of the metallic materials most used in metal working industry and its use has greatly increased in the aeronautics and automotive areas. Low weight/strength ratio, good electric and thermal conductivity, mechanical strength, and good machinability are some of the properties that improved their market share. The aluminum due to its excellent qualities has taken an important place in engineering applications, making it the most produced non-ferrous metal in the metallurgical industry. To attend the necessary requirements for engineering applications, aluminum is usually combined with other chemicals elements in the form of an alloy. The Aluminum alloys with silicon as a major alloying element are a class of alloys, which are the basis of many manufactured castings. This is mainly due to the outstanding effect of silicon in the improvement of casting characteristics, combined with other physical properties, such as mechanical properties and corrosion resistance [1]. When the primary silicon appears as coarse polyhedral particles, the strength properties decrease with increasing silicon content, but the hardness goes on increasing because of the increase in the number of silicon particles [2]. Al-Si alloys find wide applications in the marine, electrical, and automobile, and aircraft industries because of high fluidity, low shrinkage in casting, high corrosion resistance, good weld-ability, easy brazing, and low coefficient of thermal expansion [3]. 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 [4]. The strength of the alloy can increase through precipitation hardening, with or without the presence of Mg; Hardening is achieved through the precipitation of Al_2Cu or Al_2CuMg intermetallic phases during aging which leads to strengths second only to the highest strength 7xxx series alloys [5]. The grain refinement of the extruded Mg-Zn-Mn alloy byk variation of Zn concentration and they found that the mechanical properties of extruded Mg-Zn-Mn alloy enhanced when the percentage of Zn increased. The ultimate tensile strength is increased by 54.7 MPa and 69.7 MPa

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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. The greatest anti-corrosion properties were obtained with 1% of Zn added conversely, further increase of Zn percentage up to 3% declines the corrosion property [6]. The mechanical properties of Al- alloy of 3003 by variation of Zn percentage and they found that high-density particles precipitate 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 ultimate tensile strength was found with 1.5 % of Zn concentration but lowest elongation. 1.8 % of Zn content in Al 3003 presents the most balanced mechanical properties and has a great impact on the corrosion resistance of Al 3003 alloy [7]. Copper tends to precipitate at grain boundaries, making the metal very susceptible to pitting, intergranular corrosion, and stress corrosion [8]. An increase in Mg content results from the formation of new phases in microstructure by some black phases present on the copper-bearing phase in Al-6% Cu alloys. Thus the addition of magnesium results in an increased magnesium-containing phase and therefore increases hardness [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 increasing the silicon content then the melting point of aluminum alloy is decreased whereas fluidity was increased [10-11]. The hardness measurements to characterize the early stages of precipitation in three Al–Mg–Si alloys with different Cu contents (Al–0.51 at.