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RESEARCH ARTICLE

INVESTIGATION OF THE STRAIN RATE SENSITIVITY OF Mg-6Sn AND Mg-6Sn-3Y ALLOYS

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ABSTRACT

This study reports the influence of the addition of Yttrium (wt.3%) on strain-rate sensitivity of Mg-6Sn alloy. The Mg-6Sn and Mg-6Sn-3Y alloys were made by using high pressure die-cast. The microstructural and X-ray diffraction results exhibited that the Sn_3Y_5 and MgSnY intermetallic phases were formed with addition of Y to the Mg-6Sn alloy. Furthermore, the grain structure of the Mg-6Sn alloy was changed from dendritic to globular with addition of Y. The strain-rate sensitivity value of the Mg-6Sn-3Y alloy is found higher than that of the Mg-6Sn alloy for all strain value. This result was attributed to the formation of new intermetallics (Sn_3Y_5 and MgSnY) and microstructure morphology (from dendritic structure to globular).

Keywords: *Mg-Sn alloy, high pressure die casting, yttrium, strain-rate sensitivity*

1. INTRODUCTION

The strain-rate sensitivity (SRS) is very vital parameter for pure Mg and its alloys, which have the hexagonal close-packed structure apart from some Mg-Li alloys. It is well known for homogeneous deformation that it needs to at least five independent slip systems. However, many Mg alloys have only two available independent basal slip systems at low temperatures. Therefore, it can be said that they have limited ductility or formability when compared with aluminum alloys and steel [1-5]. The magnesium alloys are the best candidate for structural and automotive applications because of their lower density than that of other metallic components like steel and aluminum. However, the Mg alloys have some disadvantages (such as formability, mechanical properties and corrosion resistance), which are still not improved adequately. The ductility is one of the disadvantages for pure Mg and Mg alloys. Hence, the SRS of commercial Mg alloys has been investigated by many researchers to obtain information about tensile ductility and the deformation mechanisms [6-9]. For instance, Wang et. al. [10] displayed that the SRS of rolled Mg-3Al-3Sn alloy depends on the alloy' grain size and reported that the SRS increases with the improvement of grain size. At another study, the SRS of pure magnesium, Mg-1Al and Mg-1.4 Gd alloys was investigated by Stanford et. al. [11] and they found

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that while the Mg-1Al alloy's SRS was 30% lower than that of pure Mg and the SRS of Mg-1.4Gd alloy was similar to pure Mg. Ang et. al. [12] published article about the SRS of magnesium alloys containing aluminum. It is reported that when the Al content in Mg alloys is increase, the strain-rate sensitivity is decreased and furthermore, twinning has important effect in deformation of magnesium-aluminium based alloys.

As seen above that, a lot of studies concerned with the strain-rate sensitivity were performed on magnesium-aluminium based alloys. In the last decade, if it is considered that the findings about Mg-Sn binary alloy systems, these alloys could be an alternative to Mg-Al binary alloys due to their better mechanical properties [13-17]. However, the Mg-Sn alloys' SRS has not studied adequately. Therefore, this study investigated the SRS of Mg-Sn and yttrium-added Mg-Sn alloys. The tensile behavior of the alloys was investigated over a wide strain rate range 10^{0}-10^{-4} s^{-1}.

2. MATERIAL AND METHOD

2.1. Experimental Details

Magnesium ingot, high purity tin granules and Mg-30 wt.%Y were used to prepare Mg-xSn and Mg-xSn-yY alloys (x=6 and y=3 wt.%), whose composition is listed in Table 1. The alloys were obtained using an induction furnace in a SiC crucible under a mixture gas (99% CO_2 +1% SF_6) to prevent oxidation. Firstly, pure Mg was melted at 750ºC, after melting, and then Mg-30Y master alloy and pure tin were added. Both alloys were kept at 750ºC for 600 s to ensure chemical reaction, then the oxidized layer on the melt was cleaned. After this stage, the prepared alloys were solidified at 250ºC by a high pressure die casting machine in a mold designed to produce 4 tensile samples and metallographic samples.

Table 1. Chemical composition of Mg-Sn-Y alloy using X-ray fluorescence (Bruker S8Tiger) analysis.

Sample	Magnesium (Mg) (wt.%)	Tin (Sn) (wt.%)	Yttrium (wt.%)
Mg-6Sn	93.37	6.07	-
Mg-6Sn-3Y	90.58	5.98	3.08

Metallographic specimens were chemically etched with (20 ml CH_3 COOH, 60 ml ethylene glycol, 1 ml HNO_3 and 19 ml distilled water) acetic glycol after polishing and investigated by an optical and a scanning electron microscopy (SEM). X-ray (with a Cu Kα radiation (wave length 0.15418 nm) at 40 kV and 40 mA) patterns were characterized.

