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The Effect of Si Addition on the Microstructure and Mechanical Properties of ZA-12 Alloy

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Abstract: A ZA-12 Zinc-based alloy was melted in an induction melting furnace, and cast in a graphite mold. Different amount of Si was added for examining the microstructural evolution and mechanical properties of ZA-12 alloy. All alloys were annealed at 350oC for 22 hours to investigate the effect of the heat treatment on the properties of ZA-12 alloy. The microstructure examinations revealed that while ZA-12 alloy has a dendritic microstructure with fine grains, with the Si addition the dendrite arms were broken. After annealing, it is observed that the grain size of the alloy was coarsened and Si particles were dispersed in the structure homogeneously. The Si addition was not altering the hardness of the alloys. The hardness of all alloys was decreased with the annealing. Compression tests were performed to determine the mechanical properties. These tests showed that the yield strength is decreased with Si addition, but remain constant with increasing Si content for as casted alloys. The yield elongation was decreased continuously with increasing Si content. The annealing heat treatment slightly decreased the yield strength of alloys. It was observed that all as-cast and annealed alloys were exhibiting ductile behavior.

Keywords: Zinc-based alloys, microstructure, hardness, compression strength.

Introduction

Zinc based alloys are very attractive engineering materials due to their low density, very good castability, low energy consumption for shaping, low cost and intermediate strength and hardness, etc. (Prasad et al. 1996, Pürçek et al. 2002). The commercial zinc-based alloys called ZAMAK, ALZEN, and ZA are binary Zn-Al alloys and include small amounts of Cu. These alloys are based on Zn-Al eutectic, eutectoid, or monotectoid composition. (Savaşkan et al. 2004).

Although their poor strength and hardness the Zn-Al alloys have been used widely in a variety of industries due to their excellent fluidity. With these alloys, very thin-walled and complex shaped parts can be cast using gravity or pressure die casting with/without heating the mold (Hanna et al. 1997). In recent years some works have been made intend to improve the strength and hardness of Zn-Al alloys. In these studies, some authors suggested the alloying of Zn based alloys (Prasad et al. 1996, Savaşkan et al. 2004, Pürçek et al. 2002, Hanna et al. 1997, Şevik 2014), whereas some of them suggested reinforcing the alloy with particulates or fibers (Pola et al. 2016, Li et al. 2001, Tao et al. 1995, Xu et al. 2014, Alaneme et al. 2017, Madronero et al. 1997, Almomani et al. 2016, Liu et al. 2009).

In addition to low strength and hardness low using temperature compared to other metallic materials limits the use of Zinc based alloys. Besides these properties, the Zn based alloys are an alternative material to bronzes which are used in tribological applications. It is reported that Zn based bearings have good wear and seizure

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resistance, and a lower coefficient of friction than bronzes under heavy load and slow to medium friction speed conditions. (Prasad et al. 1996).

Further studies have been focused on increasing the hardness, strength, and wear resistance of zinc-based alloys. Abou El-Khair et al. (2004) investigated the effects of Al content on the properties of the Zn-Al binary alloys. They reported that hardness, strength, and wear resistance of the alloy is increased with increasing Al content, however ductility was degreased. Furthermore, the strength is decreased and ductility is increased with increasing temperature for Zn-Al binary alloys. A higher strength at elevated temperature was also observed with increasing Al content.

Türk et al. (2007) modified the ZA8 commercial alloy with Pb, Sn, and Cd. The samples were subjected to the wear tests and the results were compared with commercial SAE 660 bearing bronze. They found that ZA8 and modified ZA8 alloys have higher wear resistance, but also a higher coefficient of friction than bearing bronze.

On the other hand, Savaşkan et al. (2014) investigated the effects of Cu and Si on the Zn-Al alloys. They increased the Si and Cu content systemically while the Al content was 15%. They found that the hardness, tensile, and compressive strength are increased whereas the elongation and impact energy was decreased with increasing Copper content for Zn-Al-Cu ternary alloys. For Zn-Al-Cu-Si quaternary alloys, the hardness and compressive strength were increased while the tensile strength, elongation, and impact energy were decreased with increasing Si content.

