Influence of strontium addition on the wear behavior of Mg-3Al-3Sn alloys produced by gravity casting

Gülşah Germen, Güven Yarkadaş and Hüseyin Şevik, Mersin, Turkey

Article Information

Correspondence Address
Dr. Hüseyin Şevik
Department of Metallurgical and Materials Engineering
Faculty of Engineering
Mersin University, Mersin, 33343,Turkey
E-mail: sevik@mersin.edu.tr

Keywords
Magnesium alloys, strontium, wear, gravity casting

The wear behavior of Mg-3Al-3Sn-xSr alloys was tested using pin-on-disc in dry sliding condition. Wear tests were carried out at two different loads of 5 and 10 N, constant sliding speed of 1 ms^{-1} and a total sliding distance of 3.6 km at room temperature. Worn surface was analyzed using scanning electron microscopy and energy dispersive X-ray spectrometry to define the main wear mechanisms. The wear rate for all loads decreased with increasing strontium addition.

Designer's interest in aluminum alloys, magnesium alloys and carbon fiber composites for automotive applications is based on the combination of high strength properties and low density. During the past decades aluminum and polymers successfully replaced steel, taking advance of their good specific strength properties [1-4]. Nevertheless, today's average automobile weight is between eleven and fourteen hundred kilograms which have to be decreased considerably in order to decrease traveling costs and CO_2 emission which result in dramatic environmental effects. Not only the environmental point of view is critical, new generation electric vehicles have to be much lighter because heavier vehicles need larger lithium ion batteries which in turn increases costs of vehicle significantly [3-5].

However, magnesium alloys for automotive industry are still limited by some poor property profiles like low wear, corrosion and creep resistance compared with aluminum alloys [1-3]. Recently, many researchers studied the improvement of the weak mechanical properties, like wear resistance, of magnesium alloys [1, 6-10].

New magnesium alloy design approaches are one of the effective ways for the development of these properties of magnesium. Nowadays, a lot of studies about new magnesium alloy design have been done dealing with the effects of Sn or Sr addition on the mechanical properties of Mg alloys [1-3, 10]. However, only a few studies have examined the effect of Sr and Sn on the microstructure and mechanical properties of Mg-Al alloys [8, 9].

As a result, in this study, Mg-3Al-3Sn alloy was selected as base alloy and Sr was added to the base alloy for investigation of the wear properties.

Experimental procedure

Preparation and testing of alloys. The different alloy compositions were prepared in an electric resistance furnace using a mild steel crucible under a gas mixture of carbon dioxide (98 % CO_2) and sulphur hexafluoride (2 % SF_6) from commercially pure magnesium, aluminum and tin. Strontium was added in Mg-20Sr form as a master alloy. The melt was held at 760 °C casting temperature for 30 min, and stirred to ensure the homogeneity in a graphite mold.

Metallographic samples were cut from the same position of each casting using a wire erosion machine and prepared according to the standard metallographic procedures. The specimens for scanning electron microscopy (SEM) were chemi-