The alloys' tensile properties were tested via a RAAGEN tensile test machine with a strain rate of 10^{0}, 10^{-1}, 10^{-2}, 10^{-3} and 10^{-4} s^{-1}. The alloy's tensile results are the average value of three tests under each condition.

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3. RESULTS

3.1. Microstructural characterization

Fig. 1 depicts the X-RD results of the Mg-6Sn and Mg-6Sn-3Y alloys. The resulted patterns show that both α-Mg and Mg_2Sn intermetallic phases exists in both alloys. Furthermore, the peak of Sn_3Y_5 and MgSnY intermetallic phases was found with addition of Y element.

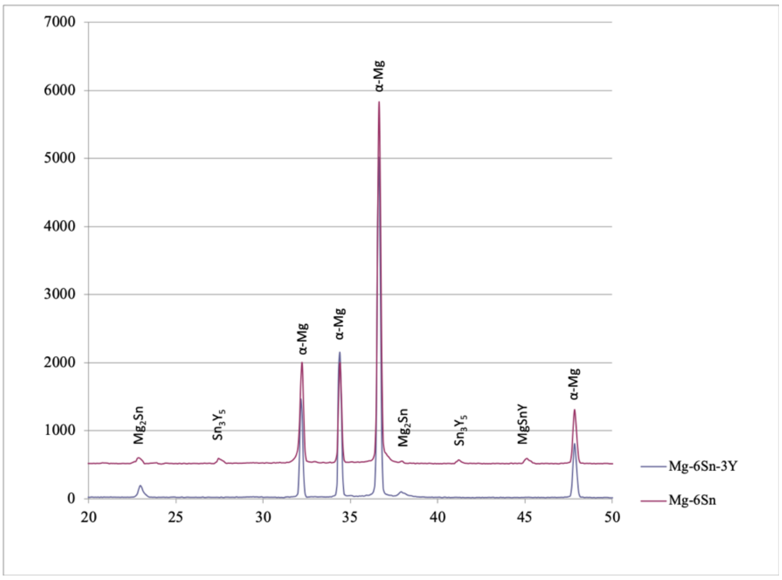
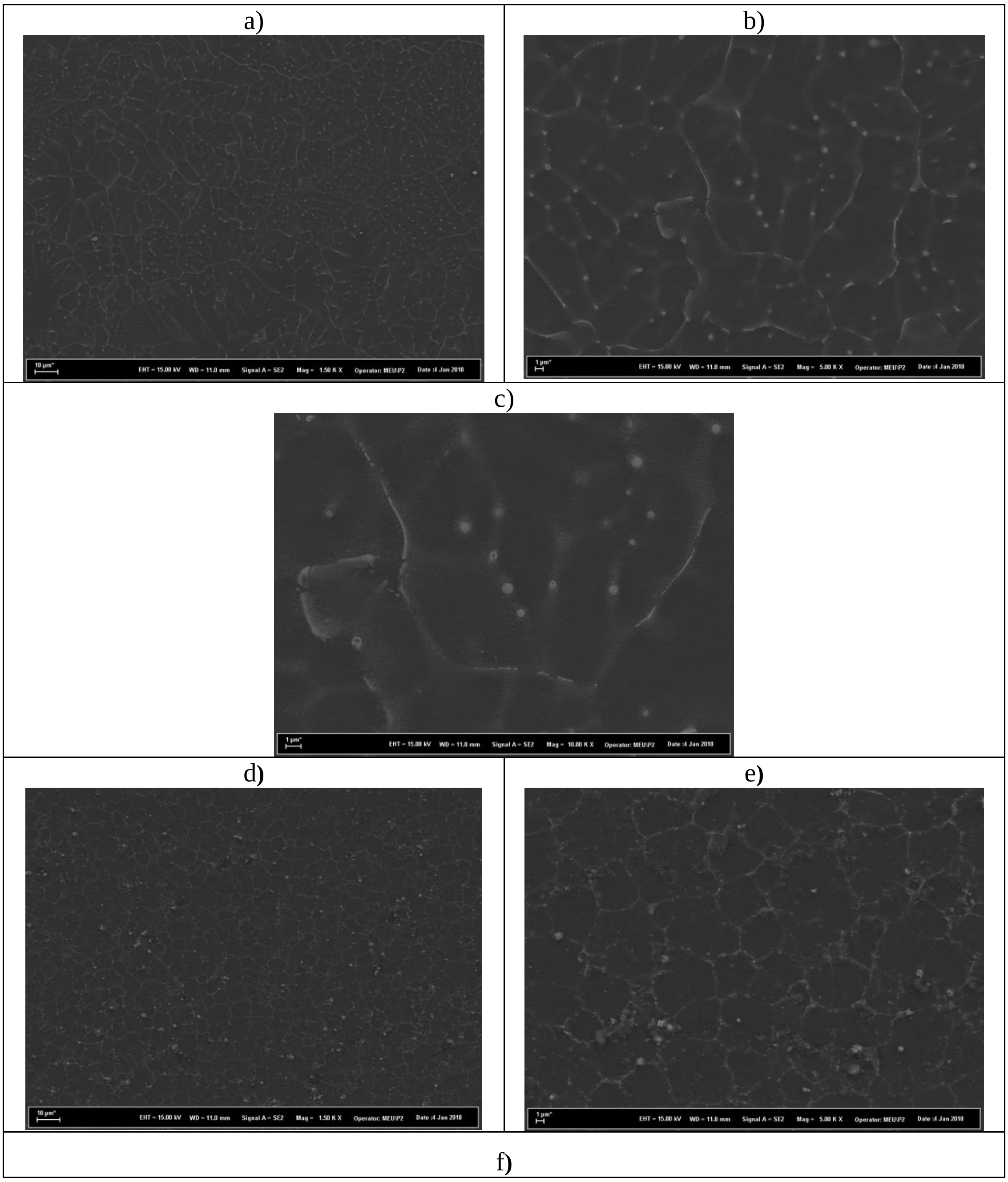


