Al-Khwarizmi Engineering Journal, Vol. 15, No. 1, March, (2019)
P.P. 63- 70

Al-Khwarizmi Engineering Journal

Improving Wear Properties of 392 Al Alloy Using Centrifugal Casting

Akeel Dhahir Subhi* **Adnan Mohsen Abd****

**, ** Department of Production Engineering and Metallurgy / University of Technology/ Baghdad*
*Email: 70071@uotechnology.edu.iq
**Email: mhsnd8500@gmail.com

(Received 15 November 2017; accepted 29 November 2018)
https://doi.org/10.22153/kej.2019.11.001

Abstract

The microstructure and wear properties of 392 Al alloy with different Mg contents were studied using centrifugal casting. All melted alloys were heated to 800 ºC and poured into the preheated centrifugal casting mold (200-250 ˚C) at different mould rotational speeds (1500, 1900 and 2300 r.p.m). It is clear from the results obtained that wear rate was dependent on the Mg content, applied load and mould rotational speed. Furthermore, wear test showed that the minimum wear rate was found in the inner layer of produced rings at mould rotational speed of 1900 r.p.m and Mg content of 5%.

Keywords: *Centrifugal casting, Wear properties, 392 aluminum alloy.*

1. Introduction

Aluminum-Silicon alloys exhibit excellent castability, fluidity and resistance to corrosion [1]. The centrifugal casting is one of the casting techniques, which consists of pouring the molten metal into a rapidly rotating mould. Centrifugal forces cause the metal to be pushed out towards the mould walls after pouring the molten alloy. Particles segregation that added or in situ formed during centrifugal casting process performs either at the inner or the outer periphery of the casting as a result of centrifugal force [2]. In the centrifugal casting method, the composition gradient is formed as a result of the difference in the centrifugal force which is generated by the difference in density between the molten metallic phase and the particles [3]. Therefore, centrifugal casting can be used to produce a gradual change from layer to layer in chemical composition, microstructure, density, grain size and other physical properties [4]. B. Zhou [1998] [5] studied the effect of cooling rate and mould rotational speed on the obtaining graded composite materials (Al-Mg_2Si) using centrifugal casting. He showed that the centrifugal force pushed particles of (Mg_2Si) which has lower density to the inner surface of the cylinder wall, and the Al phase of higher density to the outer surface of the cylinder, therefore wear resistance was high at the inner surface owing to the particles of Mg_2Si. While G. Chirita et al [2008] [6] studied the differences between centrifugal casting and traditional gravity casting of Al-Si alloys. They showed that improvement in mechanical properties and microstructure of Al-Si alloy fabricated by centrifugal casting is more than that in traditional gravity casting. Casting using centrifugal method tends to raise the rupture strength in 35% and the rupture strain in approximately 160%, young modulus in about18% and fatigue limit increase about 45%.

The parameters affecting on centrifugal casting for composite materials of Al-Si-Mg alloy manufactured using centrifugal method such as centrifugal speed, mold temperature, and pouring temperature were studied by Y. Xie et al [2009] [7]. They showed that Mg_2Si and Si particles are distributed in the inner, middle and outer periphery. They also showed that Mg_2Si concentrated in the inner periphery more than in middle and outer periphery and the amount of these particles increases with increasing centrifugal speed, pouring temperature and mold temperature of molten alloy in the inner periphery. Y. Zhai et al (2014) [8] studied how to obtain aluminum reinforced by two types of particles Si and Mg_2Si using centrifugal casting with mould rotational speed of 2000 r.p.m. They showed that the volume fraction of particles of Si and Mg_2Si in the inner periphery was high compared with that in the external periphery. Also they found that increasing the amount of Si and Mg_2Si particles led to increase the hardness of the composite. They noticed that Mg_2Si particles can be obtained when the content of Si particles and Mg not lesser than 19% and 4% respectively.

In this work Al-19%Si-Mg alloys with different Mg concentrations were prepared using centrifugal casting with different mould rotational speeds and characterized metallugraphically. Furthermore, wear test has been performed for all prepared alloys under dry sliding conditions to determine wear properties.

2. Experimental Work

Vertical centrifugal casting system has been used in this work to prepare Al-Si-Mg alloys as shown in figure (1). The mould rotational speed can be controlled by changing the outer diameter of the pulleys. Commercially pure aluminum provided by the General Company for Electrical Industries in Baghdad, Al-22%Si master alloy provided by Department of Production Engineering and Metallurgy /University of Technology in Baghdad, and master alloy of Al-50%Mg alloy are used as starting materials in this work. Chemical composition analysis of these materials is illustrated in Table 1 which was conducted at the General Company for Testing and Engineering Rehabilitation in Baghdad using spectrometer type max device. Three alloys were produced with different magnesium percentage and different mould rotational speeds as shown figure (2). The chemical compositions of manufactured Al-Si-Mg alloys are illustrated in table 2.

