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Effect of Lead Additions on Microstructure and Casting Properties of AZ91 Magnesium Alloy

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Abstract: In this study, the effect of Pb element addition varied between 0.2 - 0.4 wt.% on the microstructure and casting properties of AZ91 magnesium alloy were investigated. The microstructural results showed that as increasing Pb additions into the AZ91 alloy, the grains and the $Mg_{17}Al_{12}$ intermetallic phase becomes thinner. When examining the effect on casting properties; It was observed that the fluidity of AZ91 alloy increased as the increasing of Pb additions. 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 were observed in all of the molds with diameters of 6, 8, 10 mm. Hot tearings were observed in 0.2 wt.% and 0.3 wt.% Pb additions, while hot tearing was not observed when this ratio increased to 0.4% for the 12 mm diameter test specimens. There was also not hot tearing were observed in any sample when the sample diameter was 16 mm.

Keywords: Magnesium, AZ91, Fluidity, Hot Tearing

1. Introduction

Due to its low density, magnesium based alloys are the lightest structural metal in terms of many engineering applications such as portable microelectronics, telecommunications, aeraspace and automobile industry. The weight of Mg is 36% of Al (Al), of iron (Fe) and 78% of that of steel [1]. The main reason why the automotive industry has the biggest interest in the Mg alloys from the automotive sector today is the reduction in vehicle weight with the use of light Mg alloys fuel economy and as a consequence gas emissions can be reduced [2, 3]. AZ91 Mg alloy, formed by alloying Mg-Al-Zn elements, is mainly used for casting automobile parts. Compared with other Mg alloys, AZ91 is the most widely used commercial alloy due to its mechanical and casting properties [4]. Casting products are obtained by adding alloying elements in order to improve the structural properties of magnesium. Mg has a hexagonal lattice structure and its particle diameter permits solid solubility with a large number of elements.

When Mg is used as a structural material, it generally has a high strength / weight ratio when alloyed with the elements. The most commonly used alloy element in Mg alloys is Aluminum. In Mg-based alloys Al improves solid precipitation hardening, melt castability and reduces microporosity of Mg cast alloys. Besides, Al improves hardness, stiffness and solidification time of Mg alloys while reducing ductility. Alloy strength of Mg-Al alloys is developed by formation of $Mg_{17}Al_{12}$ intermetallics at low temperatures (≤ 120°C). However, the tendency of alloys to micropores increases with increasing Al content [5-7]. Zn is limited to 2% due to precipitation hardening, which increases resistance to ambient temperatures and at the same time increases castability and precipitation into grain boundaries, resulting in hot tearing. Si reduces the castability and fluidity of Mg alloys [5, 6, 8]. Si atoms form Mg_2Si intermetallic in solid state at room temperature [9]. The addition of alloying elements such as 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 [10-12].

In the literature there are few studies on the effect of Pb addition on the casting and microstructure properties of AZ91 alloy. Although Pb vapor is detrimental to health, the addition of a small amount may not be a serious problem as long as proper care is taken [13]. The aim of this work is to investigate the effects of Pb addition on casting properties such as microstructure properties and castability and hot tear on AZ91 alloy.

2. Experimental Studies

The Mg, Al, Zn ingots with a minimum purity of 99.9% were purchased from Karasu Metal Co., Turkey. Pure Mg and Al were melted at 750°C under a protective Ar gas in a graphite crucible. The analyzes of the alloys used in the tests are given in Table 1. Zn and Pb additions were alloyed 1 min before casting to avoid losses of Zn and Pb due to vapourisation. The molten alloy was then cast into a cast iron mould (preheated to 250°C) having 30 mm diameter and 170 mm length under protective SF_6 gas.

Table 1. *Chemical compositions of the alloys.*

Alloy	**Compositions wt.%**				
	Al	**Zn**	**Mn**	**Pb**	**Mg**
AZ91	9.13	0.78	0.18	-	Balance
AZ91+%0.2Pb	9.19	0.81	0.21	0.21	
AZ91+%0.3Pb	9.21	0.84	0.22	0.29	
AZ91+%0.4Pb	9.18	0.87	0.22	0.39	

Casting operations were carried out at 250°C which ensures optimum casting conditions by supplying SF_6 shielding gas [14]. A mold heating furnace which is capable of reaching a temperature of 300°C was used to remove the test molds to the desired temperature. For metallographic inspection, the surfaces of the samples were ground using pure water with 400 and 600 mesh SiC paper and polished with 1µm alumina paste. 5 ml of acidic acid, 10 ml of picric acid, 10 ml of distilled water and 100 ml of ethyl alcohol were used as the etchant. Microstructure studies were carried out on a Nikon Epiphot 200 optical microscope.

