Investigation Of Effect Of Cooling Speed Which In Mg Alloys Using Ceramic Mold

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Abstract: In this study, AZ91 magnesium alloy, which is commonly used in automotive, aerospace, aircraft and various other industries, and the alloy obtained by adding 0.5% Si to AZ91 (AZ91 + 0.5% Si) were produced. The microstructure and mechanical properties of these two alloys were investigated via the effect of cooling rate. For this, alloys were cast with a ceramic mold cooled with a copper base. Based on our results, it was observed that the cooling rate increased the hardness of AZ91, which was increased even more by the addition of Si at every level. Moreover, it was observed in both alloys that the grains of the $Mg_{17}Al_{12}$ phase became thinner and modified due to the cooling rates. It was found that Si addition resulted in the formation of Mg_2Si phase.

Keywords: AZ91, Cooling Rate, Mechanical Properties, Mg Alloys.

I. INTRODUCTION

Mg metal is preferred in researches for weight saving in automotive and air vehicle construction because it is the lightest structural metal in terms of engineering applications with its low density. By weight, Mg is 78% lighter than Iron (Fe) and steel, and 36% lighter than Aluminum (Al) [1]. AZ91 Mg alloy shows better casting and strength properties when compared to other Mg alloys [2]. AZ91 alloys are the most widely used commercial and structural Mg alloys due to their good casting and mechanical properties [3]. The effect of the $Mg_{17}Al_{12}$ β-intermetallic phase found in the AZ91 magnesium alloy on the mechanical properties of the alloy has been extensively studied [4],[5]. The studies were conducted by changing the percentages of Al amounts in AZ91 alloy. However, changes in the amount of Al also change the amount of β-intermetallic phase formed in the alloy as well as the limit of solid solubility in the matrix. In this case, the interpretation of mechanical properties must be based on the effect of the β-intermetallic phase in the matrix as well as the composition of the matrix [6],[7]. In studies where Si is added to the AZ91 Mg alloys, it has been reported that Si addition reduces the castability and flowability of Mg alloys [8]-[10]. Since the solubility of Si in Mg is very low, the Mg matrix composite material is liquidated with Mg_2Si formed by the addition of Si to the Mg alloy. Mg_2Si formed by Si addition is a highly useful intermetallic compound with a high melting point, low density and high modulus of elasticity [11]. In addition, in the work done by Ünal et al., the increase of Si ratio in AZ91 increased the tensile strength and yield strength proportionally. When the microstructure results were examined, it was observed that the grains became thinner depending on the amount of Si and the $Mg_{17}Al_{12}$ intermetallic phase was modified and also the Mg_2Si phase was formed. [12]. In the literature, studies on thinning of microstructure with the help of rapid solidification instead of microalloying in order to increase the mechanical properties of AZ series magnesium alloys are very limited [6],[7]. The Mg alloys formed by rapid solidification have many advantages, as they substantially liquidify the grains and precipitates, as well as extend the solid solubility, and they are reported in the literature to form non-equilibrium phases [13],[14]. In their study, Candan et al. reported that the grain size of AZ91 magnesium alloy became thinner as the cooling rate increased, the amount of $Mg_{17}Al_{12}$ phase decreased and the network structure deteriorated, and the mechanical properties of the alloy increased [15].

In this study, it was aimed to investigate the change of microstructure and hardness properties by obtaining AZ91 and AZ91 + 0.5% Si containing magnesium alloys at different cooling rates.