% Mg–0.94 at.%Si, with 0.01 at.%, 0.06 at.%, or 0.34 at.% Cu) at a range of single and multi-stage heat treatments to evaluate the changes in precipitation processes [12]. The mechanical properties of aluminum alloy Al-Si-Cu by variation of magnesium (Mg) concentration were analyzed and they found that the yield strength increases and ductility decrease at high Mg concentration in the aluminum alloy. Two types of Cu-rich intermetallics are formed during solidification, the irregular Cu-rich intermetallics has the composition of Al90Cu2Mg7Si and Al2Cu(Si) which are detectable as a solid phase only when Mg is higher than the 0.32 wt% in the aluminum alloy. The magnesium percentage enhanced the strengthening effect in the aluminum alloy of Al-Si-Cu under solution aging condition. The Mg percentage can be controlled by up to 0.75% in the aluminum alloy of Al-Si-Cu for increasing the tensile strength with sacrificed ductility [13]. The percentage of Cu improved the work hardening capacity, but slightly decreases the strain-rate hardening potential [14]. A linear single variable model for precipitation heat treated Al-Zn-Mg-Cu aluminum alloy hardness and yield strength described. Based on the major alloying elements and the strengthening of precipitate compositions, a concept model was developed [15]. The hardening the intensity of Al-Mg-Si alloys was increased when the Mg/Si ratio decreased. The strain rate sensitivity of the flow stress raises when the Mg/Si ratio decreases. The addition of 0.3 wt% Copper slightly reduces the strain rate sensitivity of the flow stress. Copper content promotes the stretch formability of the alloys due to a significant increase in the dislocation storage rate [16]. The effects of Zn content on strength and wear performance of Al−12Si−3Cu alloy synthesized by gravity casting and they observed that the hardness, yield, tensile and compressive strengths, elongation to fracture and impact toughness of the Al−12Si−3Cu−Zn alloys increased with increasing Zn content, but the tendency in the tensile and compressive strengths and ductility reversed after adding 1.5%−2% Zn. In addition, the friction coefficient and volume loss of the Al−12Si−3Cu−Zn alloys decreased with increasing Zn content [17]. The percentage of Zn can significantly improve the SCC resistance of the AA5083 alloys. This is related to the relatively low amount of continuous β (Al3Mg2) phase along the grain boundary and the formation of the Zn-containing phase such as the Al5Mg11Zn4 phase. Based on the results, the optimal Zn content with respect to SCC resistance is approximately 0.50 wt.%. Further increasing Zn content results in coarse precipitates discontinuously distributed along grain boundaries [18]. The die-cast zinc alloys possess an attractive combination of mechanical properties, permitting them to be applied in a wide variety of functional applications. However, depending on the alloying elements and purposes, some zinc alloys can be processed also by cold chamber die-casting, gravity, or sand casting as well as spin casting and slush casting [19]. In ths work, the casting of various aluminum alloys by variation of zinc percentage has been done with the help of permanent mould which is made by mild steel and investigate the mechanical properties and microstructre of aluminum alloy Al-6061 by variation of zinc percentage.