In this study, ZA-12 alloy was produced by casting and heat treatment was applied to the alloy. The effects of the applied heat treatment on the microstructure and mechanical properties of the alloy were investigated. Also, Si was added to the alloy systematically at increasing rates and heat treatment was applied to these alloys.

Method

Zinc alloy ZA-12 at the nominal composition of 88%Zn, 11.0%Al, and 1.0%Cu (wt%) and alloys modified with Si addition (Table 1) were produced in an induction melting furnace. First, Zn was melted and then Al and Cu were added. Also, ZA-12 alloys modified with Si by adding increasing amounts of Si were produced in the same way. The melted alloy was cast into a graphite mold and cooled in air. In this way, samples of 10 mm diameter and 100 mm length were obtained by casting. All cast alloys were annealed at 350 ^{o}C for 22 hours and quenched with water.

Axial compression tests and hardness measurements were applied to determine the mechanical properties of cast and annealed specimens. The compression test specimens were formed by machining. Compression tests were conducted at room temperature and a jaw speed of 10mmmin^{-1}. Hardness measurements were made by applying the Vickers tip for 10 seconds with a 1kgf load. Microstructural evolution was investigated using a light optical microscope (LOM).

Table 1. The nominal compositions of the alloys (wt.%)

Alloy	Zn	Al	Cu	Si
ZA-12	88.0	11.0	1.0	0
ZA-12+0.5Si	87.5	11.0	1.0	0.5
ZA-12+1Si	87	11.0	1.0	1.0
ZA-12+2Si	86	11.0	1.0	2.0

Results and Discussion

The Zn-Al phase diagram and the annealing temperature corresponding to the alloy composition are shown in Figure 1. The crystal structures of the existing phases are written in the figure. According to the Zn-Al phase diagram, the Zn-Al alloy with 11 wt.% Al contains phases α and η at room temperature. At 350 ^{o}C there are β and η phases. In practice, the phase β can be found in addition to α and η at room temperature depending on the cooling rate.

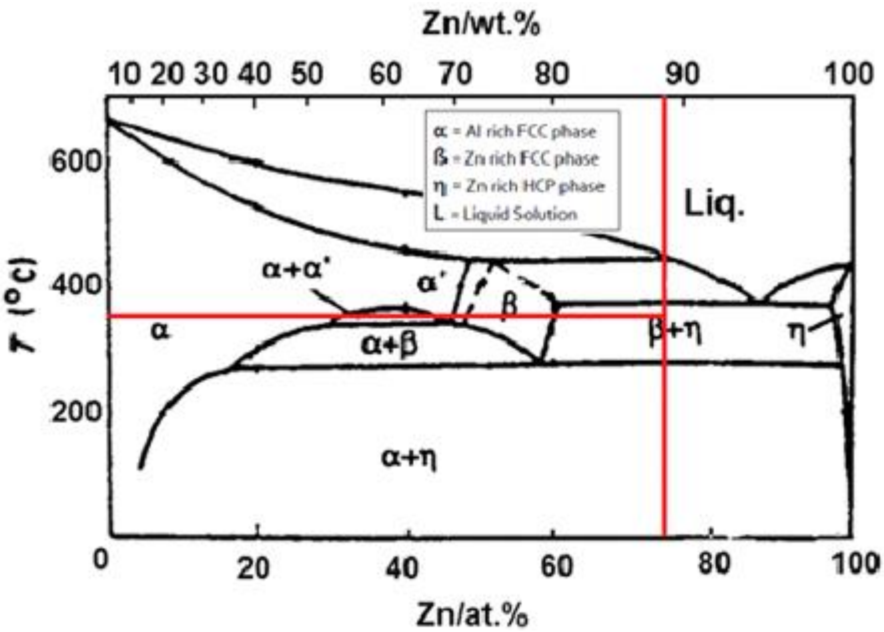
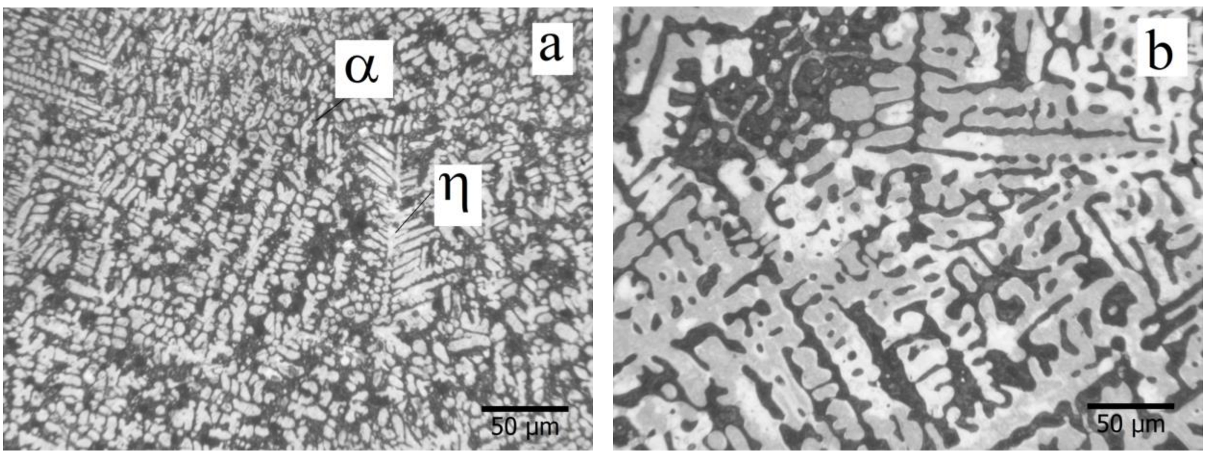