II. EXPERIMENTAL STUDIES

The melting of Mg and its alloys was carried out in a 3 kg Mg alloy melting capacity steel crucible placed inside a furnace. During the melting process, protective gas was supplied to the furnace during melting to cut off the contact of the furnace with the atmosphere. The furnace and metal temperature were selected as 755 ^{0}C considering the actual casting conditions. After the furnace reached the desired temperature, it was allowed to stand for about 15 minutes to reach the casting temperature of the alloy. After reaching the alloy casting temperature, the base of the melting pot was opened by controlling the melting furnace opening and closing arm, and the flow of molten liquid metal was ensured. During the casting process, SF_6 shielding gas was supplied to the liquid metal and the mold [16]. In the preparation of AZ91 magnesium alloy, 99.9% pure Mg, Al and Zn as well as Al-Si master alloy were used. Test specimens were cast with a second smelting from the prepared pre-alloys. In experimental studies, non-surface-active 0.5% silicon was added to AZ91 as an alloy element. Table 1 shows the analysis of the alloys used in the experiments.

Table1. Chemical compositions of the alloys used in the experiments.

Composition	% Element quantities					
	Mg	Al	Zn	Mn	Si	Diğer
AZ91	89.42	9.35	0.83	0.20	-	0.20
AZ91+%0,5 Si	89.05	9.25	0.76	0.20	0.55	0.19

20x200 mm circular cross section ceramic mold with copper cooler was used in the experiments. The data of solidification rates was transferred to a digital medium by connecting the mold-bound thermocouples to the ADAM 45-20 data acquisition module. In addition, a computer software that recorded and measured 10 temperature values were used in the module. Figure 1 shows the ceramic mold used in the experiments. The closest place to the copper cooler is specified as the 1st region and the closest place to the atmosphere was specified as the 5th region. Solidification rates, hardness and microstructure evaluations were made in 5 different regions of equal spacing. Cooling graphs were plotted for both alloys using the respective time-dependent temperature data obtained at equal time intervals. HMV model SHIMADZU digital hardness device and diamond square pyramid tip were used for hardness tests. Hardness measurements were taken from 5 different points on the surface of the specimen and the averages of these measurements were taken. For hardness and microstructure experiments, the surface of the samples were sanded with 400, 600, 800, 1000, and 1200 mesh SiC sand, and cleaned with pure water. In addition, specimens were polished with 1 μm Al_2O_3 paste and then cleaned with pure water.

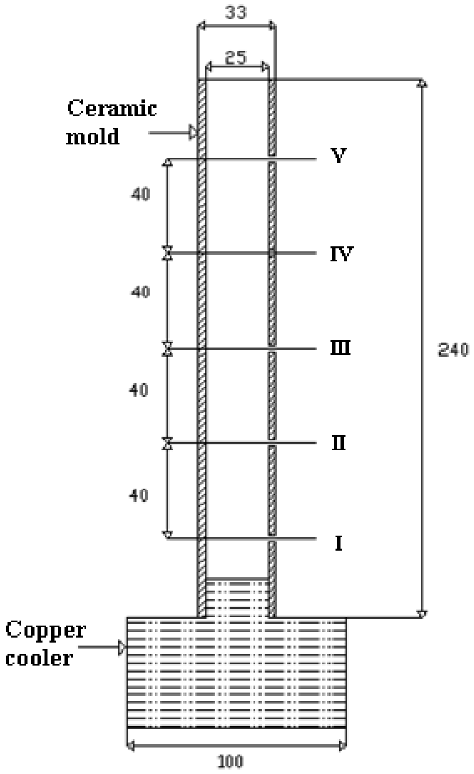

Fig. 1. Section of copper cooler ceramic mold used in the casting process. (The dimensions on the picture are taken in mm)

