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Characterization of Modified ZA Alloys with Si Addition

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Abstract

Zinc-based alloys have found many applications in recent decades. Such alloys are characterized by low melting points and high fluidity which make them suitable for foundry applications. The current study was carried out to select ZA alloys, typically ZA-8, ZA-12 and ZA-27. The effect of casting temperature, Al content, Si addition, and heat treatment on the properties of selected alloys was investigated. The result reveals that an increase in casting temperature enhances the measured hardness for all studied alloys. Also, the presence of Si in alloys in addition to the increase of Al content in alloys seems to improve the hardness and mechanical properties of alloys. Heat treatment of such a group of alloys had an adverse effect on the final properties of the alloy, as the heat treatment samples show a lowering in hardness compared to as cast samples. In addition, it was found that using of water as a cooling media instead of air enhances the final hardness of all alloys.

Introduction

In 2022, approximately 13.3 million metric tons of refined zinc metal in total was produced worldwide [1]. About 15% of world zinc is used as the base metal for the production of zinc-base alloys [2]. Zinc-based alloys possess unique properties such as low melting temperature, combined to a high fluidity, which makes them variable for complexed shapes and thin section casting, typically as low as 0.75 mm or even down to 0.13 mm [3].

Zinc alloys are used for building and architectural applications such as rainwater systems, claddings, fittings, and roofing [4]. Zinc alloys also find application as sacrificial components such as fuses, shear bolts/pins, and sacrificial anodes in corrosion protection [5]. Zinc alloys were also used in certain types of machine bearings, die-casting, and stamping dies, medical equipment, rubber products, paint pigments, and ceramics [6].

zinc alloys were produced based on a hypoeutectic composition with aluminum content less than about 6.0% Al (Eutectic point). Also, a family of hypereutectic zinc-aluminum alloys with higher aluminum contents (>6.0%Al), have become widely used as die-casting alloys. These alloys were originally designed as gravity-casting alloys [7]. Such alloys possess a higher strength than the hypoeutectic zinc alloys. Among the most used ZA casting alloys are ZA-8, ZA-12 and ZA-27. These alloys are zinc-based with high Al contents and minor alloying elements such as copper and magnesium [8]. The numerical digits (8, 12, and 27) represent the approximate percentage of Al in each. High Al content as well as improved properties and wider casting process choice, distinguishes the ZA family from standard zinc “ZAMAK” die-casting alloys [2, 9].

ZA alloys possess high tensile strength and hardness, which makes them suitable as alternative materials to cast iron, bronze, aluminum, and steel fabrications [10]. The strength range can be up to 64,000 psi depending upon alloy composition and process selection. Also, ZA materials possess good corrosion resistance under atmospheric conditions, and in various aqueous solutions and industrial and petroleum products [11]. The corrosion resistance of the ZA alloys is close to common grades of aluminum. Surface treatments such as chromating, plating, painting, and zinc anodizing provide additional corrosion protection.

Dimensional change due to residual stress or metallurgical instabilities can result in a change of critical dimensions in many alloy systems. Fortunately, residual stresses in ZA alloy are usually minimal due to low casting temperatures [12].

The current study aims to evaluate the change in mechanical and surface properties of the most applicable ZA alloys, with verification of casting temperature and heat treatment process and addition of Si to its content.

Materials and Methods

Alloys under the current study were selected according to market demand from ZA alloys. The selected alloys have the nominal composition as in Table 1

Table 1: Nominal chemical composition of selected zinc-based alloys (According to ASTM B86).

Name/ composition	Al	Cu	Mg	Fe(max)	Pb(max)	Sn(max)	Cd(max)	Zn
ZA-8	8.0-8.8	0.8-1.3	0.01-0.03	0.075	0.006	0.003	0.006	Rest
ZA-12	10.5-11.5	0.5-1.2	0.01-0.03	0.075	0.006	0.003	0.006	Rest
ZA-27	25.0-28.0	2.0-2.5	0.01-0.02	0.075	0.006	0.003	0.006	Rest

Experimental procedure

For casting the three different ZA alloys (ZA-8s, ZA-12s and ZA-27s), AlSi7Mg alloy, and Zinc with 99.96% Zn was used.

