EFFECT OF COPPER ADDITIONS ON MICROSTRUCTURE, CASTING AND MECHANICAL PROPERTIES OF AZ91 MAGNESIUM ALLOY

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Abstract: In this study, the effect of Cu element addition varied between 0.5 - 1.0 and 2.0 wt.% on the microstructure, casting and mechanical properties of AZ91 magnesium alloy were investigated. The microstructural results showed that as increasing Cu additions into the AZ91 alloy, caused coarsening of the phases occurring at grain boundaries. Addition of 2% Cu forms darker phases and shows a more homogeneous distribution in the structure of the grains. When examining the effect on casting properties; as the increasing of Cu additions the fluidity of AZ91 alloy increased was observed. In the hot tear tests two different mold systems were used. Hot tearing were observed in the longest section in the tests using " the mold same diameter, different lengths" and when the "the mold different diameter, same lengths" were used, Hot tears disappeared in all of the samples with a diameter of 12 and 16 mm while all the samples with a diameter of 8 mm had a hot tear with Cu additions. Little bit decrease in hardness observed with the addition of 0.5 wt.% Cu while 1.0 wt.% and 2.0 wt.% Cu additions showed a slight increase in hardness. Tensile strength of the alloy increased with the addition of Cu to the AZ91 alloy, but the AZ91 alloy also showed a slight decrease in elongation.

Keywords: AZ91, Fluidity, Hot Tearing, Magnesium.

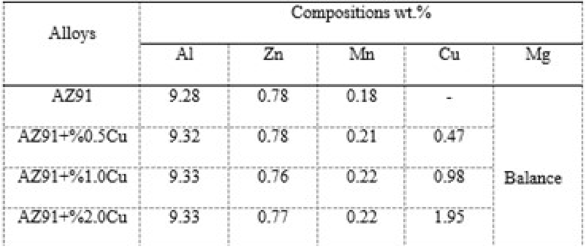
I. INTRODUCTION

Mg has 36% and 75% less strength/density than aluminium and steel, respectively [1]. Due to its low density, magnesium based alloys are the lightest structural metal in terms of many engineering applications such as portable microelectronics, telecommunications, aerospace and automobile industry [1,2]. Especially, AZ91 magnesium alloys are the most commonly used magnesium alloy with a use area of 90% [3]. AZ91 alloys have become more attractive owing to its significant mechanical properties of tensile, flow and impact strengths [4]. However, there is little data in the literature on the development of AZ91 castings and alloys such as other Mg alloys. In the literature, the addition of alloying elements such as Zn, S, Al, Sb, Ca, Bi, Pb and rare earth (RE) to the AZ91 alloy were investigated to improve the casting, microstructural stability or creep properties of the alloy [5-8], but there are few studies on the effect of Cu addition on the casting and microstructure properties of AZ91 alloy [9]. The aim of this work is to investigate the effects of Cu addition on casting properties such as microstructure properties and castability and hot tearing on AZ91 magnesium alloy.

II. DETAILS EXPERIMENTAL

The Mg, Al, Zn ingots with a minimum purity of 99.9% were purchased from Karasu Metal Co., Turkey. Pure Mg, pure Al and Al-Cu master alloys were melted at 750ºC under a protective Ar gas in a graphite crucible. The analyzes of the alloys used in the tests are given in Table 1. Zn additions were alloyed 1 min before casting to avoid losses of Zn due to vapourisation. The molten alloy was then cast into a cast iron mould having 30 mm diameter and 170 mm length under protective SF_6 gas.

Table 1. Chemicalcompositions of thealloys.