Flowing spirals were used for flow tests, and die cast molds with different diameters for hot tearing tests were used. Spirality of fluency used M. Di Sabatino et al. [15] and hot tear mold Cao and Kou [16] are of the same shape and dimensions as those used in their work. In addition, molds were prepared from cast iron for microstructure studies. In Figure 1, mold images and tensile test specimens used in the experiments are given.

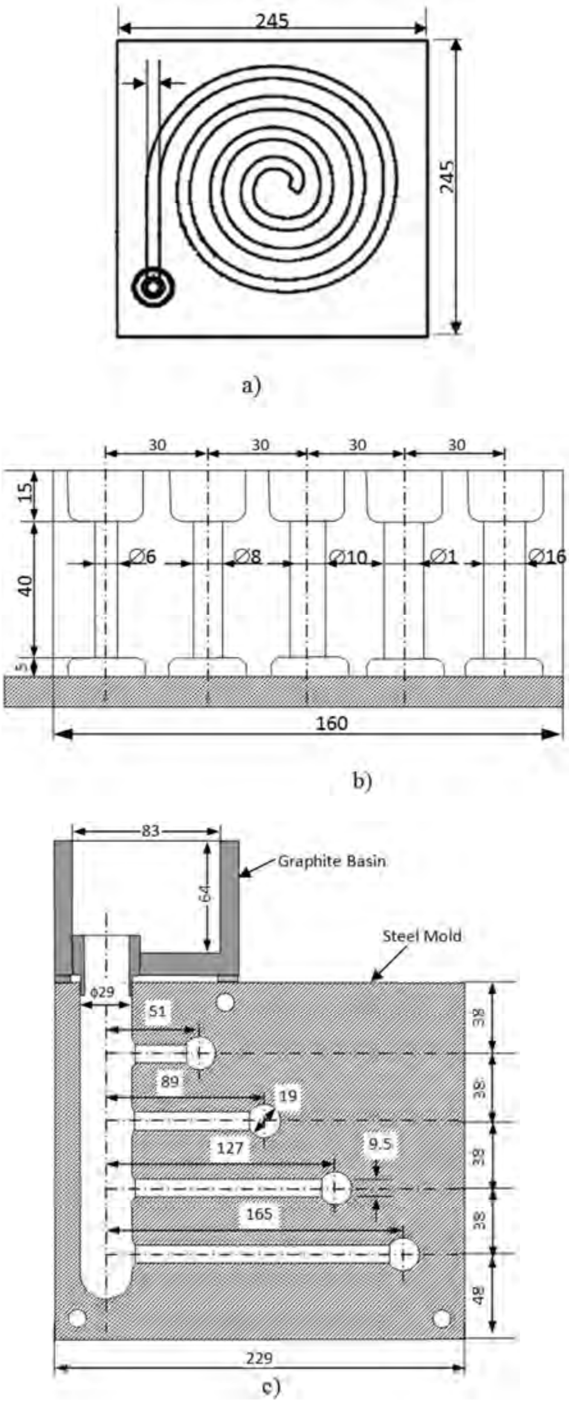

Figure 1. *Molds used in experiments a) Fluidity Spiral b) Different diameters same lengths hot tear mold c) Same diameters, different lengths hot tear mold.*

3. Results and Discussion

3.1. Microstructure

Figures 2 (a-d) show microstructure images of AZ91 alloy and additional Pb content. When AZ91 microstructure (Figure 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 [17, 18] and is generally seen as a similar structure to the Chinese script. The addition of Pb to the alloys caused a decrease in the amount of α + β eutectic. Pb in the AZ91 alloy has a high solubility of ~ 45% [19], possibly resulting in a solid solution in the structure rather than Al displacement. It is expected that Mg_2Pb phase appears in small quantities addition of Pb, as well as intermetallic phase $Mg_{17}Al_{12}$ in Pb additives. However, there is no information on the formation of Mg_2Pb phase with Pb addition in AZ91 alloy in literature. Srinivasan et al. [20] investigated the effect of 2% Pb addition on AZ91 on aging and did not mention Mg_2Pb here.