Figure 1. The X-RD results of the Mg-6Sn and Mg-6Sn-3Y alloys.

Fig. 2 shows the general microstructure of the Mg-6Sn (Fig. 2 a, b and c) and Mg-6Sn-3Y (Fig. 2 d, e and f) alloys. Microstructure images exhibit that the dendritic structured grains are dominant in the Mg-6Sn alloy. According to the phase diagram of Mg-Y binary alloy[18], there is limited solid solubility of Y in the magnesium matrix. Hence, Y atoms are pushed to the edge of the liquid /solid interface, which restricts the growing of grains and promotes new seed formation in the melt during solidification. Hence, the microstructural morphology of the Mg-6Sn alloy was changed from dendritic to globular with addition of Y.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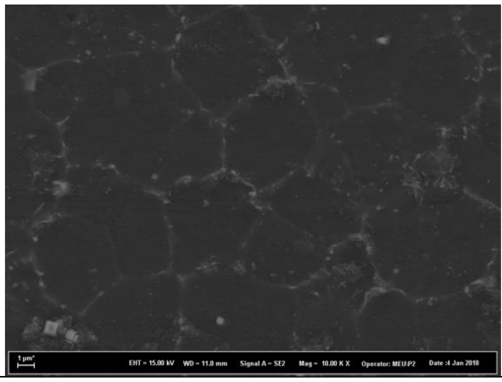
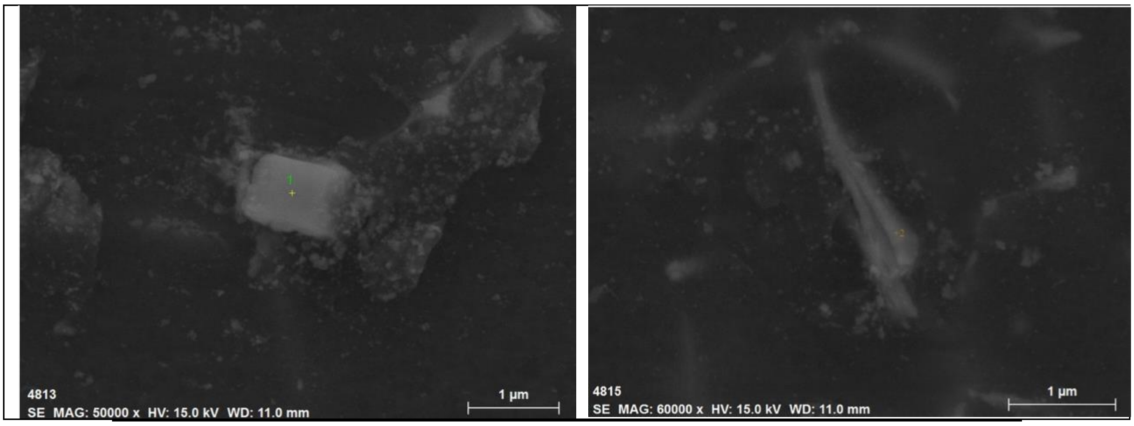


Figure 2. The SEM microstructure of experimental alloys; (a), (b) and (c) Mg-6Sn, (e), (f) and (g) Mg-6Sn-3Y.

