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Microstructural Evolution and Mechanical Properties of Mg Added 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 Mg was added for examining the microstructural evolution and mechanical properties of ZA-12 alloy. All alloys were annealed at 350oC for 22 hours to research the effect of 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 Mg addition the distance between dendrite arms was getting larger. The hardness of alloys was increased with an increase in Mg content. The hardness of all alloys was increased slightly with the annealing also. Compression tests were performed to determine the mechanical properties. These tests showed that the yield strength and elongation are increased with increasing Mg amount for as casted alloys. The annealing heat treatment decreased the yield strength of alloys. A brittleness was observed for as-cast alloys containing more than 2.0wt.% Mg. The brittleness was still existing after heat treatment for alloy including 4.0 wt.% Mg while the alloy containing 2.0 wt.% of Mg became ductile.

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

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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, Mg was added to the alloy systematically at increasing rates and heat treatment was applied to these alloys.

Method

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

Mechanical characterization of cast and annealed specimens was done by axial compression tests and hardness measurements. Compression test specimens are 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. A light optical microscope (LOM) was used to examine the changes in microstructure.

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

Alloy	Zn	Al	Cu	Mg
ZA-12	88.0	11.0	1.0	0
ZA-12+0.5Mg	87.5	11.0	1.0	0.5
ZA-12+1Mg	87	11.0	1.0	1.0
ZA-12+2Mg	86	11.0	1.0	2.0
ZA-12+4Mg	85	11.0	1.0	4.0

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 phases are seen in the figure. According to the Zn-Al phase diagram, the Zn alloy containing 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 solidification conditions.