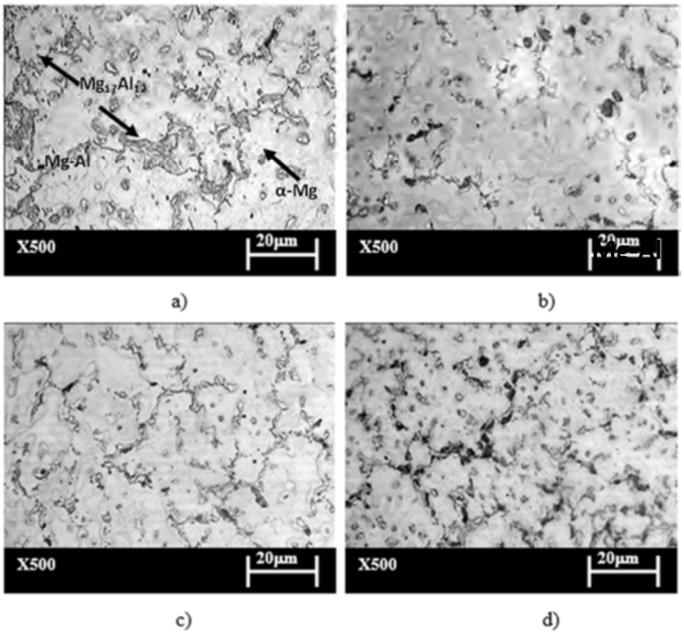

Figure 2. *Optical microstructures of the alloys: a)AZ91, b)AZ91+0.2Pb, c)AZ91+0.3Pb, d)AZ91+0.4Pb.*

3.2. Casting Properties

3.2.1. Fluidity

Figure 3 shows the fluidity values of the alloys as a function of Pb contents. Fluidity increased as increasing Pb contents. The fluidity length of the AZ91 alloy was 17.5 cm while it increased by 20 cm with the addition of 0.4 wt.% Pb. It is known that enthalpy, oxide formation, surface tension, and solidification time are the parameters affecting fluidity. For this reason, it is expected that Pb decreases the surface tension of Mg as a surface active element and accordingly increases the fluidity [21]. The Pb evaporation grade is a low element and may cause the MgO oxide formation on the surface to weaken or break during casting due to evaporation [22, 23]. Therefore, weak or broken MgO can lead to increased flow.

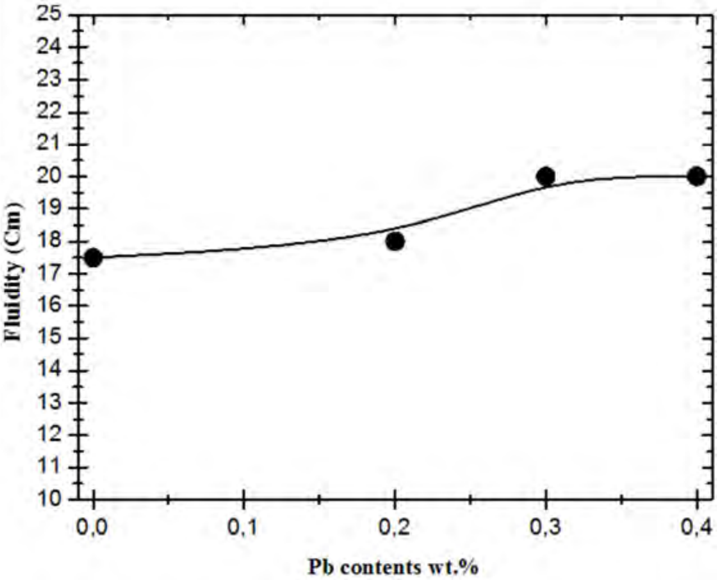

Figure 3. *Fluiditiy values of the alloys as a function of Pb contents.*

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.

(i) The Mold with Different Diameter, Same Lengths

Figure 4 shows the results of the hot tear test of the AZ91 alloy and additions of Pb element, after casting in the molds of different diameters, same lengths. Hot tears disappeared in all of the samples of 0.4 mm Pb and 16 mm diameter with a diameter of 12 mm while all the samples with a diameter of 10 mm had a hot tear with Pb additions.