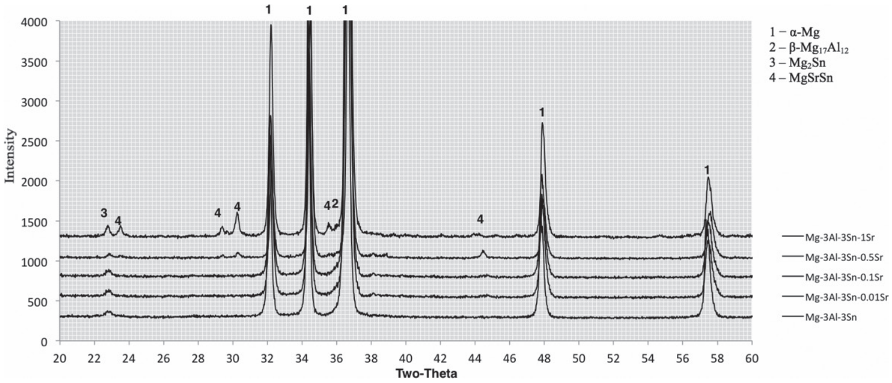
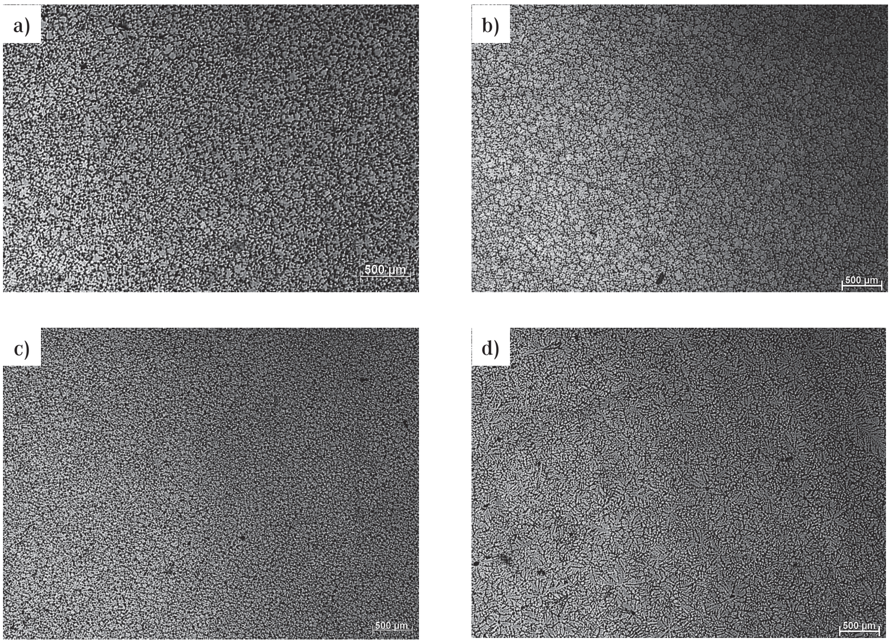


Figure 1: XRD spectrums of all alloys



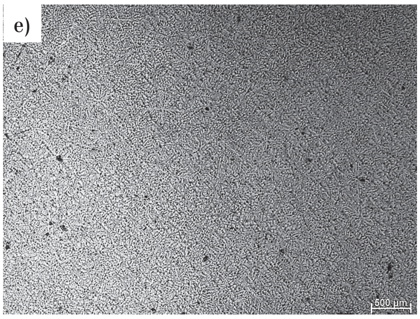
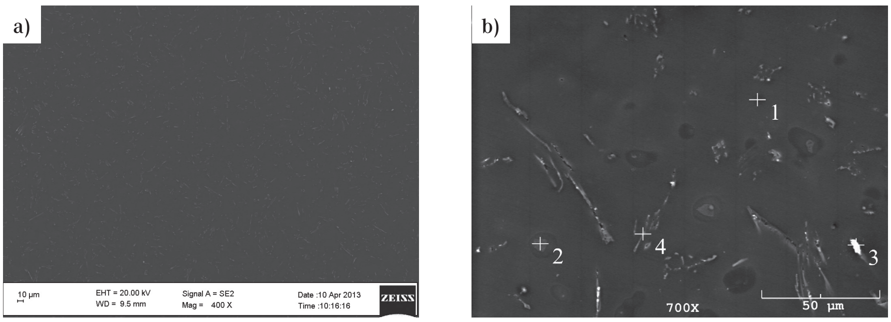


Figure 2: Optical micrographs of a) Mg-3Al-3Sn, b) Mg-3Al-3Sn-0.01Sr, c) Mg-3Al-3Sn-0.1Sr, d) Mg-3Al-3Sn-0.5Sr, e) Mg-3Al-3Sn-1Sr

Table 1: Yield strength [4] and hardness of the tested materials

Alloy	Yield strength (MPa)	Hardness (Brinell)
Mg-3Al-3Sn	69	42
Mg-3Al-3Sn-0.01Sr	87	43
Mg-3Al-3Sn-0.1Sr	90	43
Mg-3Al-3Sn-0.5Sr	92	45
Mg-3Al-3Sn-1Sr	93	48



Spot No.	Chemical compositions (at.-%)				Atomic ratio		
	Al	Sn	Sr	Mg	Sn/Sr	Al/Sr	Mg/Al
1	3.93	0.30	–	95.77	–	–	24.36
2	37.48	0.20	–	62.32	–	–	1.66
3	5.60	3,08	2,36	88.96	1.3	0.42	15.88
4	2.52	1.18	1.12	95.18	1.05	0.44	–

Figure 3: Mg-3Al-3Sn-1Sr alloy, a) SEM microstructure, b) EDX analyzes

cally etched with acetic glycol (20 ml acetic acid, 1 ml nitric acid, 60 ml ethylene glycol, 19 ml distilled water). X-ray diffraction (XRD) analysis was also carried out to identify the phases present in the experimental alloys.