Firstly, bulk Al alloy and Zn ingots were cut off into small pieces. Weighting according to each alloy composition requirement, putting the weighted materials of Zn and Al respectively and loaded into the furnace at selected temperature. After melting of the component, the Cu powder was added to the alloy and stirred. After 1 hour, the crucible was taken out of the furnace and slag was scraped. The melt is cast into a steel mold and cooled down. Casting of each alloy was carried out at three different temperatures (750, 800, and 850 ºC). All casting conditions are listed in Table 2.

After casting, samples were ground up to 800 mesh with SiC paper and polished for like mirror surface. Hardness Vickers for microhardness, as well as Rockwell C Macro Hardness Testing, were applied.

Table 2: Casting conditions for all produced samples.

Sample No	Alloy	wt. [Zn], gm	wt. [AlSi7Mg], gm	Temp. ºC
1	ZA-27s	86	31.3	750
2	ZA-12s	74	10.3	
3	ZA-8s	98	8.1	
4	ZA-27s	67	26	800
5	ZA-12s	121	17.5	
6	ZA-8s	97	8.5	
7	ZA-27s	66	25.4	850
8	ZA-12s	99	13.8	
9	ZA-8s	93	8.1	

Heat treatment

heat treatment had been done to investigate the effect of the heat treatment process/Temperature as well as cooling media (water or air) on the samples' final hardness.

The heat treatment was applied for the three different ZA alloys (ZA-8s, ZA-12s and ZA-27s). Each was cut off into two parts, one part was treated at a temperature of 250 ºC and another at 350 ºC. The treatment was holed in the furnace for 1.5 hours. Heat treatment temperatures were suggested by others [13-15].

To study the effect of cooling media/rate, sample No. 7 was cut off into four parts, two of which are placed in the furnace at a temperature of 250 ºC (one part is cooled in air, and another in water), and the other two parts treated at 350 ºC (part of which is also cooled in air and the other part in water). The time of heat treatment for all samples was 1.5 hours. After heat treatment, the samples were ground and prepared for hardness testing and microscopic examination. The etching agent used was Nital etchant.

Results and Discussion

Effect of casting temperature and Al content on alloy properties

The selected ZA alloys were prepared and cast with different Al content (ZA-8s, ZA-12s, and ZA-27s)

The selected alloys were modified by adding silicon to alloys (with about Si 7% from Al content) and the final alloys have calculated composition shown in Table 3. The proven composition was analysed by XRF methods for ZA-27s alloy and shown in Table 4.

Table 3: The calculated chemical composition of selected zinc-based alloys.

Name/ composition	Al	Si	Cu	Zn
ZA-8s	7.3-8.2	0.60	0.8-1.3	Rest
ZA-12s	9.5-10.5	1.0	0.5-1.2	Rest
ZA-27s	25.0-27.0	2.0	2.0-2.5	Rest

Table 4: Composition of ZA-27s alloy by XRF technique.

Name/ composition	Al	Si	Cu	Mg	Fe	Mn	Zn
ZA-27s	23.0	2.4	3.0	0.10	0.09	0.03	Rest

When comparing the estimated and measured compositions for the ZA-27s alloy, Tables 3&4 show that the alloy compositions were produced almost precisely.

All three samples were cast at three different temperatures (750, 800, and 850 ºC). The temperature range for the study was chosen according to preliminary experiments and the higher temperature was limited to 850 ºC to minimize Zn losses. The result of hardness (both RCH and HV) was used for testing the produced samples. The improvement of hardens values indicates improvement of other mechanical properties (tensile strength) according to ASTM e140.

Figure 1a&b show hardness for all samples (both RCH and HV) with different casting temperatures.