Alloys	Compositions wt.%				
	Al	Zn	Mn	Cu	Mg
AZ91	9.28	0.78	0.18	-	Balance
AZ91+%0.5Cu	9.32	0.78	0.21	0.47	
AZ91+%1.0Cu	9.33	0.76	0.22	0.98	
AZ91+%2.0Cu	9.33	0.77	0.22	1.95	

Castingoperationswere done at 250° C whichsupplies optimum casting conditions by using SF_6 shielding gas [10]. A moldheatingfurnacewhich is capable of reaching a temperature of 300 ° C was used toremove the test moldstothedesiredtemperature. Formet allographicinspection, thesurfaces of the samples were ground using pure water with 600-800-1000-1200 mesh SiCpaperandpolishedwith 1µm aluminapaste. 5 ml of acidicacid, 10 ml of picricacid, 10 ml of distilledwaterand 100 ml of ethylalcoholwereused as theetchant. Microstructure studieswerecarriedout on a Nikon Epiphot 200 opticalmicroscopeand JEOL JSM 6060 LV model ScanningElectronMicroscope (SEM).

Molds having same size and shape are used with the fluidity and hot tearing tests molds used in the literature [11]. Fluidity spirals were used for fluidity experiments and two different methods were used for the hot tearing experiments. One of the method is, the mold having same lengths and different diameters, the other method is the mold having different lengths, same diameters. In **Fig.1**, fluidity and hot tearing test molds images used in the experiments are given.

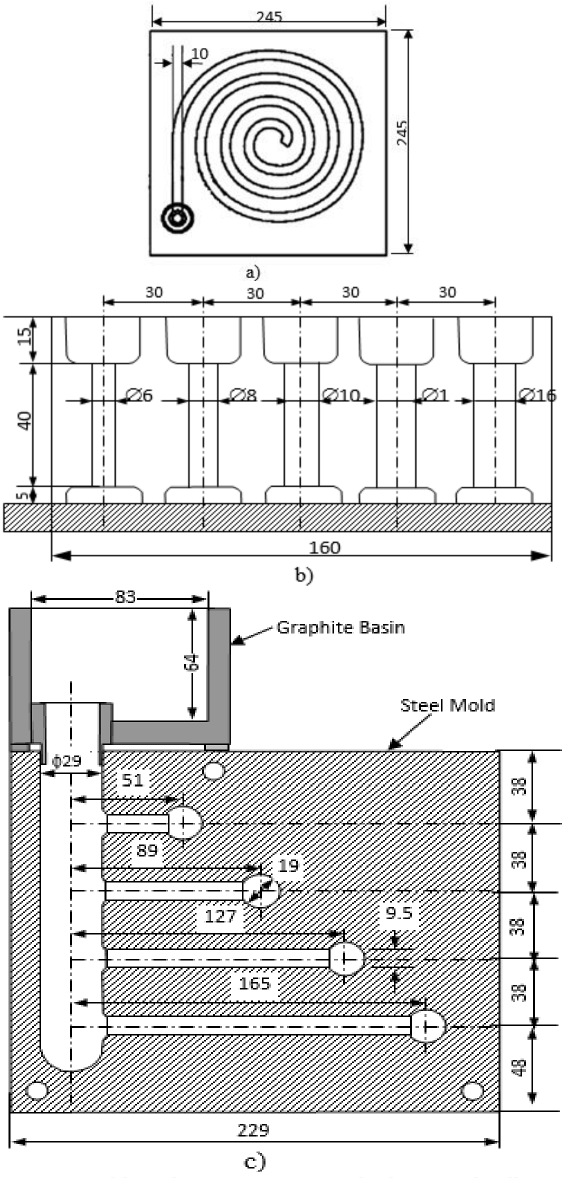


Fig.1.Moldsused in experiments a) Fluidity Spiralandb) Differentdiameterssamelengths hot tearmold c) Samediameters, differentlengths hot tearmold.

The hardness values were determined by Brinell hardness testing with a load of 5 N. At least 5 successive hardness measurements were made on each sample. The tensile test samples had a diameter of 8 mm and a length of 40 mm. The tensile tests were performed (ASTM E 8M-99) with a crosshead speed of 0.8 mm min^{-1} at room temperature. Each data represents the average of at least five samples tested.