2. Materials and Methods

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 the machining process. The permanent die consists of an Upper plate, baseplate, slot for tensile specimen, lever etc. The material used for making die is mild steel. The casting of AA6061 with different Zn percentage was done by an open-hearth furnace as shown in fig.1, and the temperature was measured by a thermocouple.

Figure 1: Casting of an aluminum alloy by different Zn content

3. Results and Discussion

3.1 Tensile strength

Mechanical properties play an important role in improving the product quality. Tensile and hardness tests are commonly used to determine the mechanical properties of an aluminum alloy. The tensile property is to measure the strength of a material and its ability to resist the loads without failure, whereas hardness of a material is the measurement of its resistance to plastic deformation. For determining the ductility of a material, the sample is pulled in tension at constant rate in universal testing machine and ultimate tensile strength, yield strength and percentage elongation of a specimen are obtained.
This chapter provides a detailed information about tensile, hardness and impact tests for aluminum and zinc based alloys. The data so obtained has been analyzed and discussed with respect to the corresponding values.

Table 1: Mechanical properties of cast aluminum alloy 6061

Material	Tensile strength (MPa)	Strain (%)	Hardness (HV)
Al-6061	198.1	6.8	124

The aluminum zinc alloy was successfully synthesized by the die casting method. Mixing of zinc and aluminum particles lead to the cluster formation and hence results in the formation of improved alloy. The zinc particles are uniformly distributed in aluminum alloy Al-6061 and the tensile strength of cast alloy increased with increasing the zinc content as shown in Fig. 2. The tensile test of composites was carried out to evaluate the ultimate tensile strength, percentage elongation, and micro-hardness of Al-6061 by variation of Zn percentage (1-5%). The tensile test was conducted on composite Al-alloy along the length of the composite from similar locations. The composite aluminum alloys with zinc percentage of 1wt%, 2wt%, 3wt%, 4wt%, and 5wt% were considered. The average of three ultimate tensile strength values was recorded for each composite aluminum alloy. The tensile test result of aluminum alloy Al-6061 with variation of zinc (1-5%) percent are shown in table 2 and fig. 2. The tensile strength values lie in the range of 198.1 to 244.9MPa at room temperature. It observed that increase in tensile strength may be attributed to the dissolution of the Zn rich intermetallic phase particles, mainly the Al_2Zn phase during solution treatment, and solid solution hardening is the process mainly responsible for the observed increase in strength. The value of ultimate tensile strength of cast aluminum alloys are higher than the base aluminum alloy Al-6061.
The ultimate tensile strength value of the composite aluminum alloys has increased with the increase of Zn percentage from 1wt% to 4wt% and thereafter decrease with the further addition of 5wt%. It was observed that ultimate tensile strength (244.9 MPa) value has been the maximum at 4wt% Zn addition. The strain values for different percentage of Zinc addition vary in the range of 6.8 to 8.1%.
The % improvement of tensile strength, strain and micro hardness of cast aluminum alloy of Al-6061 with variation of Zinc (1-5%)in comparison to base Aluminum alloy Al-6061 as shown in table 2.

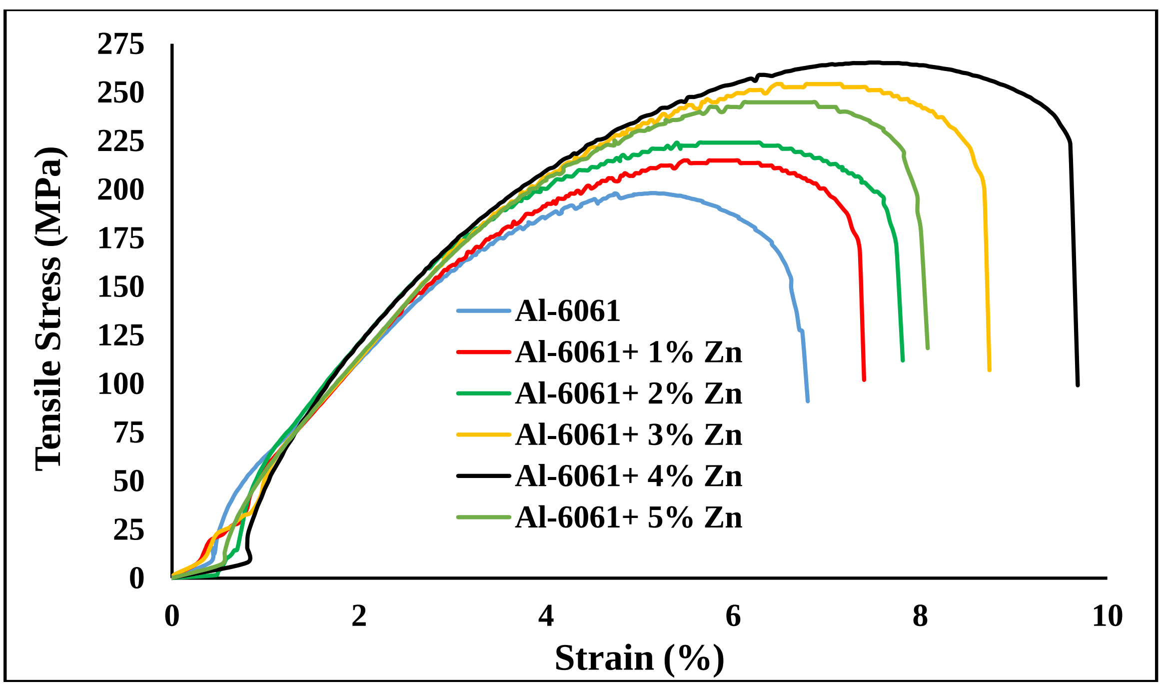


Figure 1: Combine Comparison of aluminum alloyAl-6061 with variation of Zn content