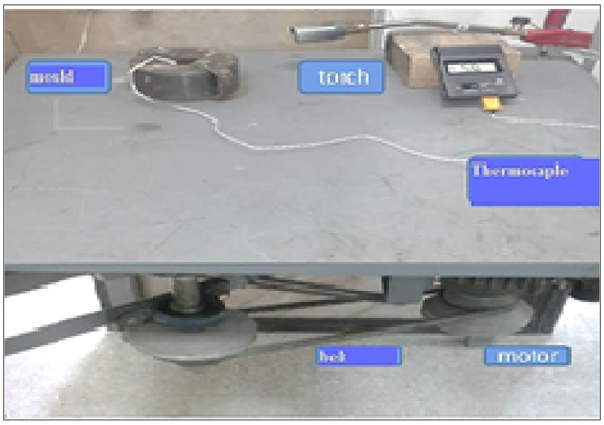

Fig. 1. Vertical centrifugal casting system.

Table 1,
The chemical composition analysis of Al-Si master alloy and pure aluminum used.

Materials	Si	Fe	Cu	Mn	Mg	Cr	Ni	Zn	Ti	Al
Master alloy (Al-22%Si)	21.7	0.48	0.02	0.013	0.005	0.024	0.007	0.034	0.025	Bal.
Pure Al	0.8<	0.4	0.04	0.01	0.005	0.003	0.001	0.03	0.009	Bal.

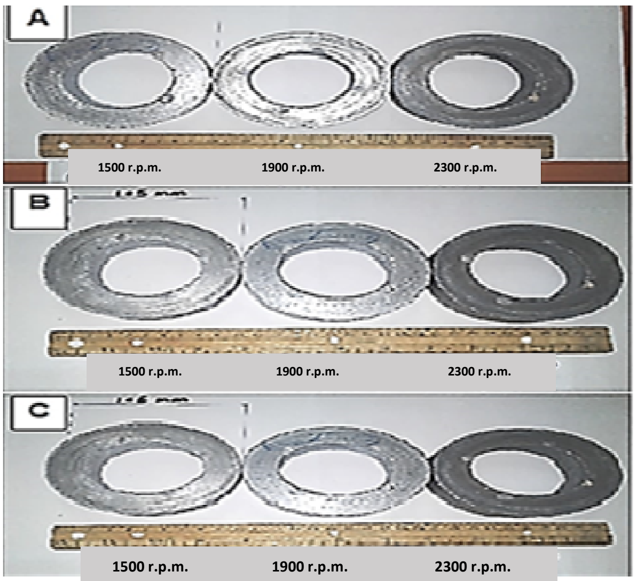

Fig. 2. Shows Al-Si-Mg alloys manufactured with different Mg contents using different mould rotational speeds (a) 392 Al alloy, (b) Al-19%Si-3%Mg alloy and (c) Al-19% Si-5% Mg alloy.

Table 2,
The chemical composition analysis of manufactured Al- Si-Mg casting alloys

	Chemical composition %										
Sample	**Si**	**Fe**	**Cu**	**Mn**	**Mg**	**Cr**	**Ni**	**Zn**	**Ti**	**Pb**	**Al**
Al-19%Si-1%Mg alloy (alloy A)	20.3	0.24	0.06	0.02	1.1	0.002	0.001	0.01	0.01	0.06	Bal.
Al-19%Si-3%Mg alloy (alloy B)	19	0.23	0.12	0.03	2.9	0.004	0.001	0.004	0.01	0.01	Bal.
Al-19%Si-5%Mg alloy (alloy C)	19.7	0.31	0.37	0.07	5.1	0.009	0.001	0.01	0.01	0.03	Bal.

Wear test was achieved using standard pin-on-disc machine, at the Department of Materials Engineering. It consists of a steel disc rotated continuously and considered as a counterface material. The wear test pin was supported with holder vertically at one end of a lever arm. The disc was made from AISI steel with hardness of (277 Hv). The motor has rotational speed fixed at 950 rpm. Wear rate is determined using the following equation [8]:

Wear rate (g/cm) $=\Delta W/(2\pi rnt)$ …(1)

Where $\Delta W= (W_1-W_2)$ is weight loss after testing (g)
r is sliding circle diameter (cm)
t is wear test time (15 min)
n is disc rotational speed (r.p.m) .