III. RESULTS AND DISCUSSION

3.1. Microstructure

Fig.2(a-d) show microstructure images of AZ91 alloy and as a function of Cu contents. Figure 3 also shows the SEM image of AZ91+2.0 wt.% Cu alloy. When AZ91 microstructure (Fig. 2a) is examined, it is seen that the structure is formed mainly by eutectic and intermetallic phases extending along the grain boundaries in the main matrix of α-Mg. These phases are the $Mg_{17}Al_{12}$ (β) intermetallics with Mg-Al (α+β) eutectic. The morphological structure of the $Mg_{17}Al_{12}$ phase is similar to the literature [12] and is generally seen as a similar structure to the Chinese script. The addition of 1.0 wt.% Cu to AZ91 alloy caused coarsening of the phases occurring at grain boundaries. Addition of 2.0 wt.% Cu forms darker phases and shows a more homogeneous distribution in the structure. Although no changing was observed according to AZ91 in microstructure (Fig. 2) up to (0.5 wt.%, 1.0 wt.%) by addition of Cu to AZ91 alloy, the increase of secondary phases at grain boundaries attracted attention. Most likely these are eutectic and intermetallic phases.

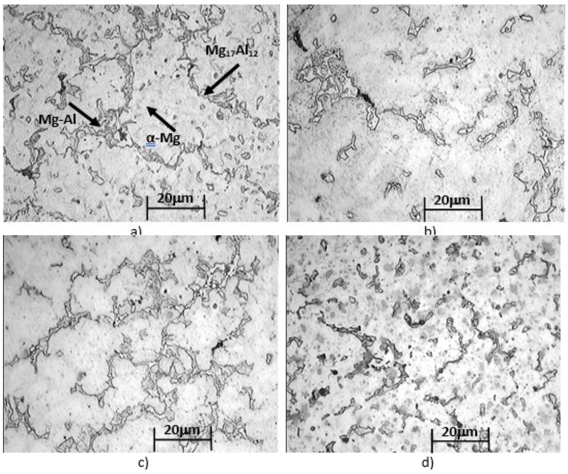


Fig.2. Optical microstructures of thealloys: a) AZ91, b) AZ91+0.5 wt.%Cu, c) AZ91+1.0 wt.%Cu, d) AZ91+2.0 wt.%Cu

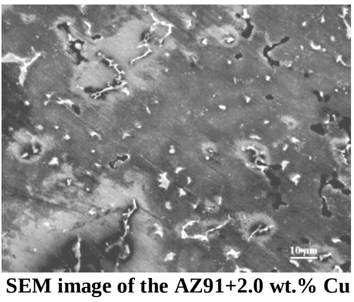


Fig.3. SEM image of the AZ91+2.0 wt.% Cu alloy

3.2. Casting Properties

3.2.1. Fluidity

Fig.4 shows the fluidity values of the alloys as a function of Cu contents. Fluidity increased with the increasing Cu contents. The fluidity length of the AZ91 alloy was 17.5 cm while it increased by 20 cm, 23 cm and 21 cm with the addition of 0.5-1.0-2.0 wt.% Cu additions respectively.

Although it is not a surface-active element, the reason why copper did not increase the fluidity of AZ91 alloy is the eutectics with low melting temperature which are formed by copper with Al, Mg and Zn.

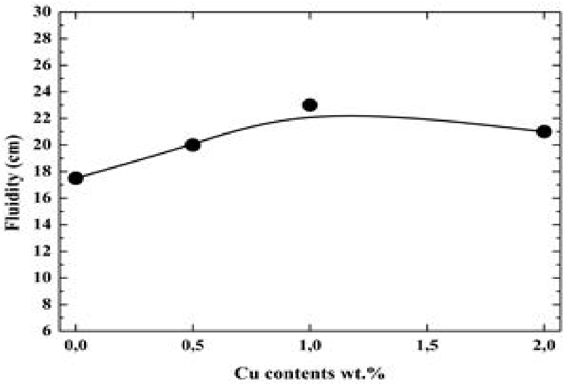


Fig.4. Fluidity values of the alloys as a function of Cu contents.

As the eutectics last during solidification, it may take more time to solidify the excess eutectic, which may increase the fluidity. Contrary to other additive elements, this increase is supported by the increased amount of Cu and increased flow.