Table 2: % improvement of Mechanical properties of Al-6061 by variation of Zn content

Material	Tensile strength (MPa)	% stress Improvement	Strain (%)	% Strain Improvement	Hardness (HV)	% Hardness Improvement
Al-6061 with 1% Zn	214.9	8.6	7.4	8.82	132	6.45
Al-6061 with 2% Zn	224.2	13.4	7.8	14.85	142	14.52
Al-6061 with 3% Zn	254.3	28.8	8.7	28.53	148	19.35
Al-6061 with 4% Zn	265.0	34.3	9.7	42.65	157	26.61
Al-6061 with 5% Zn	244.9	24.0	8.1	19.12	143	15.32

3.2 Hardness Test

Some alloys may improve their strength and hardness by the formation of uniformly small dispersed particles within the original matrix when the solidified alloy is subjected to heat treatment. These particles are called second phase particles and the strengthening achieved through the precipitation of these particles is known as age hardening. These precipitated particles strengthen the heat treated alloys by blocking the movement of dislocation. Al-Zn alloys are suitable for casting, as these alloys can be heat treated and can be age hardened [20-21].

Zinc is the only material that is having greatest impact of all alloying elements on the strength and hardness of aluminum cast alloys. Zn improves the machinability of aluminum alloys by increasing the hardness, making it easier to generate small cutting chips and fine machined finishes.

Fig. 3 elucidate the variation of zinc content on the hardness of cast aluminum alloy. It may be observed that hardness of cast aluminum alloy was increased with increased in zinc percentage, the highest hardness value was obtained in cast Al-6061 + 5% Zn is 157 HV whereas the minimum hardness (124 HV) was obtained in base aluminum alloy Al-6061.

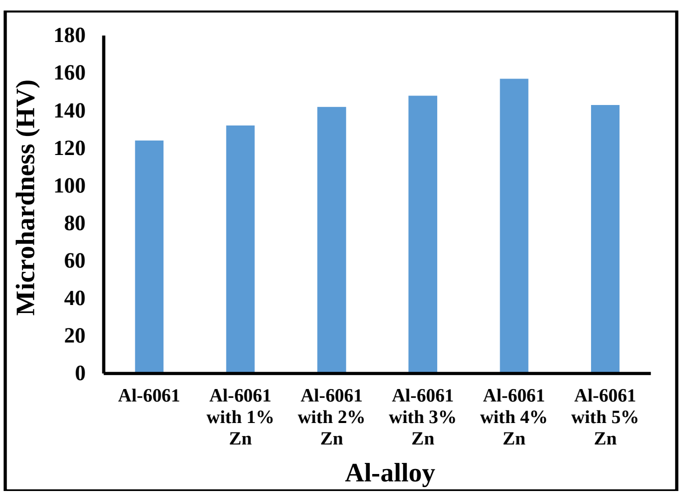
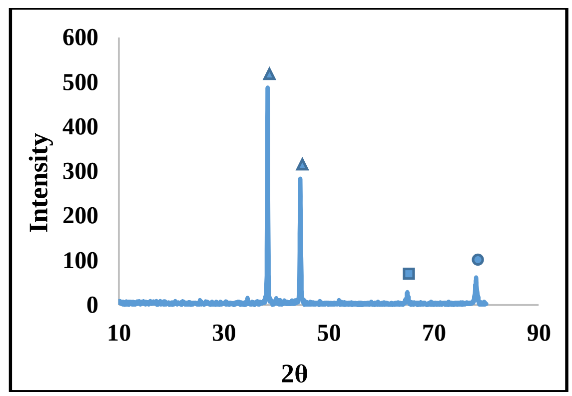