Brinell hardness of the alloys was measured by using an applied load of 31.25 kg and a ball diameter of 2.5 mm as indenter. The load was applied for 30 s. The hardness of each alloy was taken as average of five readings.

Wear testing. Dry sliding wear tests were implemented on pin-on-disk equipment. The test samples having dimensions of ⌀ 5 mm × 20 mm were machined using a wire erosion machine to slide against a rotating heat-treated DIN 8620 steel disc of hardness 63 HRC with a diameter of 100 mm. Before the wear tests, each specimen was polished, checked in complete contact with the surface of the steel disc and cleaned with alcohol. Wear tests were carried out at two different loads of 5 and 10 N, constant sliding speed of 1 m × s^{-1} and a total sliding distance of about 3.6 km. The coefficient of friction was calculated by dividing the frictional force (measured using a load cell) by the normal load. After each wear test, the pins were cleaned and dried prior to each weight measurement.

Results and discussion

Microstructure. The phases identified for all alloys by XRD as described elsewhere [4] are provided in Figure 1. While the main alloy was mainly composed of α-Mg, β-$Mg_{17}Al_{12}$ and Mg_2Sn phases, the modified alloy contained also the intermetallic phase MgSrSn after 0.5 wt.-% Sr addition.

Figure 2 displays the optical micrographs of base alloy and modified alloys, exhibiting a reduced grain size with increasing Sr content. Moreover, the grain morphology changed from globular to dendritic after 0.5 wt.-% Sr addition.

SEM micrograph and EDS analyses of Mg-3Al-3Sn-1Sr alloy are shown in Figure 3. It can be clearly seen from Figure 3a that the rod-like MgSrSn intermetallic phase was formed in the Mg-3Al-3Sn-1Sr alloy. According to the atomic ratio, it could be said that the first and second spot in Figure 3b were α-Mg and β-$Mg_{17}Al_{12}$ phases and third and fourth spot could be determined as MgSrSn intermetallic phase, respectively.

The yield strength and hardness of all alloys are presented in Table 1. The result indicates that the yield strength of base alloy increased with increasing Sr addition, like as hardness of Mg-3Al-3Sn alloy. This is probably the result of the new intermetallic MgSrSn, which occurs at the grain boundaries and help to increase the hardness and yield strength of the alloy. Furthermore, the enhancement in yield strength value is attributed to the hindering dislocation motion because of MgSrSn intermetallic phase.

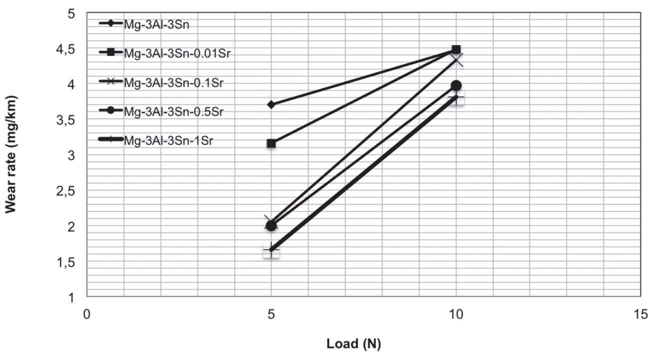


Figure 4: Wear rate against loads of all alloys

In Figure 4, the wear rate for all alloys is plotted as a function of applied load at constant sliding speed of 1 m × s^{-1}. It can be seen from Figure 4 that the wear rate of Mg-3Al-3Sn alloy was more than that of the modified alloys at all load conditions. Figure 5 displays the wear tracks of Mg-3Al-3Sn and Mg-3Al-3Sn-1Sr alloys obtained by SEM of the worn surface for dry sliding conditions, respectively. Figure 6 shows the wear tracks of Mg-3Al-3Sn-1Sr alloy achieved by BSE (backscatter electron) of the worn surface. SEM analyses showed that both abrasive and adhesion wear mechanism could be observed on the worn surface of the alloys. In addition to this, the abrasive wear of the Mg-3Al-3Sn alloy was more than of the Mg-3Al-3Sn-1Sr alloy. It can be drawn from Figures 4 and 5 that Mg-3Al-3Sn alloy gained resistance against abrasive wear because of the new intermetallic phase MgSrSn. The improvement of wear resistance of Mg-3Al-3Sn alloy was attributed to the microstructure change and the increment in the hardness and yield strength of the alloys.