3. Results and Discussion
3.1 Microstructure Study

Figure 3 illustrates the microstructure of 392 Al alloy at mould rotational speed of 1900 r.p.m. In the inner layer as shown in figure (3-a- b) primary silicon particles distribute heterogeneously, and take up a higher volume fraction (28%). The volume fraction of primary silicon particles reduces gradually as shown in fig (3-c to h). In the near outer layers (3-i), the volume fraction of appeared primary silicon particles was (18.5%). At the outer layer (figure 3- j), primary silicon also appears. The reason for that is the high cooling rate at this speed which prevents the homogenous distribution but gradual distribution of primary silicon particles. This can be explained on the basis that at this speed of mould rotation, the centrifugal force impels the primary silicon particles to outside at the rapid solidification which take place on the molten alloy in contact with mould wall which led to retention of primary silicon at outer layer, and as the rapid solidification continue, silicon particles move toward inside. As the latent heat of freezing evolves through solid-liquid interface toward liquid metal front, this allows for silicon particles to grow and move quickly in the molten metal until it reaches inner layer of the casting.

Figure (4) illustrates the microstructure of Al-19%Si-3%Mg alloy at mould rotational speed of 1900 r.p.m. This mould rotational speed led to give higher centrifugal force, which results in clear gradation of primary Si particles in the matrix with volume fraction 25% and average particle of 14% µm at the inner regain.

The addition of 5% magnesium led clearly to evolve Mg_2Si phase in the matrix, in conjunction with α-Al and silicon phases in Al-19%Si-5%Mg alloy at mould rotation of speed of 1900 r.p.m as shown in figure (5). It is clear that plenty of black granular (Mg_2Si) particles appear for the first time, almost all of them are distributed in the inner zone and the middle zone as shown in figure (5- a-e) with volume fraction of Mg_2Si phase of (9)% with average particles size of (23) µm, and volume fraction of Si (20)% with particle average size of (24) µm in inner layer. Only a few of them are distributed in the external zone as shown in figure (5- j). The primary Si particles are only distributed in the inner, some in the middle, and the outer zones, just like the Mg_2Si particles. Also it is noted that refined dendrites of α–Al in the outer region and near outer region due to the quenching of molten metal interacting with mould surface which results in high solidification velocity as shown in figure (5-f-j). It is clear that the primary silicon and Mg_2Si distribution depends on solidification process and centrifugal force during centrifugal casting of the Al-19%Si-5%Mg alloy. The Mg_2Si and Si particles are moved and concentrated in the inner region of the ring as a result of the density of (Mg_2Si) with the value of 1.93 g/cm^3 [9], which is less than that of base alloy, under the centrifugal force effect, where the cooling rate decreased as shown in figure (5-a-e). There are very few of particles in the middle region (figure 5-f-i) of the ring. At the same time, under the centrifugal force effect, primary silicon particles were gathered toward the inner region of the ring. This can be explained on the basis that the Mg_2Si particles centripetal velocity is higher than that of primary silicon.