III. RESULTS AND EVALUATION

A. Microstructure

Microstructure studies were carried out on castings performed on ceramic molds. In experimental studies; AZ91, AZ91 + 0,5 wt. % Si alloys were poured into ceramic molds, respectively, and microstructure analyses were obtained from samples taken from 5 different regions solidifying at different cooling rates. In Figure 2, microstructure images obtained according to cooling rates and the alloy are presented. In the microstructure of the AZ91 alloy cast in a ceramic mold, α+Mg main matrix phase is present. It is seen that the structure consists of eutectic and intermetallic phases extending along the grain boundaries within the main matrix. These phases are assumed to be Mg-Al eutectic and $Mg_{17}Al_{12}$ intermetallic. When the microstructure drawings were examined, it was observed that the grain structure of the alloy became smaller and the grain boundaries of the $Mg_{17}Al_{12}$ intermetallic phase increased due to the increase of the cooling rate. Compared with the literature, the stable solidification of AZ91 starts at approximately 600 °C with the nucleation of α (Mg) solid from the melt, which is the primary Mg. These nuclei grow and solidification finishes at 470 °C [8],[17]. A separated eutectic formation consisting of α (Mg) and $Mg_{17}Al_{12}$ phases is observed in the microstructure. Thus, it is understood that the microstructure of non-equilibrium AZ91 is composed of α (Mg) and $Mg_{17}Al_{12}$, which is an intermetallic phase [18],[19]. With the addition of Si to AZ91 alloy, a change in the grain boundaries was observed. The $Mg_{17}Al_{12}$ phase at the grain boundaries was fragmented and, in addition, the Mg_2Si phase was formed. This has also been reported by other studies. [20]-[23].

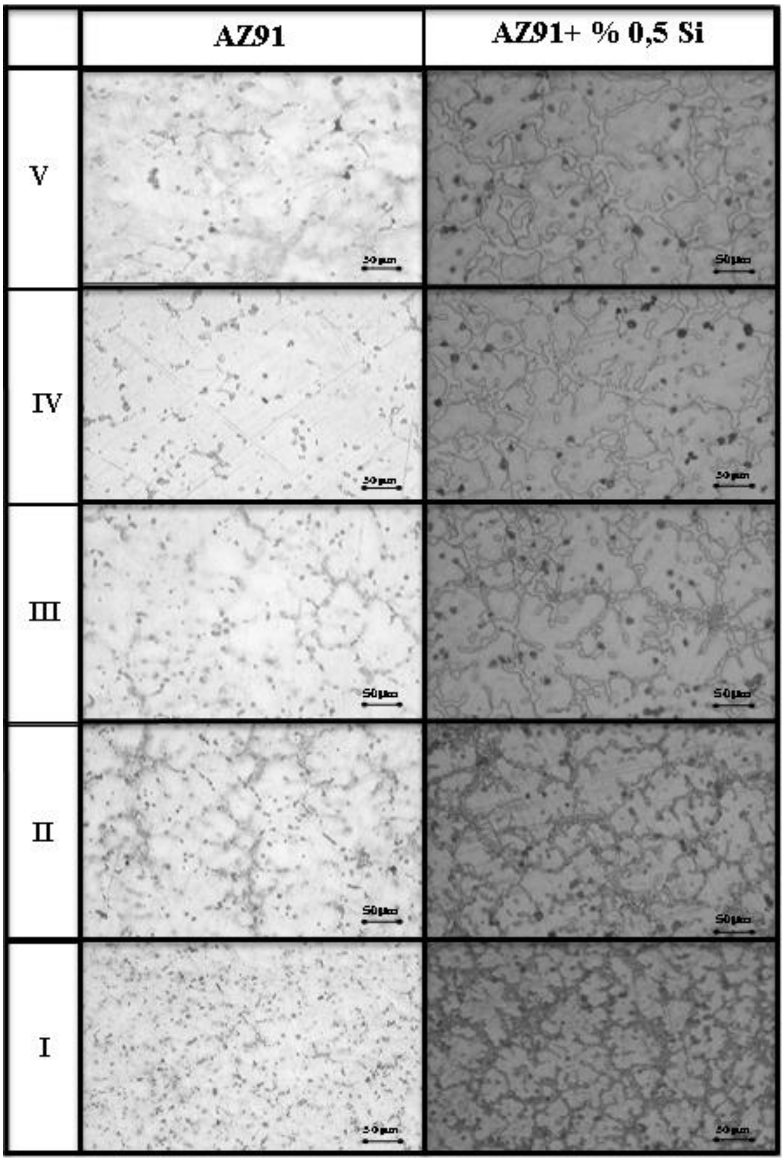

Fig. 2. Microstructure images of AZ91 and AZ91 + 0.5% si alloys, depending on the cooling rate.