Figure 2: Hardness of aluminum alloy with variation of zinc content

3.3 XRD analysis

X- Ray diffraction was used for examine the phase detection of cast aluminum alloy Al-6061 with variation of Zn percentage (1 to 5%) and found three major phases Al, $MgZn_2$, and Mg_2Si as shown in fig. 4. Magnesium (Mg) and Silicon (Si) elements were found in the weldment besides the aluminum (Al), it is found that Mg and Zn created the phase after the precipitation reaction in the cast aluminum alloy. A very high intensity was found from aluminum, because of fragmentation of precipitates the intensity of $MgZn_2$ was increases after adding Zn percentage in Al-6061. The alloying elements such as Zn and Mg existing in cast aluminum alloy and make precipitation reaction and form a strong precipitate of $MgZn_2$ to give a higher strength. Fine recrystallized grains and increase of grain boundaries was found in the cast aluminum alloy with 4wt% Zn predict higher micro-hardness. Because of fine precipitates and fine grains structure, the cast aluminum alloy with 4wt% is associated with plastic deformation and high temperature, due to precipitates formation at high temperature along the grain boundaries.



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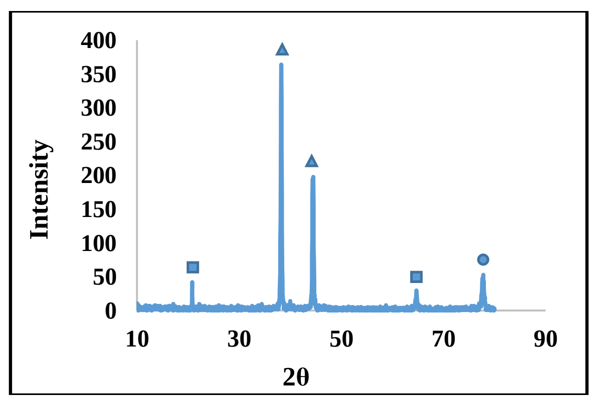

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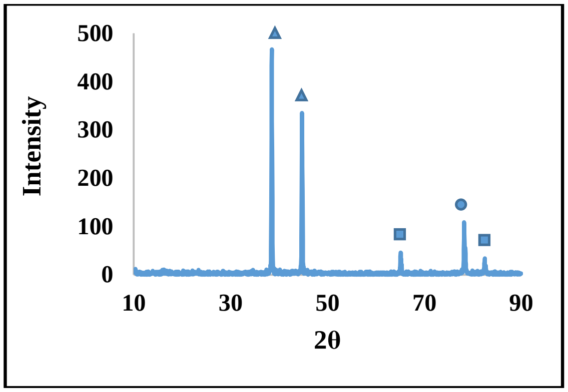

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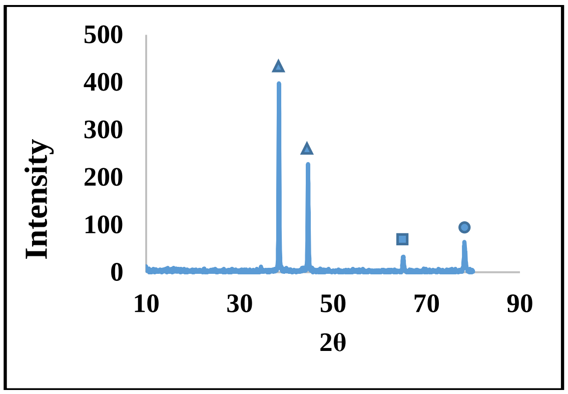