Muthuraja et. al [19] have been thermodynamically computed the phase diagram of magnesium-yitrium-thin ternary alloy systems. They mentioned the prensence of the Sn_3Y_5 and MgSnY intermetallic phases in Mg-3Sn-15Y alloy. The EDS measurement of the Mg-6Sn-3Y alloy is shown in Fig. 3. Considering the atomic ratio of Sn to Y, the spot 1 could be idendified as MgSnY ternary intermetallic phase. Since spot 2 contains a higher amount of Y than the spot 1, it was thought that the spot 2 was Sn_3Y_5 intermetallic phase.



Spot No:	Chemical compositions, (at.%)			Atomic ratio	
	Sn	Y	Mg	Mg/Sn	Sn/Y
1	28.19	29.52	42.29	1.5	0.95

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2	11.03	14.98	73.99		5.94	0.73

Figure 3. The EDS measurement of the Mg-6Sn-3Y alloy.

3.2. Tensile properties

Fig. 4 exhibits tensile test curves at different strain rates ranging from 10^{-4} to 10^{0} s^{-1} for the Mg-6Sn and Mg-6Sn-3Y alloy, respectively. Table 2 depicts mechanical properties of the Mg-6Sn and Mg-6Sn-3Y alloys at different strain rate. It can be seen from Fig. 4 a and b the test curves of the both alloys that the yield strength value was decreased with declining strain rate, while the elongation of alloys increased with declining strain rate. Furthermore, the alloys' tensile strength was reduced with decreasing strain rate.

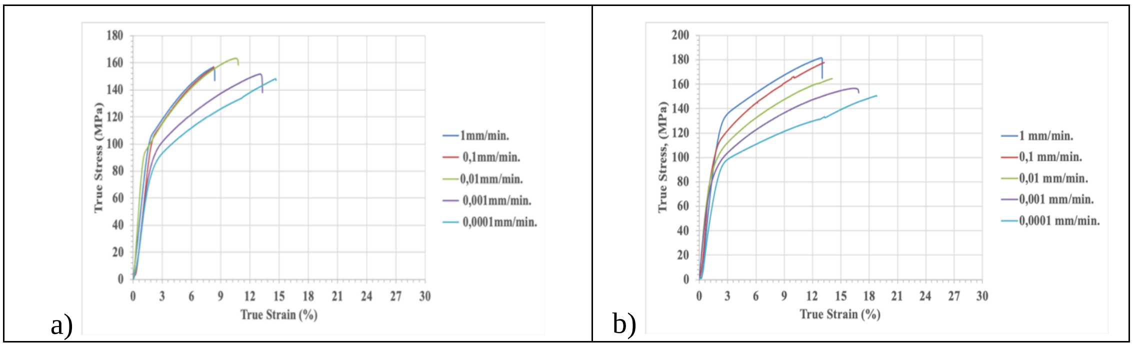

Figure 4. Stress-Strain curves of experimental alloys at different strain rate.

Table 2. The Alloys's yield, tensile and elongation to failure results at various strain rates.

Strain rate, (s^{-1})	Yield strength, (MPa)		Tensile strength, (MPa)		Elongation to Failure, (%)	
	Mg-6Sn	Mg-6Sn-3Y	Mg-6Sn	Mg-6Sn-3Y	Mg-6Sn	Mg-6Sn-3Y
10^{0}	108	137	156	186	8,32	13,01
10^{-1}	106	115	154	178	8,47	13,26
10^{-2}	96	111	152	164	10,72	13,96
10^{-3}	94	102	149	157	13,21	16,92
10^{-4}	84	96	146	153	14,53	18,81

3.3. Strain rate sensitivity (SRS)

The stress- strain curves can be used for describing the SRS exponent (*m*), which is determined by the following equation [8, 10, 20-21].

$$m = \frac{\ln\left(\frac{\sigma 1}{\sigma 2}\right)}{\ln\left(\dot{\varepsilon}1/\dot{\varepsilon}2\right)} \quad (1)$$

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where σ is the true flow stress at a given true strain rate $\dot{\varepsilon}$ under constant temperature and strain (ε). Fig. 5 shows variations of strain-rate sensitivity with true strain. It can be said that from Fig.5 strain-rate sensitivity rises with strain in both of the experimental alloys. Also, the Mg-6Sn-3Y alloy's SRS is found higher than that of the Mg-6Sn alloy for all strain value.