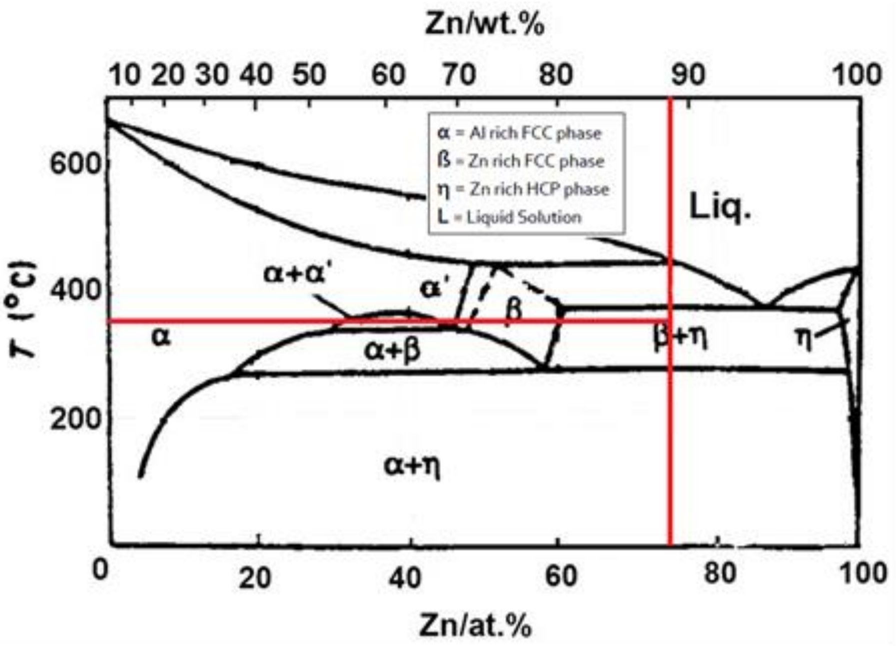
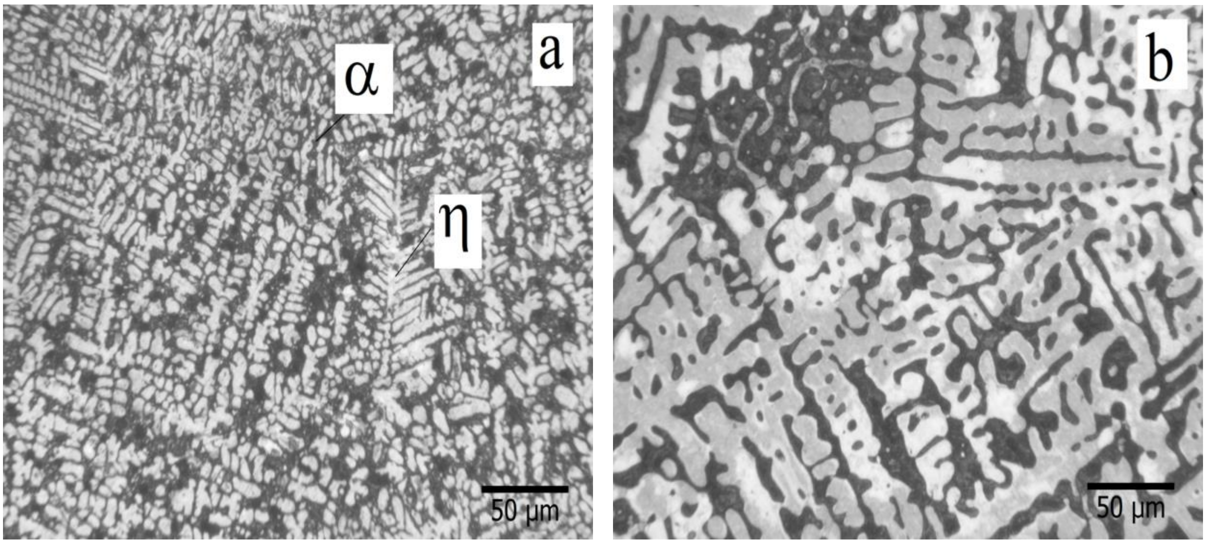
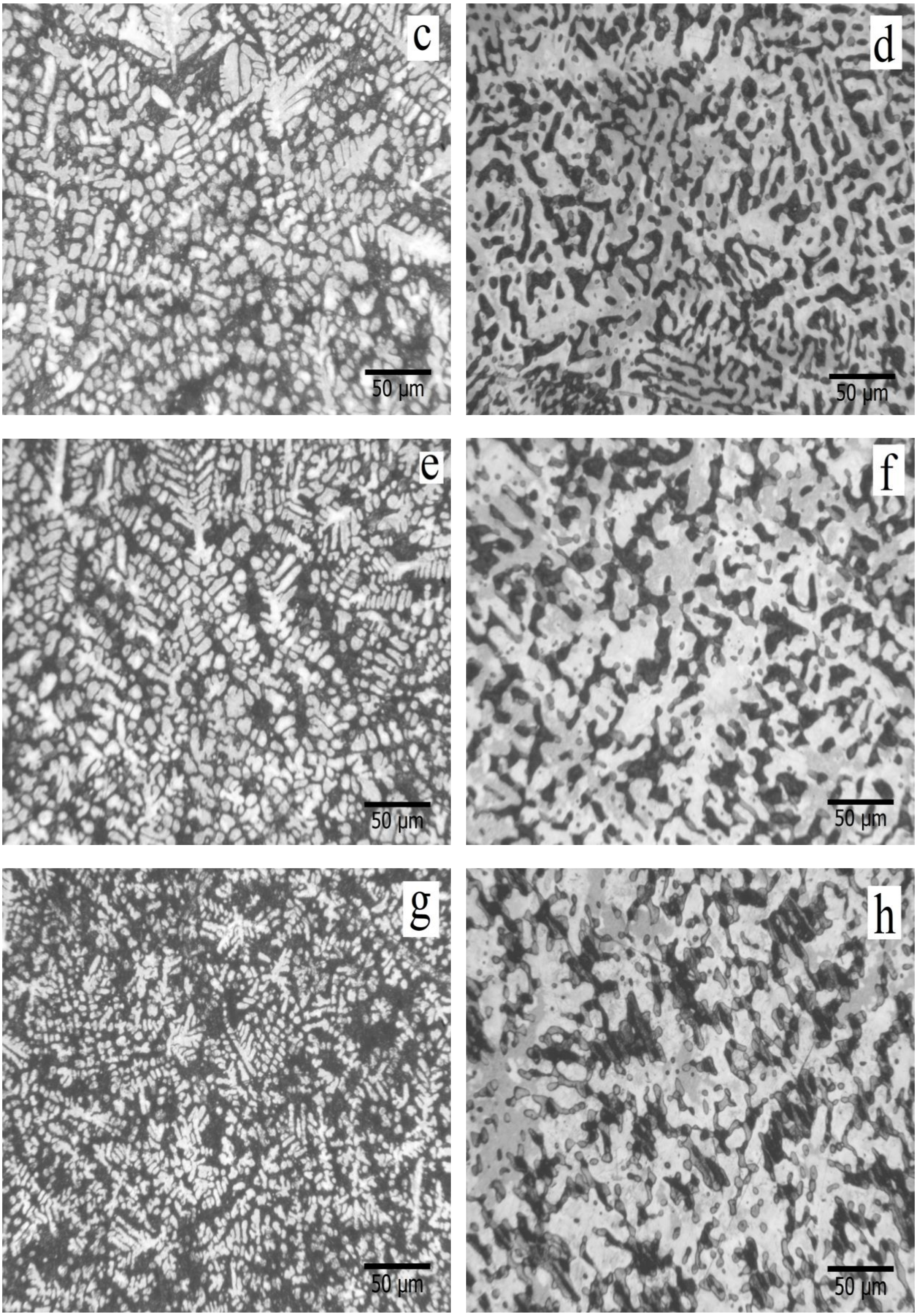