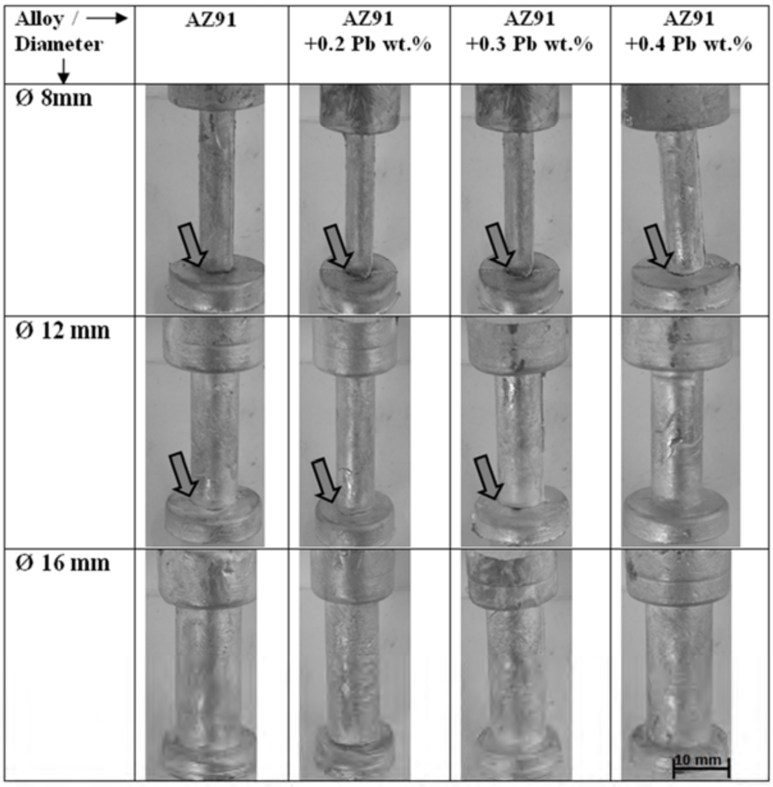

Figure 4. *Hot tear images of the alloys using the mold with different diameter, same lengths.*

(ii) The Mold with Same Diameters Different Lengths

Figure 5 shows the results of the hot tear test after casting in the molds of different lengths same diameters with the additions of the Pb element to the AZ91 alloy. As can be seen in Figure 5, the longest arm in the mold is located at the bottom and hot tears for each alloy are visible on this arm adjacent to the runner. Hot tearing is not visible in other shorter arms. This indicates that the sensitivity of the long arm to hot tear is more effective than that of the other arms, which is explained by the fact that the shortening is longer in the long arm.

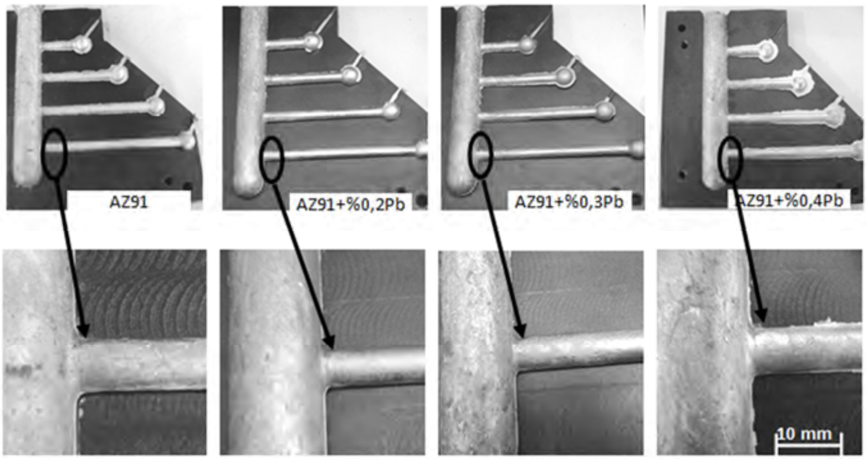

Figure 5. *Hot tear images, the mold with same diameters, different lengths.*

As the sample diameter increases, hot tearing did not occur. This may be due to the mold design. Casting in the same diameter, different length method is done with large diameter vertical runner and arms are in horizontal position. It may be less common for hot tearing as the upper arms may be subject to preheating and unit shortening may be less during runner filling. On the other hand, casting is done vertically in different diameters and the effect of preheating can be negligible compared to other method.

4. Conclusion

1. Microstructure studies showed that the addition of Pb to the alloys caused a decrease in the amount of $\alpha + \beta$ eutectic.
2. Fluidity increased as increasing Pb contents. The fluidity length of the AZ91 alloy was 17.5 cm while it increased by 20 cm with the addition of 0.4 wt.% Pb.
3. Hot tearings were observed in "the mold with different diameter, same lengths" in 0.2 wt.% and 0.3 wt.% Pb additions, while hot tearing was not observed when this ratio increased to 0.4% for the 12 mm diameter test specimens. There was also not hot tearing were observed in any sample when the sample diameter was 16 mm.
4. Hot tearings did not occur in "the molds with different lengths same diameters" as the sample diameter increases. This may be due to the mold design.