B. Cooling Diagrams

By cooling Mg alloys at different cooling rates, cooling curves were obtained for each solidification rate in order to make a comparison with the conventional casting method. Casting of the investigated alloys was done in a ceramic mold at room temperature. The graphs showing the time-dependent temperature change obtained during the casting of AZ91 and AZ91 + 0.5 Si alloys in ceramic molds are given in Figures 3 and 4, respectively.

When the cooling curves were examined, it was observed that in both AZ91 and AZ91 + 0.5% Si alloys, region 1, that is the region closest to the copper cooler showed the fastest cooling. While the difference between region 1 and region 2 was clearly visible, it was observed that the difference between regions 3, 4 and 5 was not much. It was interpreted that the lack of difference was due to the fact that regions 4 and 5 were closer to the atmosphere.

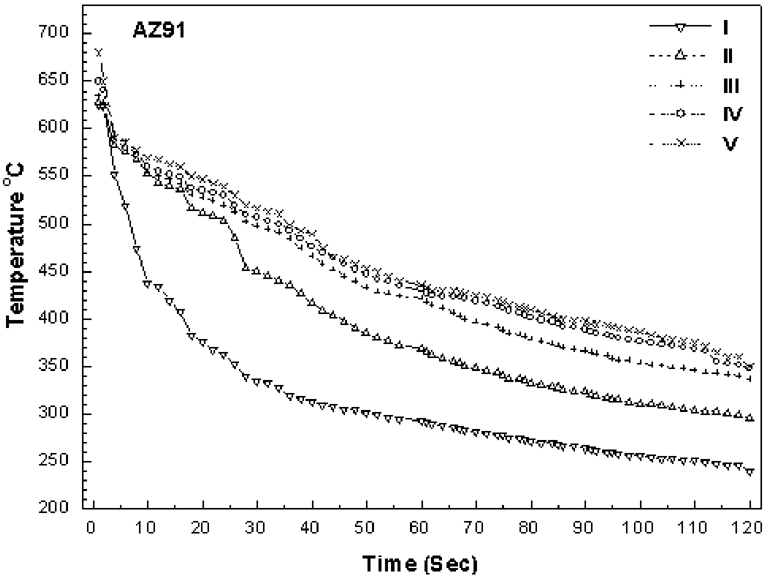

Fig. 3. Cooling graph of AZ91 alloy

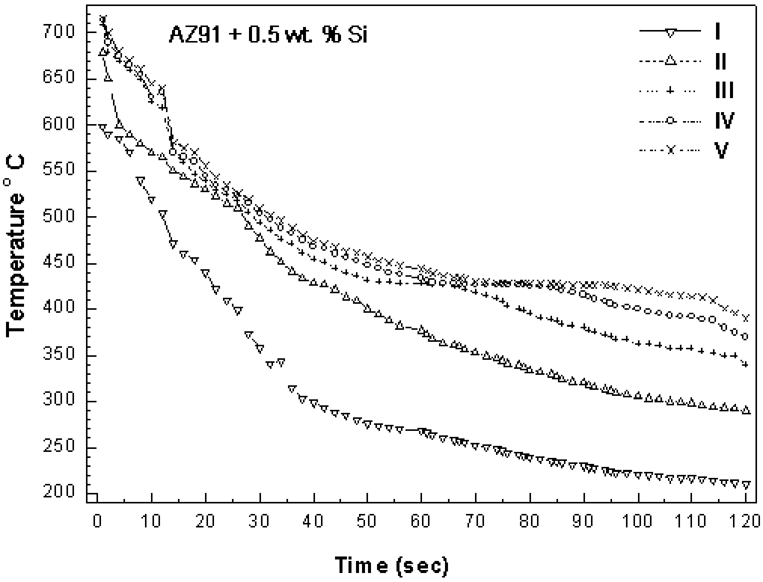

Fig. 4. Cooling graph of AZ91 + 0,5% Si alloy

C. Results of Mechanical Experiments

No tensile specimen was obtained in the ceramic mold; therefore only hardness values were obtained. In this study, hardness of alloys was measured in 5 different regions by Vickers hardness measurement method. Figure 5 shows changes in the hardnesses of AZ91 and AZ91 + 0.5% Si Mg alloys based on the cooling rates. As the cooling rate decreased, hardness decreased first in region 3 in both alloys, while a slight increase was observed in regions 4 and 5, since they were closer to the atmosphere. Hardness