Figure 1. The binary phase diagram of the Al-Zn system.

Microstructure

The microstructures of the cast and annealed alloys obtained from the optical microscope 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. It is seen that the dendritic structure is preserved and the η phase expands after annealing (Figure 2a, b). When Mg is added to ZA-12 alloy in as-cast form, the dendritic structure deteriorates as the amount of Mg increases (Figure 2 c, e, g, i). In the ZA-12 alloy containing 4 wt.%Mg, the η phase appears to have a rosette-like growth. Also, a new phase appears in gray. In the literature, it is recommended to keep the amount of Mg low in Zinc-based alloys. Because Mg makes the alloy brittle. After the Mg containing alloys are annealed, it is seen that the dendritic structure is destroyed and the grains become coaxial. After the heat treatment, the new phase formed together with the α phase dispersed at the boundaries of the η phase became prominent. The particle size of the η phase decreases with increasing Mg amount.

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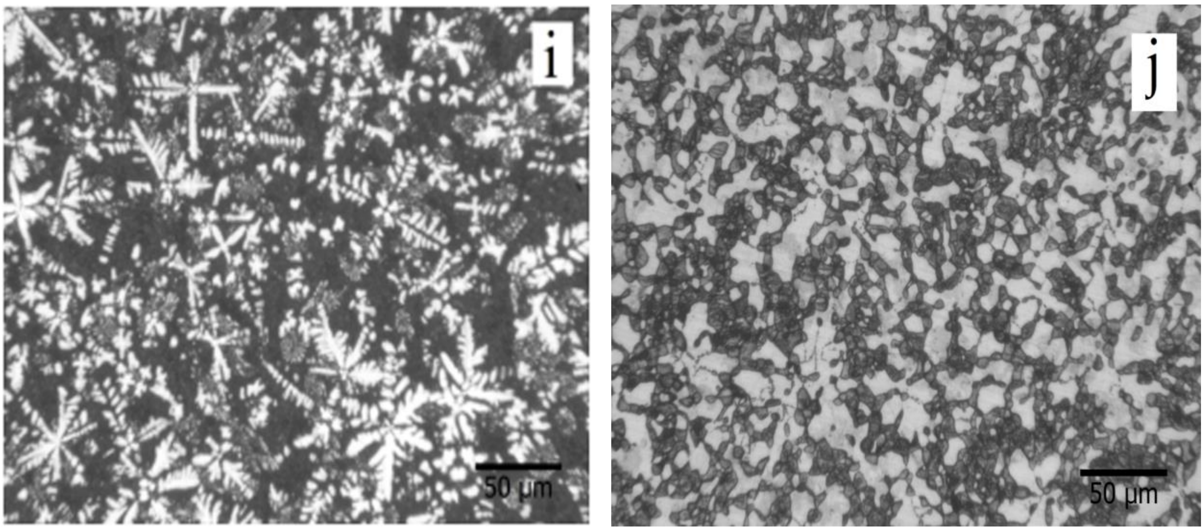

Figure 2. The LOM micrographs of the as-cast and annealed alloys. a) ZA-12 as-cast, b) ZA-12 annealed, c) ZA-12+0.5Mg as-cast, d) ZA-12+0.5Mg annealed, e) ZA-12+1Mg as-cast, f) ZA-12+1Mg annealed, g) ZA-12+2Mg as-cast, h) ZA-12+2Mg annealed, i) ZA-12+4Mg as-cast, j) ZA-12+4Mg annealed

Compression Strength and Hardness

The compression test results and hardness values are summarized in Table 2. The methods used in the determination of mechanical properties are shown on the stress-strain curve obtained as an example of the compression test of the ZA-12 cast alloy given in Figure 3. All alloys, except the brittle alloys, behaved similarly to figure 3. The stress-strain curve of a brittle alloy is given in Figure 4.