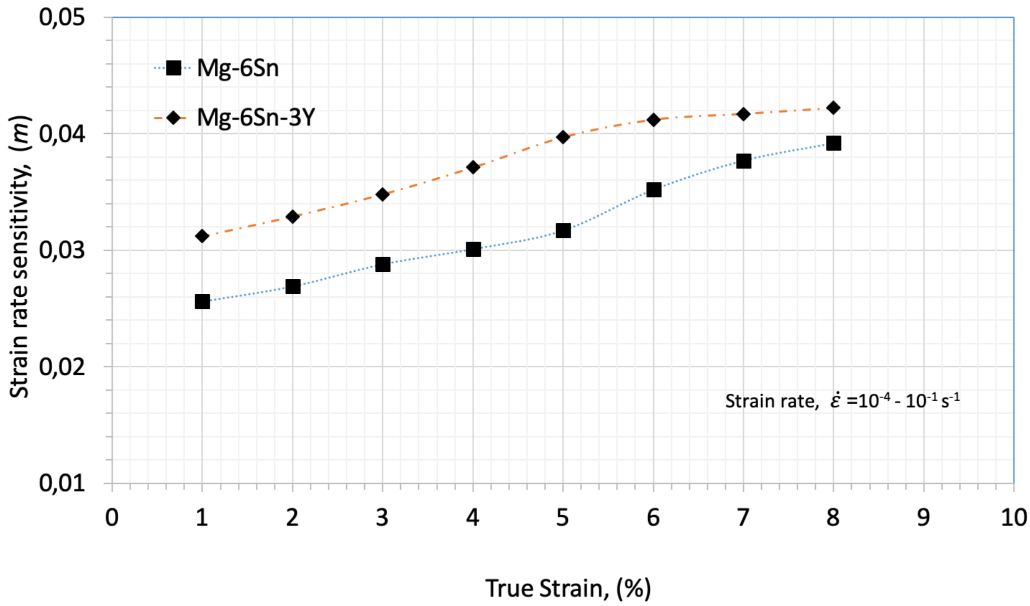

Figure 5. Variations of strain-rate sensitivity with true strain, $\dot{\varepsilon}=10^{-4}$ - 10^{-1} s^{-1}.

3.4. Fracture

Fracture morphology of Mg polycrystalline alloys apart from some Mg-Li based alloys is generally quasi-cleavage fracture or brittle through cleavage because of their h.c.p. crystal structure. The major plastic deformation mode occurs via dislocation slips on prismatic and basal planes as well as deformation twinning [3, 10, 22-24]. Fig. 6 exhibits the fractured surfaces of the Mg-6Sn (Fig. 6 a and b) and Mg-6Sn-3Y (Fig. 6 d and c) alloys at the lowest and highest strain rates. Largely, it was observed from Fig. 6 (a) and (b) that quasi-cleavage, tearing edges and dimples can be detected on the fractured surface of the main and Y content alloys. Furthermore, it can be said that more uniform dimples, which are much larger and deeper, can be observed on the Mg-6Sn-3Y fractured surface compared to that of the Mg-6Sn alloy. This result proved that the Mg-6Sn-3Y alloy displays a more ductile behavior.