Figure 1. The Al-Zn phase diagram.

Microstructure

According to the Zn-Si phase diagram, Zn and Si have no solubility in each other. On the other hand, according to the Al-Si phase diagram, Si can dissolve in Al maximum 1.6wt.% at the eutectic temperature of 557 ^{o}C, but there is no solubility at the room temperature again. The microstructures of the cast and annealed alloys have taken with the LOM are shown in Figure 2. All microstructure photos were taken at the same magnification. In the figure, it is seen that the ZA-12 alloy has a dendritic structure with very small fine particles. There are short and long dendrite arms in the microstructure. It is seen that the dendritic structure is preserved and the η phase expands after annealing (Figure 2a, b). Si addition does not affect the microstructure significantly. In small amounts, only dendrite arms are shortened. In high Si contents, Si was dispersed in the matrix as small particles. The microstructure of the Si-containing alloys after annealing is similar to the ZA-12 alloy. The only difference is that in annealed alloys, dendrite arms are shortened and Si particles become more pronounced (Figure2h).



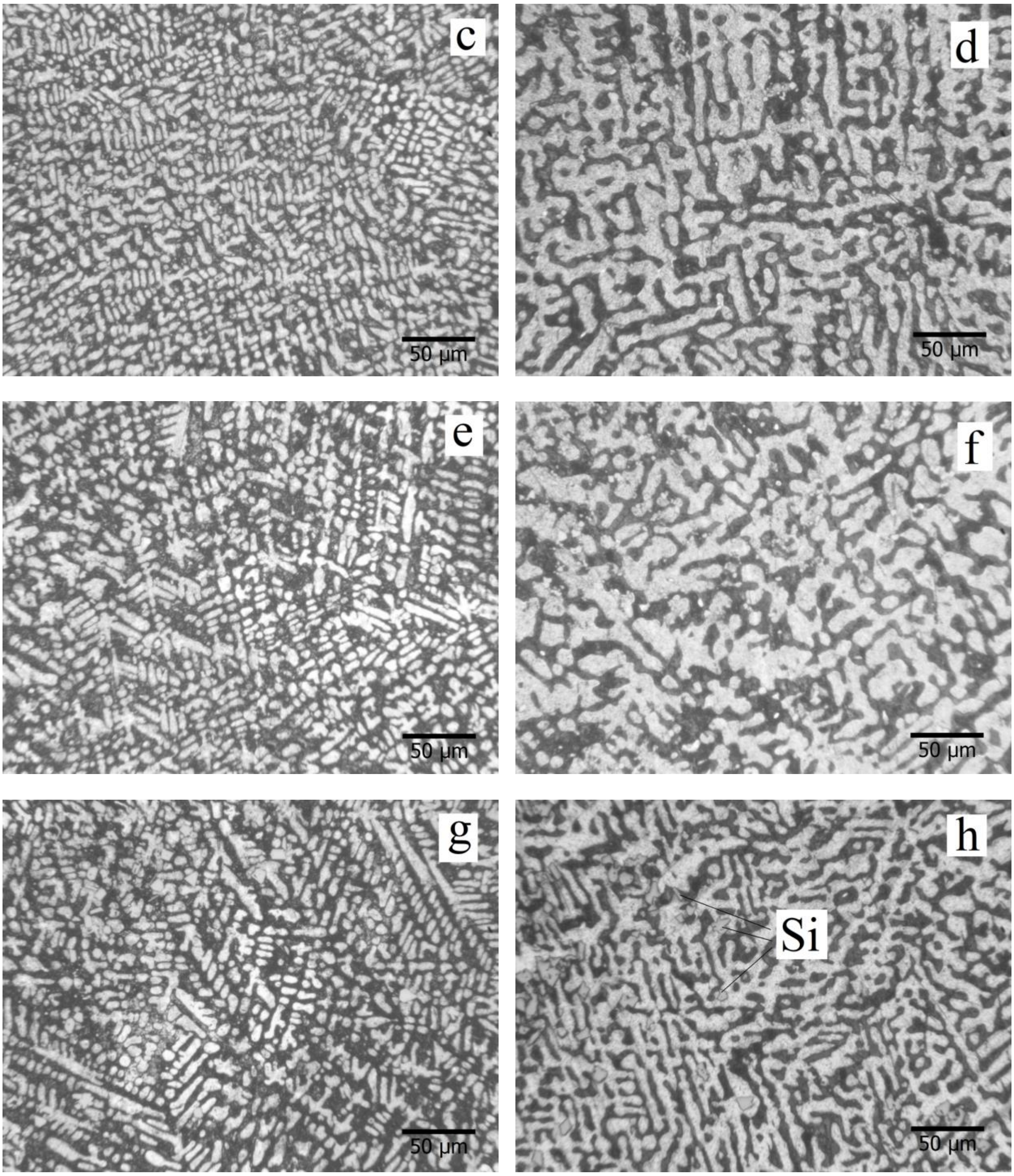