Acknowledgements

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References

[1] G. S. Cole, Summary of Magnesium Vision 2020: A North American Automotive Strategic Vision for Magnesium, Magnesium Technology, ed. R. S. Beals et al., 35-40, (2007).

[2] C. Blawert N. Hort, K. U. Kainer, Automotive Applications of Magnesium and Its Alloys, Trans. Indian Inst. Met. Vol. 57, 397-408, (2004).

[3] G. S. Cole and A. M. Sherman, Light weight materials for automotive applications. Materials Characterization, 35, (1) 3-9, (1995).

[4] D. Eliezer, E. Aghion, F. H. Froes, Magnesium Science, Technology and Applications, Advanced Performance Materials, 201-212, (1998).

[5] L. P. Barber, Characterization of the Solidification Behavior and Resultant Microstructures of Magnesium-Aluminum Alloys, A Thesis of Master, Worcester Polytechnic Institute, Worcester, 10-46 (2004).

[6] Z. Zhang, Development of Magnesium-Based Alloys for Elevated Temperature Applications, Doctor of These, Faculte Des Sciences Et De Genie Universite, Quebec-Canada, 2-75, (2000).

[7] S. Johansson, Magnesium Alloys, Summary of chapter 1-7 in Light alloys by I. J. Polmear, Engineering Materials, 5, 17-20, (2002).

[8] H. K. Kazdal, Magnezyum Alaşımları: Otomotiv Endüstrisinde Uygulaması ve Geleceği, Tubitak, Marmara Araştırma Merkezi, Kocaeli, 3-39, (1999).

[9] T. Aizawa, R. Song, Mechanically induced reaction for solid-state synthesis of Mg_2Si and Mg_2Sn, Intermetallics, 14, 382-391, (2006).

[10] M. O., *Pekgüleryüz*, A. A., *Kaya* Creep resistant magnesium alloys for power train aplications, *Advanced Engineering Materials*, DGM, *5*, 197-221, (*2004).*

[11] N. Balasubramani, A. Srinivasan, U. T. S., Pillai, B. C., Pai, Effect of Pb and Sb additions on the precipitation kinetics of AZ91 magnesium alloy Mater. Sci. Eng. A 457, 275-281, (2007).

[12] Y. Guangyin, S. Yangshan, D. Wenjiang, Effects of bismuth and antimony additions on the microstructure and mechanical properties of AZ91 magnesium alloy Mater. Sci. Eng. A 308, 38-44, (2001).

[13] OECD Nuclear Energy Agency, Science Reports, Chapter 13, (2007).

[14] M.Ünal, An investigation of casting properties of magnesium alloys, Ph.D Thesis, Gazi University, Ankara, Turkey, (2008).

[15] M. D., Sabatino, F. Syvertsen, L. Arnberg, A. Nordmark, An improved method for fluidity measurement by gravity casting of spirals in sand moulds, International Journal of Cast Metals Research, 18, 59-62, (2005).

[16] G. Cao, S. Kou, Hot cracking of binary Mg-Al alloy castings, Mater. Sci. Eng. 417, 230-238, (2006).

[17] Q. Wang, Y. Lu, X. Zeng, W. Ding, Y. Zhu, Q. Li, L. Jie, Study on the fluidity of AZ91+xRE magnesium alloy, Mater. Sci. Eng. 271: 109-115, (1999).

[18] C. D. Lee, K. S. Shin, Effect of microporosity on the tensile properties of AZ91 magnesium alloy, Acta Materialia, 55, 4293-4303, (2007).

[19] K. T. Kashyap, C. Ramachandra, M. Sujatha, B. Chatteri, Role of diffusional coherency strain theory in the discontinuous precipitation in Mg-Al alloy, Mater. Sci. 23, 39-45, (2000).

[20] A. Srinivasan, U. T. S. Pillai, B. C. Pai, Effect of Pb addition on ageing behavior of AZ91 magnesium alloys, Mater. Sci. Eng. 452, 87-92, (2006).

[21] B. Gravert, Y. Yu, K. Nisancioglu, Passivity Breakdown of Aluminum Alloys by Surface Enrichment of Group IIIA-VA Trace Elements, 9th International Symp. Paris, 627-632, (2006).

[22] H. Westengen, T. K. Aune, *Magnesium Casting Alloys*, Magnesium Technology, Springer, 145-204, (2006).

[23] S. Candan, M. Unal, M, Turkmen, E. Koc, Y. Turen, E. Candan, Improvement of mechanical and corrosion properties of magnesium alloy by lead addition, Mater. Sci. Eng. A, 501, 115-118, (2009).