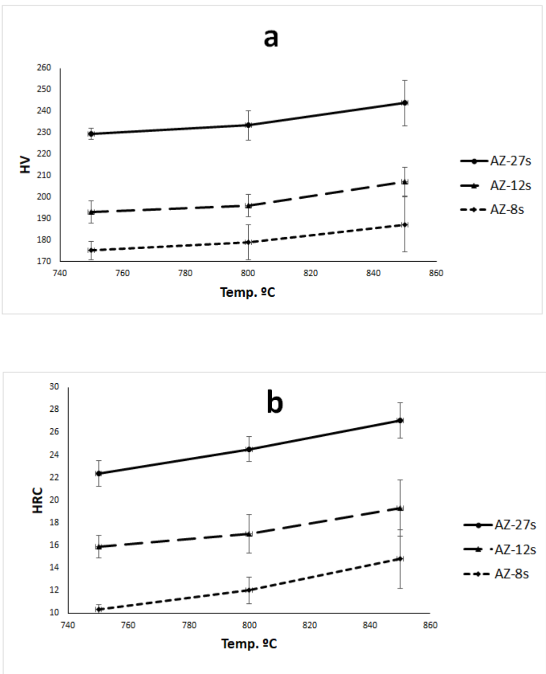

Figure 1-a,b Effect of AL content on hardness in ZA alloys.

As can be observed from Rockwell Hardness results shown in Figure 1a, the hardness value of ZA-27s alloy changed from 22.38 HRC at 750 ºC, 24.52 HRC at 800 ºC and maximized to 27.08 HRC at 850 ºC of casting temperature.

For ZA-12s and ZA-8s alloys, the same effect of casting temperature can be observed. The three alloys show that the hardness HRC was increasing with increasing casting temperature. The same results for 7075 aluminum alloy were achieved by others [16].

A plot of the samples' microhardness values (HV) is presented in Figure 1-a. The HRC data are shown in Figure 1-b. A comparable pattern is evident in every outcome. For ZA-27s alloy, it shows the maximum HV results compared to other alloys (ZA-12s and ZA-8s). ZA-27s alloy shows 229 HV at 750 ºC, 233 HV at 800 ºC and the maximum was 243 HV at 850 ºC of casting temperatures.

As shown in Figure 1-a,b, the hardness of samples produced at higher temperatures results in higher hardness. Higher temperature allows for more solubility of copper in the matrix. as well as the presence of Si in alloys which promotes final alloys hardness [17, 18].

As can be noticed from the above results in compared to hardness values for nominated alloys (ASTM B86), the modified alloyed hardness improved remarkably by adding Al-Si instead of pure Al to the alloys. According to ASTM B86, the highest hardness for the standard selection of ZA alloys was ZA-27, with a BH of 119, or roughly HV 125. This indicates that the addition of Si element to the alloys improved the hardness of the produced samples.

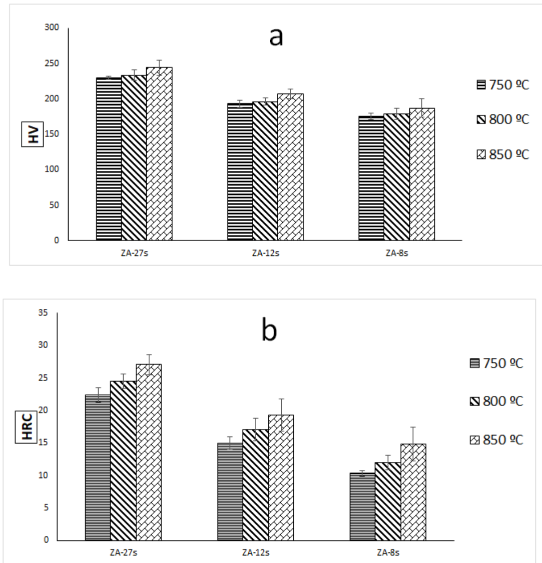

Figure 2-a,b Effect of AL content on hardness in ZA alloys.