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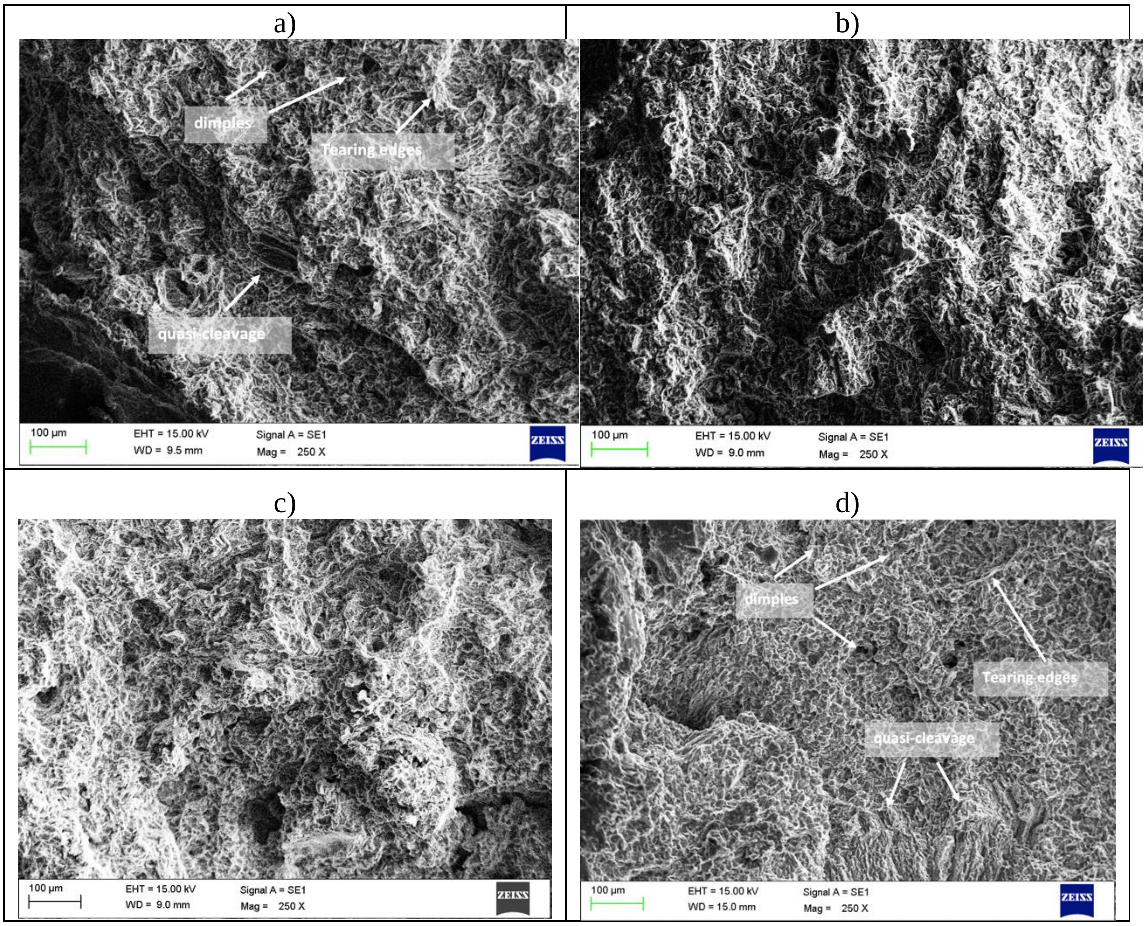

Figure 6. The fracture surfaces of (a) and (b) the Mg-6Sn and (c) and (d) Mg-6Sn-3Y alloys at the lowest and highest strain rates.

4. DISCUSSIONS

Obtained results showed that the Mg-6Sn-3Y alloy exhibited more plastic deformation behavior than Mg-6Sn alloy for all strain rates (Fig. 4). Furthermore, the strain rate sensitivity value of Y including alloy is higher than Mg-6Sn alloy for all strain rates (Fig. 5). The underlying cause in the Mg-6Sn-3Y alloy is probably the formation of new intermetallics (Sn_3Y_5 and MgSnY) and microstructure morphology (from dendritic structure to globular). Because, it is thought that the microstructural modifications were increased the density of dislocations, and the twins of deformation in the α-Mg grains. Additional newly formed twin boundaries from deformation twins probably play an important

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role for barriers to mobility of dislocations and stock the pile-up of dislocation, which could provide huge resistance to the more dislocation movement.

5. CONCLUSIONS

The conclusions as follows;

1. The α-Mg and Mg_2Sn intermetallic phases have found in both alloys. Moreover, the new Sn_3Y_5 and MgSnY phases were observed with the addition to Y.
2. The microstructure of Mg-6Sn alloy was changed from dendritic to globular with the addition of alloying element Y.
3. The main fracture mechanisms of the both alloys were the quasi-cleavage, tearing edges and dimples for both the alloys. In addition to this, the fractured surfaces of the Mg-6Sn-3Y alloy at high and low strain rates have more uniform dimples. It means that the Mg-6Sn-3Y alloy exhibits a more ductile behavior.

The strain rate sensitivity value of Y including alloy is higher than that of Mg-6Sn alloy for all strain. The underlying cause in the Mg-6Sn-3Y alloy is probably the formation of new inter-metallics and microstructure morphology (from dendritic structure to globular).

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