values of AZ91 alloy were 57.43 HV in region 1, 56.76 HV in region 2, and 52.73 HV in region 3, whereas the hardness values of AZ91 + 0.5% Si alloy were 61.63 HV in region 1, 59.40 HV in region 2, and 57.53 HV in region 3. As it was mentioned in the microstructure studies (Figure 2), as the cooling rate increases, the grain size decreases. In the literature, it is stated that the decrease of grain size increases the number of grains in the material, and thus the grain boundary ratio, and grain boundaries have an effect of preventing the dislocation movement. As the particle size decreases, the hardness and strength of the material are expected to increase [15]. The decrease in hardness due to the increase in cooling rate can be caused by the composition of the alloys as well as by the cooling rates. The presence of the $Mg_{17}Al_{12}$ phase indicates that the brittle phases along the grain boundaries are frailty paths. Since the ceramic mold size and dimensions were not suitable for obtaining a tensile sample, no tensile test was performed.

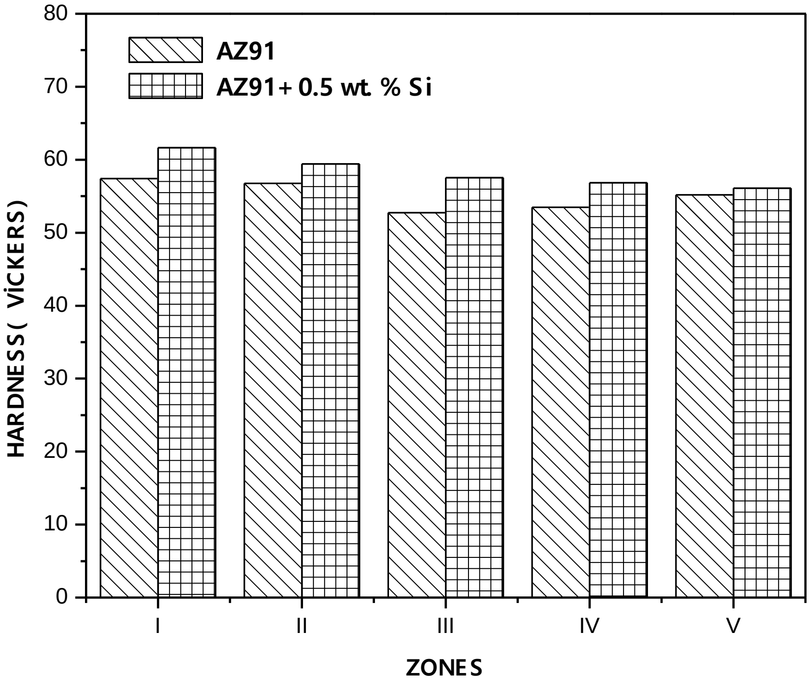

Fig. 5. Hardness change graph based on cooling rates of AZ91 and AZ91 + 0.5% Si alloys

IV. Conclusions

According to hardness test results, it was observed that the alloy hardness increased with the addition of 0.5% Si to AZ91. When the cooling curves were examined, it was found that the conversion points were the same but the time taken to reach these points were different. Hardness test results showed that hardness increased as the cooling rate increased.

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