Another result can be concluded from Figure 2-a,b that an increase in Al content results in a large increase in the hardness of samples. Alloys with higher Al contents increase alloy mechanical properties as well as hardness, which indicates improvement of surface properties of such alloy and is recommended for higher wear resistance applications. The same results were proven for other Al alloys by others [19]. Such changes in properties can contribute to that the atom size of Al is relatively bigger which results in lattice distortion of FCC phase and formation of Zn-Al intermetallic compound (β)

Also, an increase of hardness in alloys with higher Al content can contribute to an increase of α phase in alloy (see Figure 3-a,b,c) The presence of the α-phase can enhance the hardness of the Zn-Al alloy, the same conclusion was achieved by others [15].

Microstructure examination of ZA-27s, ZA-12s, and ZA-8s alloy shown in Figure 3-a,b,c respectively

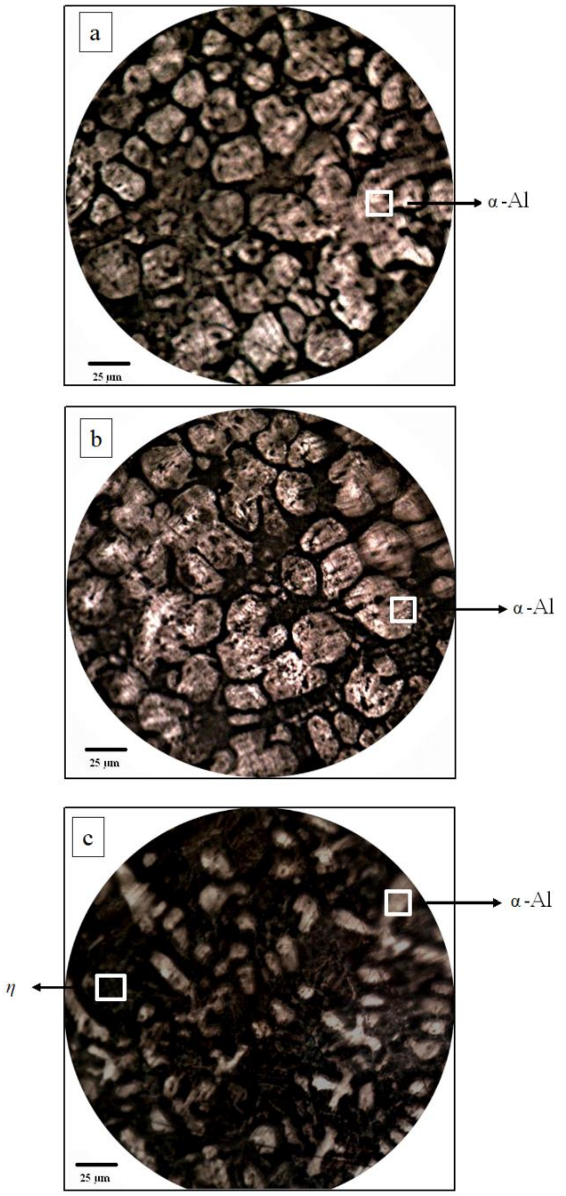

Figure 3-a,b&c Microstructure examination of ZA-27s, ZA-12s& ZA-8s respectively.

As shown in Figure 3-a, b, c, the dendritic structure (α phase) occupies a small area in ZA-8s alloy, and η phase (dark area) is the dominant one. The area of the dendritic structure increases by increasing the Al content as a result of more formation of the α phase. With increasing the area of the α phase, mechanical strength is enhanced. Alloy ZA-27s showed a predominant α phase because it has a higher content of Al.

Heat treatment of ZA alloys

Heat treatment was performed for selected ZA alloys casted at 750 °C at 250°C and 350°C respectively for durations of 1.5 h. The results of HCR were plotted for as cast and heat-treated samples as shown in Figure 4.