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+0.5Mg	551	2.43	896	39.52	58	134	240	580	2.58	792	32.60	56	153	246
ZA12+1Mg	602	2.72	850	32.57	58	146	244	634	2.56	764	29.50	53	154	258
ZA12+2Mg	650	2.72				175	221	668	2.55	797	28.40	58	170	241
ZA12+4Mg	759	2.76				199	306	678	2.56				183	279

As can be seen from the table, when the amount of Mg addition to the cast alloy increased, the yield strength and strain, hardness, and Elasticity Modulus increase. But, the stress and strain values at the limit of constant plastic deformation rate and the plastic deformation limit (εp) are decreased. While cast alloys containing up to 1wt.% Mg show ductile behavior, alloys containing more than 1wt.% Mg was quite brittle. Interestingly, the alloy containing 2wt.%Mg, which was brittle in its cast form, gained ductile character at the end of the annealing process, while the alloy containing 4wt. %Mg remained brittle.

The annealing heat treatment affects the mechanical properties of alloy ZA-12 and alloys modified with Mg. In the case of annealing at 350 ^{o}C and rapid cooling in the alloy without Mg addition, the yield strength and elongation, hardness, and elastic modulus increase, while the strength and elongation at the constant plastic deformation rate limit and the plastic deformation limit decrease. The increase in the amount of β phase in the alloy may have caused this result. While the yield strength increased with increasing Mg addition in annealed alloys, 0.5wt.% Mg addition increased the yield elongation but adding more Mg resulted in a decrease in yield elongation. Hardness and Elasticity Modules of annealed alloys are higher than cast alloys. Annealing has also reduced the plastic deformation limits of all alloys.

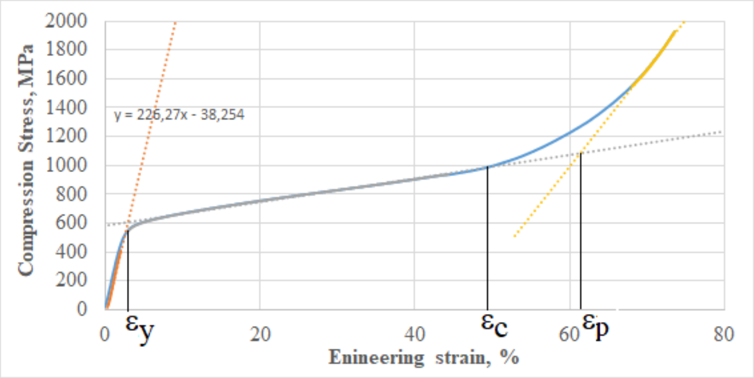

Figure 3. The stress-strain curve of as-cast ZA-12 alloy.

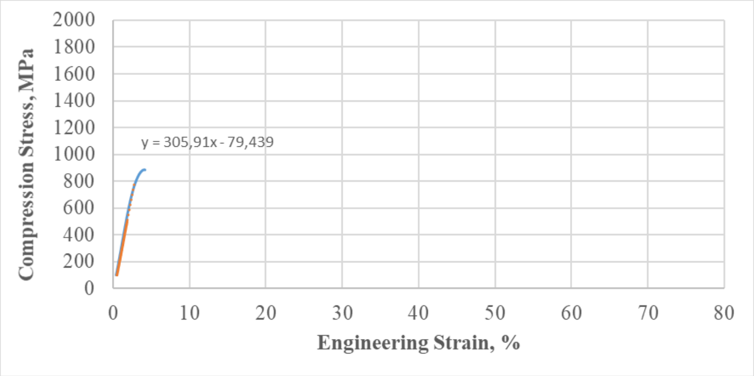

Figure 4. The stress-strain curve of as-cast ZA-12 alloy including 4 wt. % Mg

Conclusion

Increasing amounts of Mg were added to the commercial ZA-12 zinc alloy and the effect of Mg 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 metal alloys can be changed by heat treatment. This study revealed that the microstructure and mechanical properties of the ZA-12 alloy and the Mg modified alloys changed. It was observed that the mechanical properties of ZA-12 alloy improved only with solution heat treatment. The Mg-added alloy, which was evaluated as brittle, could be made ductile by heat treatment.

Recommendations

Advanced studies such as SEM-EDS and XRD are required to determine the phases in the alloy microstructure.

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