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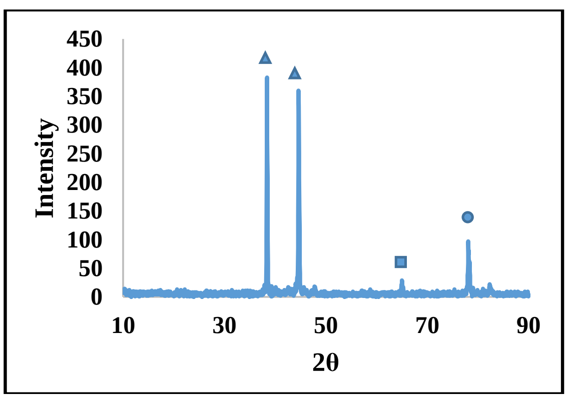
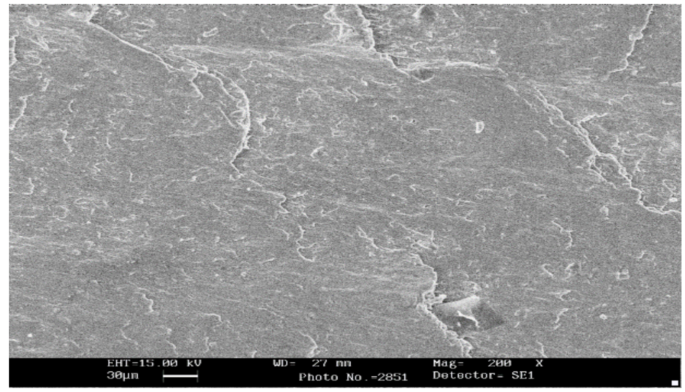


(e)

Figure 4: XRD patterns of the Al-6061, (a) 1wt%, (b) 2wt%, (c) 3wt%, (d) 4wt%, (e) 5wt%

3.4 Microstructural Analysis

The microstructure of composite Al-alloy with variation of Zn percentage reveal that the zinc reinforcement have both affected the mechanical properties and microstructure. In composite aluminum alloy, as the percentage of Zn increased from 1wt% to 4wt%, zinc is observed to have become finer. This suggested that zinc morphology was affected by particle additions. Higher percentage (>4wt%) 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 [22]. The microstructure of base material (AL-6061) and Al-6061 + 1% Zn, AlL-6061 + 2% Zn, Al-6061 + 3% Zn, Al-6061 + 4% Zn, Al-6061 + 5% Zn were analyzed.



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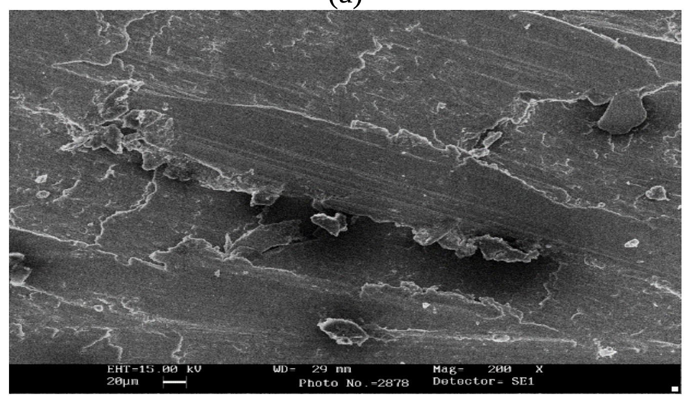

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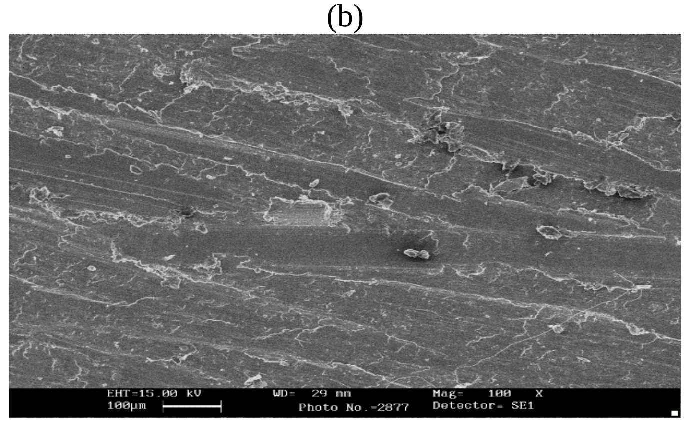