Figure 2. The LOM micrographs of the as-cast and annealed alloys. a) ZA-12 as-cast, b) ZA-12 annealed, c) ZA-12+0.5Si as-cast, d) ZA-12+0.5Si annealed, e) ZA-12+1Si as-cast, f) ZA-12+1Si annealed, g) ZA-12+2Si as-cast, and h) ZA-12+2Si annealed.

Compression Strength-Strain and Hardness

The compression test results and hardness values are listed in Table 2. The methods used in the determination of mechanical properties are shown on the compression stress-strain curves in Figure 3. All alloys behaved similarly to figure 3. The effect of Si addition on the mechanical properties of the ZA-12 alloy can be seen in Figures 4 and 5.

As can be seen from the table, the yield strength, yield elongation, hardness, and elasticity module of ZA-12 alloy increased with the annealing process. On the other hand, the strength (σc) and strain (εc) at the constant plastic deformation rate limit, and the amount of plastic deformation (εp) decreased. These changes in the mechanical properties are caused by the changes in the microstructure of the ZA-12 alloy with the applied heat treatment. Probably, the increase in the amount of β phase at room temperature as a result of rapid cooling after annealing at 350°C resulted in these results. It is seen in Figures 2a and b that the amount of phase α decreases after annealing.

Table 2. The mechanical properties of the alloys in as-cast and annealed form.