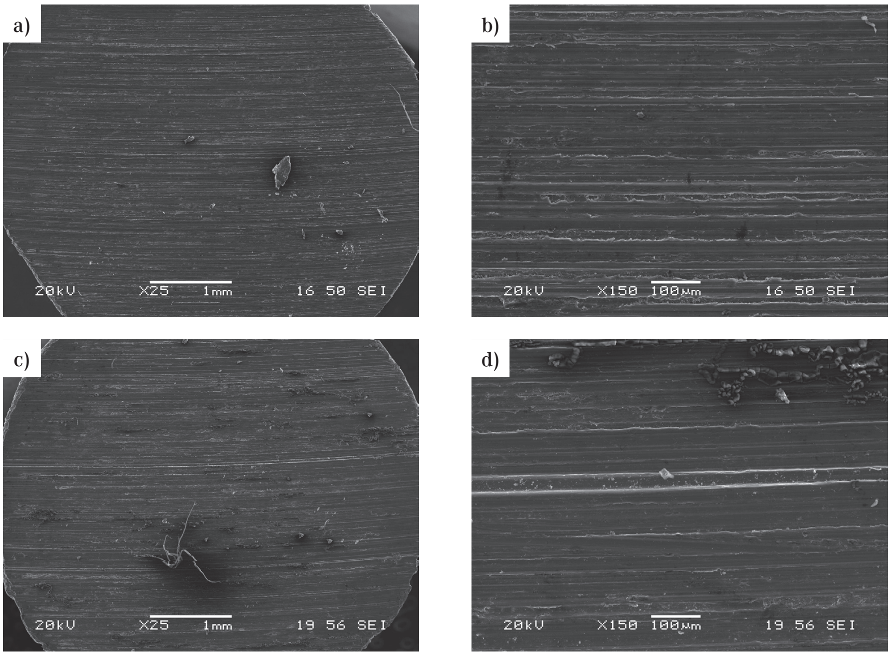


Figure 5: SEM micrographs of worn surfaces of a) and b) Mg-3Al-3Sn, c) and d) Mg-3Al-3Sn-1Sr, applied load 10 N

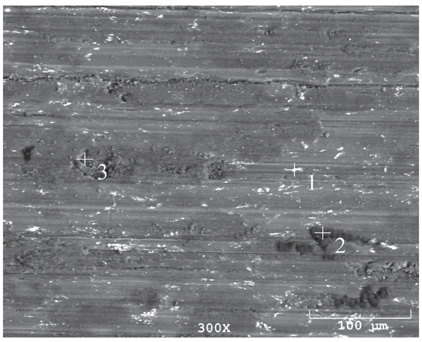


Figure 6: EDS analyzes of the worn surface of the Mg-3Al-3Sn-1Sr alloy at an applied load of 10 N

Spot No.	Chemical compositions (at.-%)					Atomic ratio			
	Al	Sn	Sr	Mg	O	Sn/Sr	Al/Sr	Mg/Al	Mg/O
1	2.62	3.10	4.16	90.12	–	0.74	0.62	–	–
2	0.67	0.24	0.12	40.08	58.89	–	–	–	0.68
3	1.32	0.58	0.24	60.78	37.08	–	–	–	1.63

Conclusions

1. The main components in the base alloy were α-Mg, β-$Mg_{17}Al_{12}$ and Mg_2Sn phases. With addition of Sr, the new intermetallic phase MgSrSn was detected.
2. The hardness of Mg-3Al-3Sn alloy increased with increasing strontium concentration.
3. The wear rate of the alloys continuously increased at all load conditions with increasing strontium concentration.