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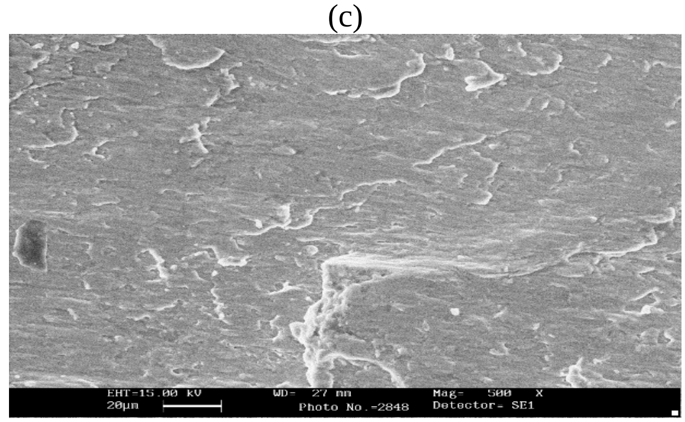

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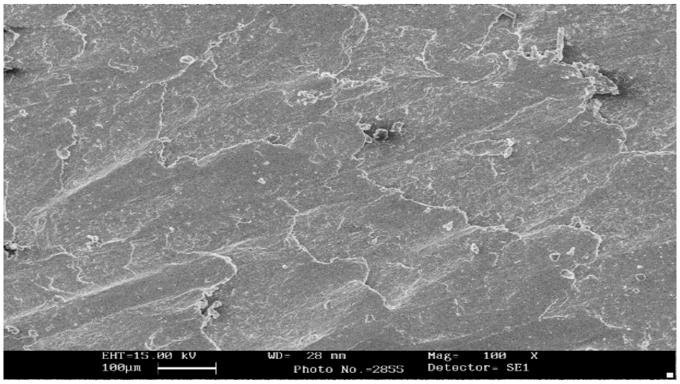

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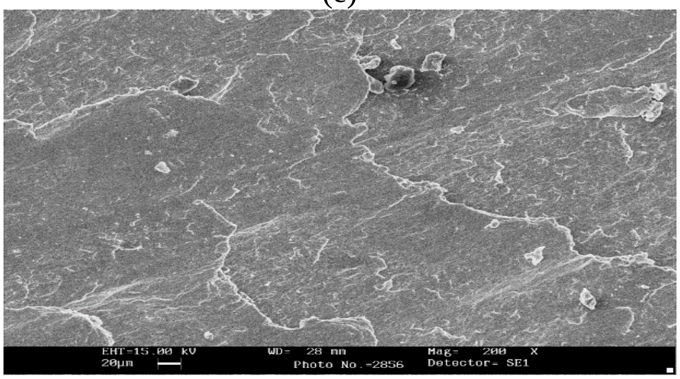


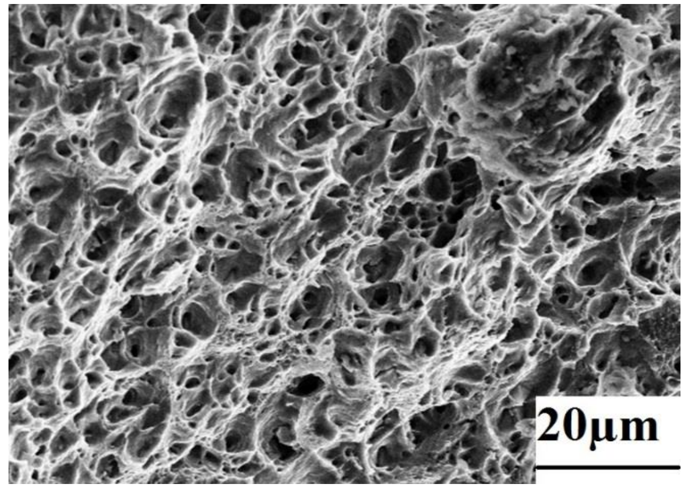
(f)

Figure 5: SEM images of (a) Al-6061, (b) 1wt%, (c) 2wt%, (d) 3wt%, (e) 4wt%, (f) 5wt%

Fig. 5 clearly shows that the zinc content in the aluminum alloy Al-6061 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 aluminum 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.