As can be noticed from Figure 4, the HRC of ZA-27s samples decreased by 6.1% at 250 C and decreased by 26.2% at 350 C after heat treatment in comparison to the value for as cast one. HRC of ZA-12s samples decreased by 12% at 250 C° and decreased by 18.2% at 350 C after heat treatment in comparison to the as-cast one. HRC of ZA-8s samples decreased by 10% at 250 C and decreased by 15.86% after heat treatment from as cast. In general, it can be remarkable that the hardness of alloys ZA-27s, ZA-12s, and ZA-8s was decreased after heat treatment, such behaviour can be contributed to softening of the alloy [20,21] the same behaviour was noticed by others [22,23].

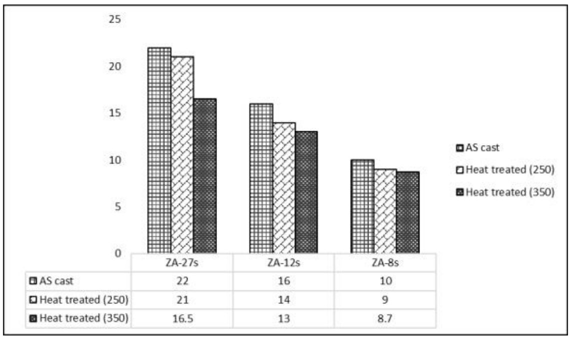

Figure 4 Effect of heat treatment on HCR harness of ZA alloys.

Furthermore, a slit effect caused by heat treatment temperatures on the final hardness of samples containing higher concentrations of Al and Si is seen.

Figure 4 also shows that heat treatment at 350°C results in a greater softening of the final alloy hardness as the alloy's Al-Si content increases.

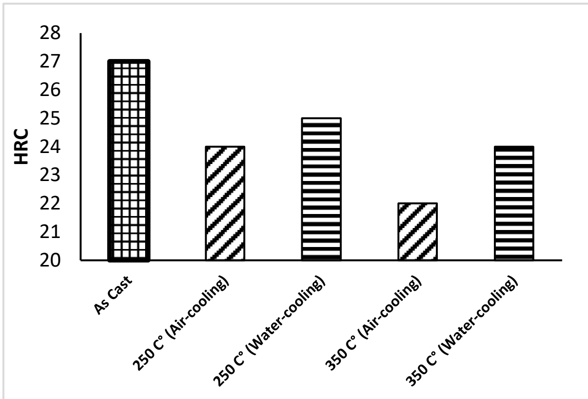

Figure 5 Effect of cooling media on the hardness of heat-treated ZA alloys.

Samples of the alloy ZA-27s were cast at 850 ºC, heat-treated at 250 and 350 ºC, and then cooled with air or quenched in water. The HRC of each sample is shown in Figure 5. It can be remarked that the HRC of samples treated at 250 ºC increased from about 24 to about 25 HRC when quenched in water instead of air-cooling. For samples treated at 350 ºC, hardness increased from 22 to 24 HRC by using water as a cooling media. Such behavior can be attributed to the grain refining effect resulting from using a higher cooling rate (for water) instead of a slower one for air.

The grain size changed strongly related to the cooling rate used. With a low cooling rate, there wasn't enough diving force for nucleation effectively. Because of this, the low numbers of newly formed grains in the new phase expand quickly, resulting in a final structure made up of only a few massive grains. With a higher cooling rate, a final structure of many small grains is well obtained [24].

Conclusions

ZA alloys with higher Al contents result in an increase of alloy mechanical properties as well as hardness, which indicates an improvement of surface properties of such alloy and is recommended for higher wear resistance applications.

The improvement of mechanical properties for ZA alloy with higher Al content contributed to the increase of α phase in the alloy, such a result was proven by microscopic examination.

Final hardness for ZA alloys increased by adding Si to its components.

The final properties of studied ZA alloys are affected greatly by casting temperature.

The increase in casting temperature increases alloy hardness and consequently its mechanical properties (Tensile Strength).

Heat treatment for the selected ZA alloys samples at 250 and 350 ºC shows a decreasing in hardness compared to as-cast samples.

Samples exposed to a higher cooling rate (quenching in water) exhibit a slight increasing in hardness compared to samples cooled in air.

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Conflicts of interest

There are no conflicts to declare.

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