3.2.2.Hot Tearing Tests

The hot tear test results were given as two different methods with the same lengths, different diameters and different lengths, same diameters. In the literature, which method is more effective has not been reported, so two different methods will be given comparatively to try to understand which is more effective.

3.2.2.1.The Mold With Different Diameter, Same Langths

Fig. 5 shows the results of the hot tear test of the AZ91 alloy and additions of Cu element, after casting in the molds of different diameters, same lengths. Hot tears disappeared in all of the samples with a diameter of 12 and 16 mm while all the samples with a diameter of 8 mm had a hot tear with Cu additions.

3.2.2.2.The Mold With Same Diameter, Different Langths

Fig. 6showstheresults of the hot tear test aftercasting in themolds of differentlengthssamediameterswiththeadditions of the Cu element tothe AZ91 alloy. As can be seen in Fig. 6, thelongestarm in themold is located at thebottomand hot tearsforeachalloyarevisible on thisarmadjacenttotherunner. Hot tearing is not visible in othershorterarms. Thisindicatesthatthesensitivity of thelongarmto hot tear is moreeffectivethanthat of theotherarms, which is explainedbythefactthattheshortening is longer in thelongarm. InFig 6, it wasobservedthatlongestarm hot tearingoccurswiththeaddition of 2,0 wt. % Cu to AZ91 alloy. Howevertherewasno hot tearswiththeadditionbyupto %2,0 wt. Cu wereobserved. As thesamplediameterincreases, hot tearingdid not occur. Thismay be duetothemolddesign. Casting in thesamediameter, differentlengthmethod is done withlargediameterverticalrunnerandarmsare in horizontalposition. Itmay be lesscommonfor hot tearing as theupperarmsmay be subjecttopreheatingandunitshorteningmay be lessduringrunnerfilling. On theotherhand, casting is done vertically in differentdiametersandtheeffect of preheating can be negligiblecomparedtoothermethod.