3.5 Fractography analysis of cast aluminum alloy 1wt%, 4wt%

Fractured surfaces of the fragmented tensile specimens of cast aluminum alloy with zinc percentage of 1wt%, 4wt% were analyzed by SEM machine to understand the effect of microstructure on the failure pattern of aluminum alloys. In order to understand the mode of failure during tensile test, analysis of fractography was carried out on the composite aluminum alloy after tensile fracture. The fractured SEM images for different percentage of zinc in the range of 1wt%-5wt% reveal ductile mode of failure. Due to less magnesium in the cast aluminum alloy that has not triggered the reaction around the zinc particles, the interfacial reaction zones were not seen around the fractured region. The fractured surface was clearly seen with small dimples, which indicates good bonding between the reinforcement and matrix. The mechanism of crack propagation sappears to be due to voids formed at the vicinity of the zinc particles signifying ductile mode of failure as shown in fig.6.



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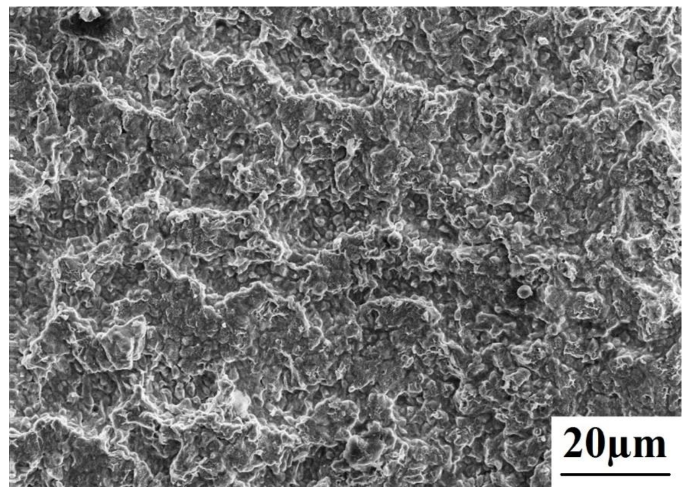

(b)

Figure 6: Fractography images, (a) 1wt%, (b) 4wt%

4. Conclusions

The mechanical properties of aluminum alloys Al-6061 with variation of zinc concentration are achieved using experimental method. The influences of zinc concentration on mechanical properties of aluminum alloy Al-6061 have been studied. Based on Mechanical testing, the following conclusion can be drawn.

- The ultimate tensile strength value of the composite aluminum alloys has increased with the increase of Zn percentage from 1wt% to 4wt% and thereafter decrease with the further addition of 5wt%.
- It was observed that ultimate tensile strength (244.9 MPa) value has been the maximum at 4wt% Zn addition.
- The strain values for different percentage of Zinc addition vary in the range of 6.8 to 8.1%.
- The minimum ultimate tensile strength was obtained 198.1N/mm^2 in base aluminum alloy Al-6061.
- By addition of more zinc, the solidifications temperature for aluminum alloy AL-6061 reduces and this is an important factor to consider.

- Hardness was improved when concentration of Zinc increased, maximum hardness was obtained in Al-6061 with 4% Zinc concentration.
- The alloying elements such as Zn and Mg existing in cast aluminum alloy and make precipitation reaction and form a strong precipitate of $MgZn_2$ to give a higher strength.
- Fine recrystallized grains and increase of grain boundaries was found in the cast aluminum alloy with 4wt% Zn predict higher micro-hardness and tensile strength.
- Because of fine precipitates and fine grains structure, the cast aluminum alloy with 4wt% is associated with plastic deformation and high temperature, due to precipitates formation at high temperature along the grain boundaries.

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