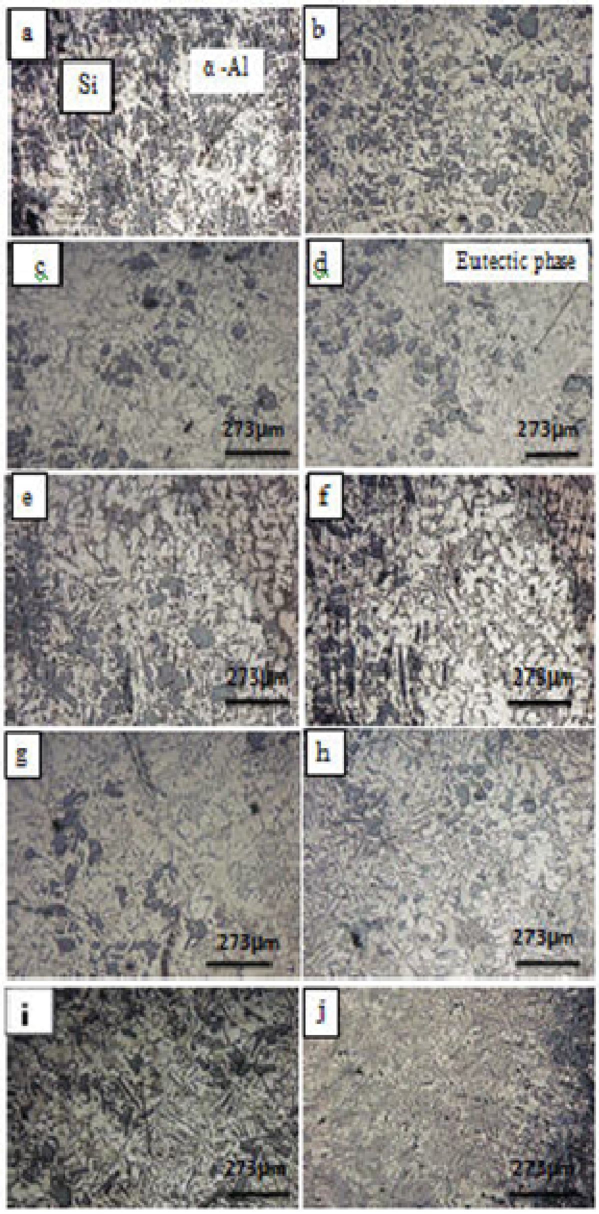

Fig. 3. Microstructure of 392 Al alloy at different zones (a) 2 mm, (b) 4 mm, (c) 6 mm, (d) 8 mm, (e) 10 mm, (f) 12 mm, (g) 14 mm, (h) 16 mm, (i) 18 mm, (j) 20 mm, determined from the inner surface at mould rotational speed of 1900 r. p.m..

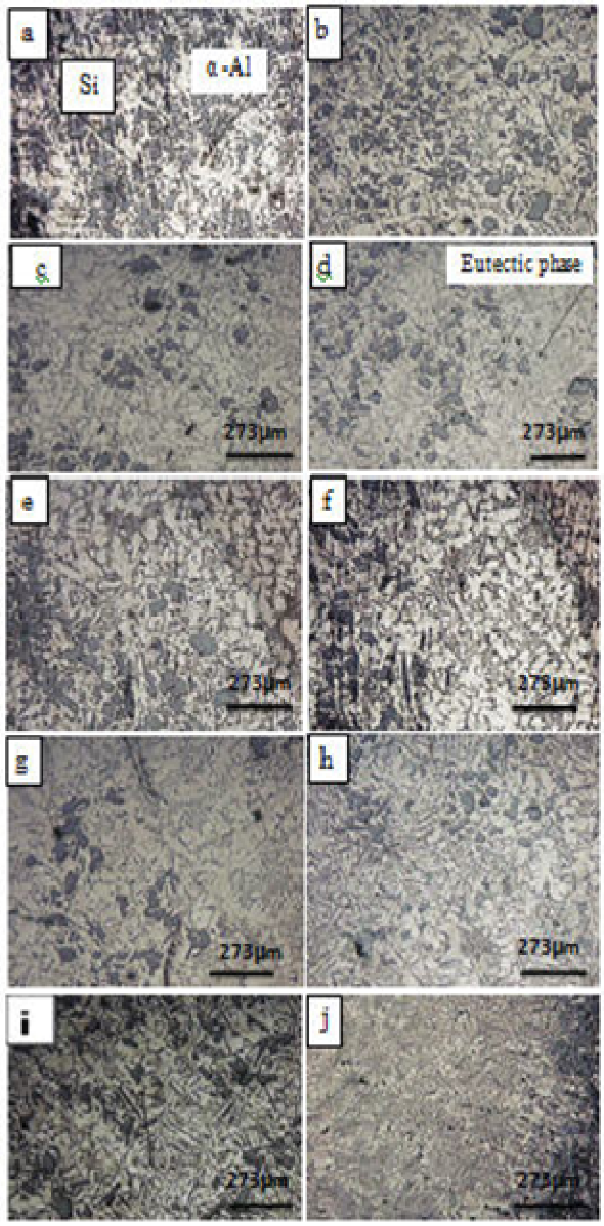

Fig. 4. Microstructure of Al-19%Si-3%Mg at different zones (a) 2 mm, (b) 4 mm, (c) 6 mm, (d) 8 mm, (e) 10 mm, (f) 12 mm, (g) 14 mm, (h) 16 mm, (i) 18 mm, (j) 20 mm determined from the inner surface at mould rotational speed of 1900 r. p.m..