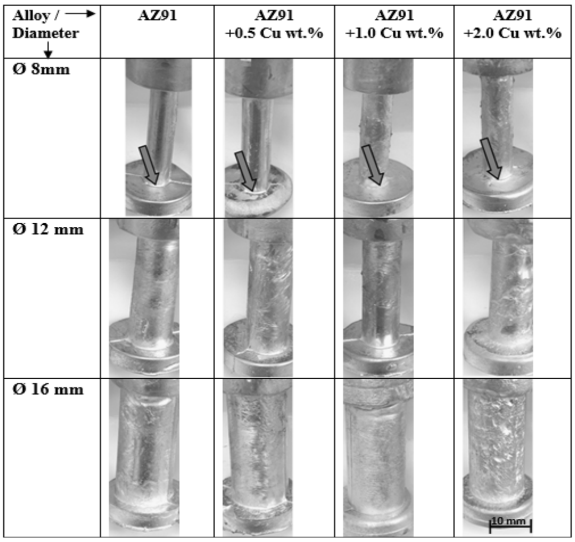


Fig.5. Hot tearimages of thealloysusingthemoldwithdifferentdiameter, samelengths

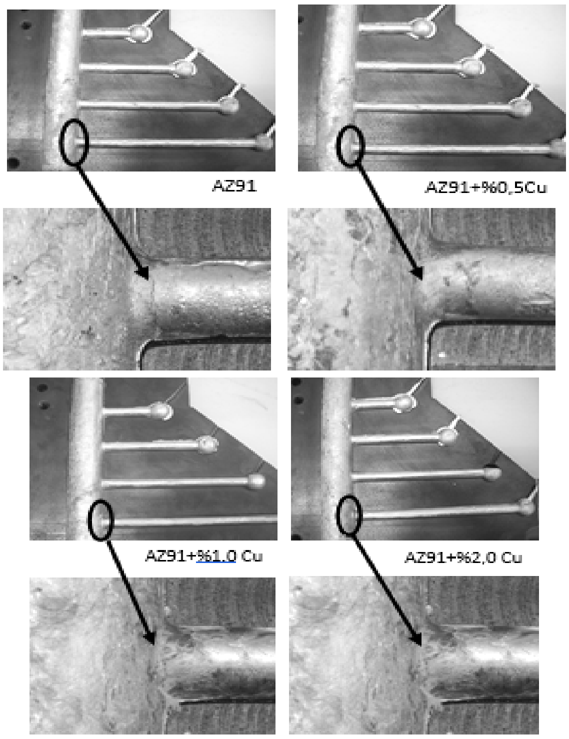


Fig.6. Hot tear images, the mold with same diameters, different lengths

Hot tearing test resultsshowedthattheeffect of hot tearing using the mold with different diameter, samelengthswasmoreeffectivethanthemoldwithsamediameters, different lengths.

3.3. Mechanical Properties

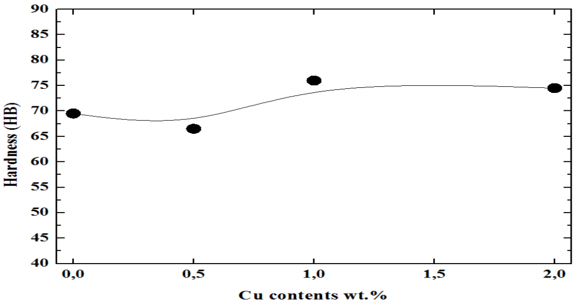


Fig.7.Hardnessvalues of thealloys.

Fig. 7showsthehardnessvalues of thealloys as a function of Cu contents As shown in Fig. 7., little bit decrease in hardnesswasobservedwiththeaddition of 0.5 wt.% Cu to AZ91 alloy. However, 1.0 wt.%and 2.0 wt.% Cu additionshowed a slightincrease in hardness. Forinstance, thehardness of AZ91 alloywasdecrasedfrom 69,5 HB to 66,5 HB (i.e. a 4% decrease) withtheaddition of 0.5 wt.% Cu, whileincreasedto 76HB (i.e. a 9% decrease) withtheaddition of 1.0 wt.% Cu.

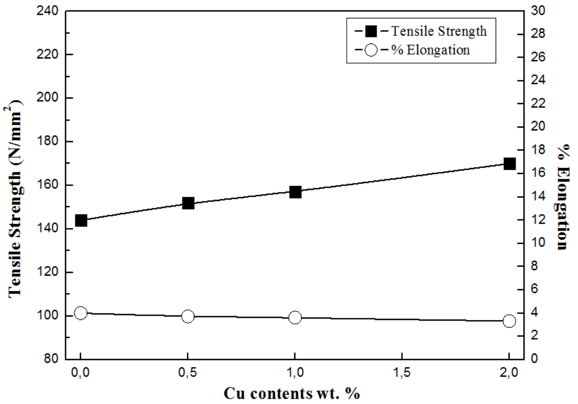


Fig.8. Tensile strengthandelongationvalues of thealloys.

Fig.8showsthe tensile strength (UTS) andelongationvalues of thealloys as a function of Cu contents. Tensile strength (UTS) of thealloyswasincreasedwiththeincreasing of the Cu additions. Theaddition of 0.5 wt.%, 1% and 2% Cu tothe AZ91 alloyincreasedthe tensile strength of thealloyproportionally, but the AZ91 alloyalsoshowed a slightdecrease in elongation. Especiallythe UTS of AZ91 alloywasincreasedfrom 144 MPato~170 MPa (i.e. a 18% increase). Increasinghardnessand UTS can be attributedto presence of intermetallicphase.

CONCLUSIONS

1. The microstructural results showed that as increasing Cu additions into the AZ91 alloy, caused coarsening of the phases occurring at grain boundaries. Addition of 2wt.% Cu forms darker phases and shows a more homogeneous distribution in the structure of the grains
2. Hot tearing test results showed that the effect of hot tearing usingthemoldwithdifferentdiameter, samelengths was more effective than themoldwithsamediameters, differentlengths
3. As theincreasing of Cu additionsthefluidity of AZ91 alloyincreased
4. Tensile strength (UTS) of the alloys was increased with the increasing of the Cu additions

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