	As-cast							Annealed						
	%0.2 Yp		Consatant plastic deformation rate		εp	H	E	%0.2 Yp		Consatant plastic deformation rate		εp	H	E
Alloy	σ,MPa	ε,%	σ,MPa	ε,%	%	HV	MPa	σ,MPa	ε,%	σ,MPa	ε,%	%	HV	MPa
ZA12	495	2.35	990	49.64	62	128	226	530	2.66	860	38.38	57	144	228
ZA12+0.5Si	315	1.97	735	44.26	56	116	207	289	1.56	567	34.19	62	91	209
ZA12+1Si	314	1.88	724	45.95	59	125	211	290	1.61	553	33.67	56	92	212
ZA12+2Si	303	1.67	686	47.05	57	124	221	286	1,62	545	35.10	54	97	203

The addition of Si at increasing rates to the ZA-12 alloy generally resulted in a slight decrease in mechanical properties. There was no significant change in the mechanical properties with the additional annealing process. Si added alloys exhibited similar deformation behavior to the ZA-12 alloy. The reason for this is that Silicium forms a solid solution with neither Zinc nor Aluminum. Si is present in the structure as separate particles dispersed in the matrix (Figure 2c-h).

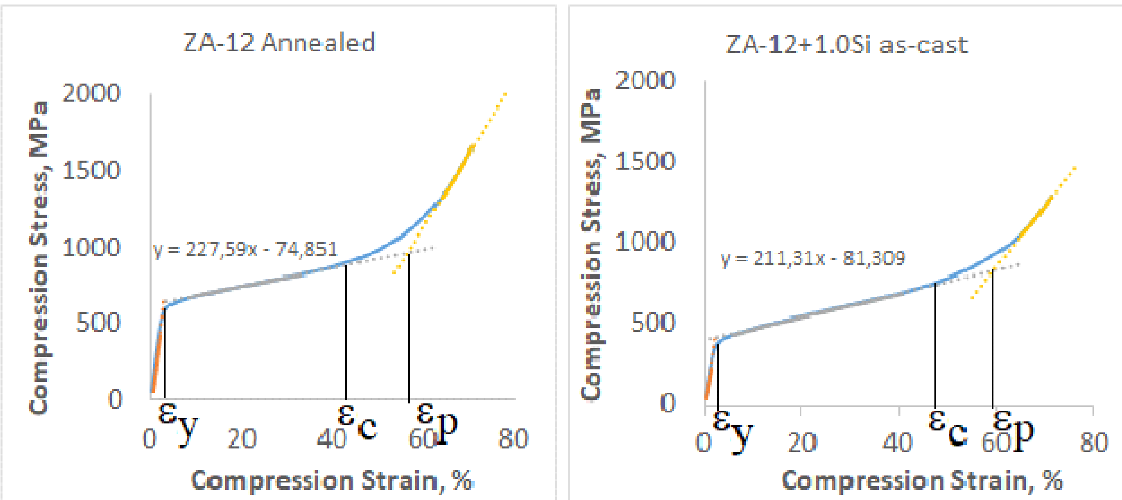


Figure 3. The compression stress-strain curves of some alloys

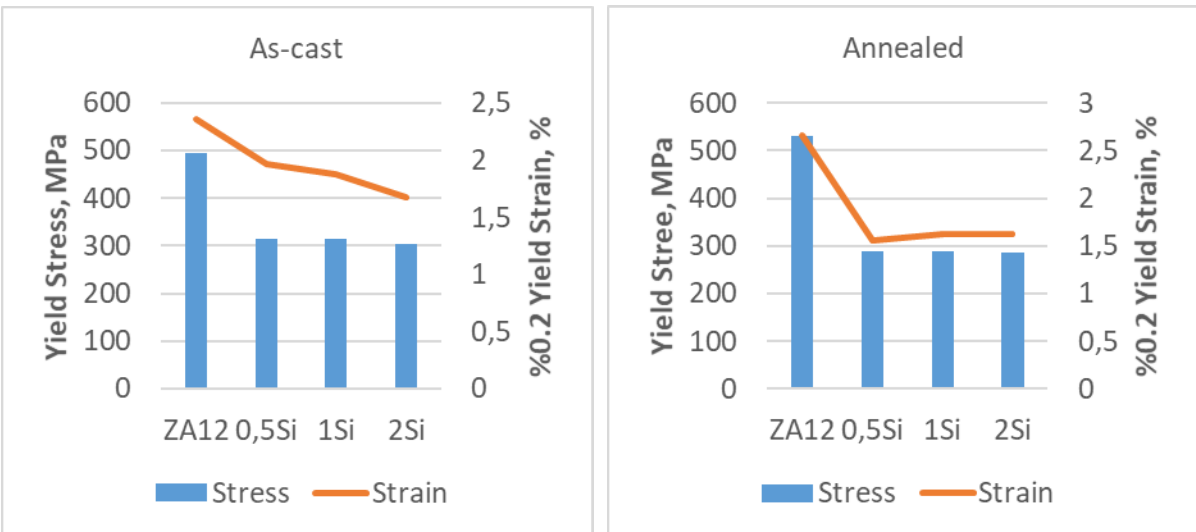


Figure 4. The compression yield strength and strains (εy) of the alloys