References

1 P. Poddar, A. Das, K. Sahoo: Dry sliding wear characteristics of Rheocast Mg-Sn based alloys, Materials and Design 54 (2014), pp. 820-830 DOI:10.1016/j.matdes.2013.08.068
2 M. Pekguleryuz, M. Celikin: The role of α-Mn precipitation on the creep mechanisms of Mg-Sr-Mn, Mat. Sci. and Eng. A 556 (2012), pp. 911-920 DOI:10.1016/j.msea.2012.07.091
3 S. Park, J. Jung, J. Yoon, B. You: Influence of Sn addition on the microstructure and mechanical properties of extruded Mg-8Al-2Zn alloy, Mat. Sci. and Eng. A 626 (2015), pp. 128-135 DOI:10.1016/j.msea.2014.12.039
4 G. Germen, H. Şevik, C. Kurnaz: Influence of strontium addition on the mechanical properties of gravity cast Mg-3Al-3Sn alloy, 3rd Inter. Advanced in Applied Phys. and Mater. Sci.

Cong., AIP Publishing, Antalya (2013), Turkey, pp. 199-202 DOI:10.1063/1.4849258
5 A. Mayyas, A. Qattawi, M. Omar, D. Shan: Design for sustainability in automotive industry: A comprehensive review, Renewable and Sustainable Energy Reviews 16 (2012), pp. 1845-1862 DOI:10.1016/j.rser.2012.01.012
6 J. Kim, N. Kang, C. Yim, B. Kim: Effect of calcium content on the microstructural evolution and mechanical properties of wrought Mg-3Al-1Zn alloy, Mater. Sci. and Eng. A 525 (2009), pp. 18-29 DOI: 10.1016/j.msea.2009.07.048
7 H. Friedrich, S. Schumann: Research for a new age of magnesium in the automotive industry, Journal of Materials Processing Technology 117 (2001), pp. 276-281 DOI:10.1016/S0924-0136(01)00780-4
8 S. Kleiner, O. Beffort, A. Wahlen: Microstructure and mechanical properties of squeeze cast and semi-solid cast Mg-Al alloys, Journal of Light Metals 2 (2002), pp. 277-280 DOI:10.1016/S1471-5317(03)00012-9
9 P. Bala Srinivasan, C. Blawert, W. Dietzel: Dry sliding wear behavior of conventional and recycled high pressure die cast magnesium alloys, Mater. Charact. 60, (2009), pp. 843-847 DOI:10.1016/j.matchar.2009.01.014
10 P. Zhao, Q. Wang, C. Zhai, Y. Zhu: Effects of strontium and titanium on the microstructure, tensile properties and creep behavior of AM50 alloys, Mater. Sci. Eng. A 444 (2007), pp. 318-326 DOI:10.1016/j.msea.2006.08.111

Bibliography

DOI 10.3139/120.110806
Materials Testing
57 (2015) 11-12, pages 997-1000

ISSN 0025-5300

Abstract

Einfluss von Strontiumzugabe auf das Verschleißverhalten von Mg-3Al-3Sn Kokillengusslegierungen. Das Verschleißverhalten von Mg-3Al-3Sn-xSr Legierungen wurde mittels des Stift-Scheibe-Versuchs unter trockenen Reibbedingungen untersucht. Die Verschleißversuche wurden bei zwei verschiedenen Belastungen von 5 und 10 N, einer konstanten Reibgeschwindigkeit von 1 m × s^{-1} und einer gesamten Reibstrecke von 3,6 km ausgeführt. Die verschlissenen Oberflächen wurden mittels Rasterelektronenmikroskopie und EDX untersucht, um die Hauptverschleißmechanismen zu ermitteln. Die Verschleißrate reduzierte sich bei allen Belastungen mit zunehmendem Strontiumgehalt.

The authors of this contribution

Dr. Hüseyin Şevik, born in 1980, earned a BSc degree in Metallurgy Engineering from Sakarya University, Turkey, in 2001, followed by an MSc degree in 2004 and his PhD in Metallurgy and Materials Engineering from University of Sakarya in 2011. His doctoral work was focused on magnesium alloys and their mechanical properties. Now, he is working as a lecturer at Mersin University, Turkey.

Dr. Güven Yarkadaş, born in 1974, earned a BSc in Metallurgy Engineering from Istanbul Technical University, Turkey, in 2001, followed by an MSc degree in 2004 and a PhD in Metallurgy and Materials Engineering from University of Sakarya in 2010. His doctoral work was focused on the effects of mechanical activation on soda roasting of chromite. Now, he is working as a lecturer at Mersin University, Turkey.

Gülşah Germen, born in 1988, earned a BSc degree in Metallurgy Engineering from Karadeniz Technical University, Turkey, in 2012. Now, she is studying for her MSc degree while working as a research assistant at Mersin University, Turkey.