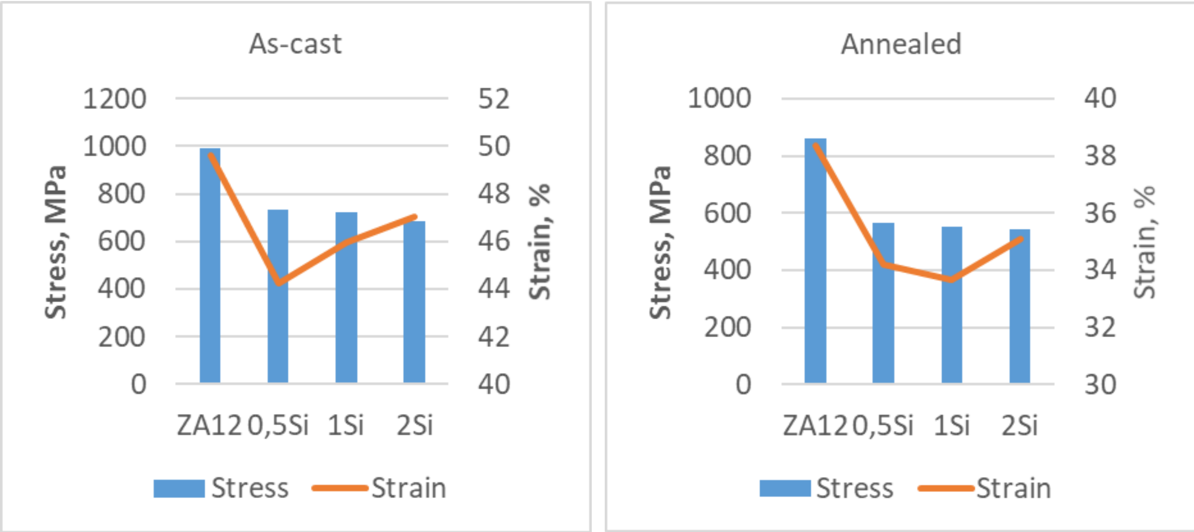


Figure 5. The constant plastic deformation rate limits (εc) of the alloys.

Conclusion

Increasing amounts of Si were added to the commercial ZA-12 zinc alloy and the effect of Si addition on the microstructure and mechanical properties of the ZA-12 alloy was investigated. ZA zinc alloys are only considered as-cast alloys. However, it is known that the microstructure and mechanical properties of many alloys can be changed by heat treatment. This study revealed that the microstructure and mechanical properties of the ZA-12 alloy changed significantly with the annealing heat treatment, whereas the alloys modified with Si were not. It was observed that the mechanical properties of ZA-12 alloy improved only with solution heat treatment. The Si-added alloys were had similar deformation behavior to ZA-12 alloy. The Si addition did not make the alloy more brittle.

Recommendations

Advanced studies such as SEM-EDS and XRD are required to determine the phases in the alloy microstructure. The sliding friction and wear properties of annealed and Si added alloys should be revealed.

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