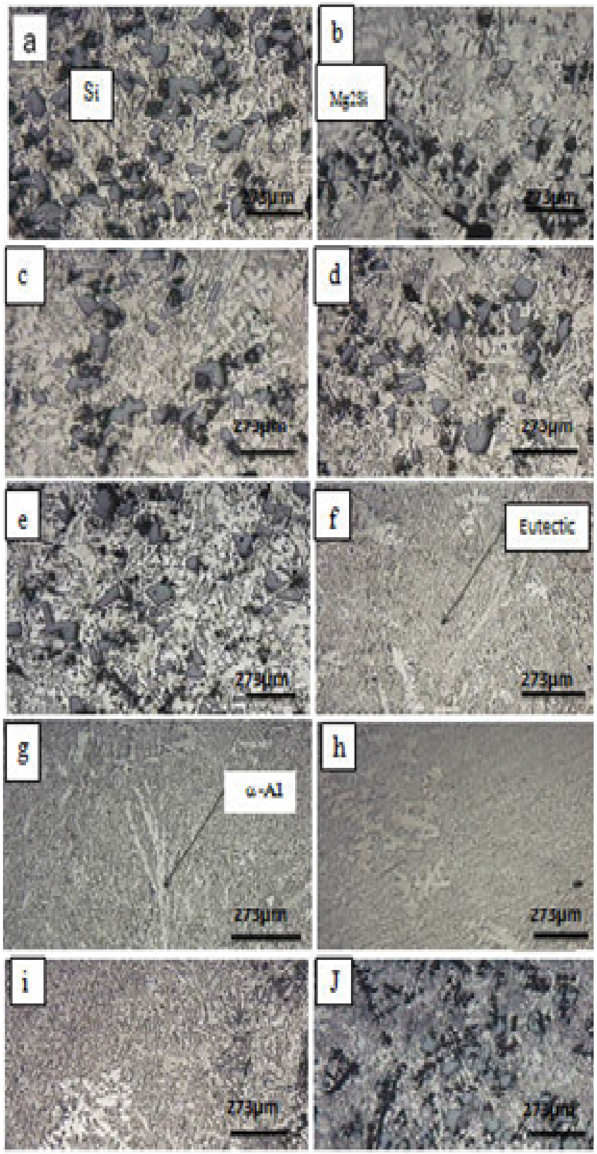

Fig. 5. Microstructure of Al-19%Si-5%Mg at at different zones (a) 2 mm, (b) 4 mm, (c) 6 mm, (d) 8 mm, (e) 10 mm, (f) 12 mm, (g) 14 mm, (h) 16 mm, (i) 18 mm, (j) 20 mm determined from the inner surface at mould rotational speed of 1900 r. p.m.

3.2 Wear Behavior Study

The relationship between wear rate and loads of Al-Si-Mg alloys are showed in figures (6-8) at different Mg percentage and mould rotational speeds. It is noted from these figures and eye observations that oxidative-metallic wear is the wear mechanism during dry sliding. The dry sliding of centrifugal casted Al-Si-Mg Alloys on the carbon steel counterface was achieved at room temperature. The plastic deformation of Al-Si-Mg alloys pins increases with increasing load. This leads to an increase in the contact area between pin surface and counterface. Oxidative wear occurs as a result of oxidation of hardened surface and fracture. The fractured surfaces (debris) are compacted between the two surfaces, pin and counterface. During metallic wear, the pin surface of Al-Si-Mg alloys is characterized by deformation in the surface and subsurface region and fracture. The plastic deformation is concentrated firstly in pin surface of Al-Si-Mg alloys. Therefore, an increase in the density of dislocation is occurred which results in brittleness in pin surface of Al-Si-Mg alloys. This brittleness creates small cracks in the subsurface region of pin worn surface of Al-Si-Mg alloys. Finally, these cracks are expanded toward the external pin surface under the influence of applied load. It is clear from figures (9-11) which represent the relationship between wear rate and mould rotational speeds that the best result was achieved at mould rotational speed of 1900 r.p.m especially for Al-19%Si-3% and Al-19%Si- 5% Mg alloys. There is decreasing in the wear rate value for 392 Al alloy at mould rotational speed of 1900 r.p.m. Therefore, one can have concluded that the lower wear rate can be obtained when mould rotational speed is 1900 r.p.m. This means that the best gradual distribution of primary silicon and Mg_2Si particles that withstand the applied load achieved at mould rotational speed of 1900 r.p.m. In other words, the larger volume fraction of primary silicon and Mg_2Si particles in the inner region contributed to high value of hardness due to the high hardness value of primary silicon (1000-1300 Hv) and Mg_2Si particles (460 Hv) [10]. Therefore, primary silicon and Mg_2Si particles segregation in the inner region imparted a lower wear rate at 1900 r.p.m mould rotational speed compared with other mould rotational speeds. The increase of this segregation especially for Mg_2Si particles with increasing Mg content makes Al-19Si-5%Mg alloy has a lower wear rate compared with others Al-19%Si-Mg alloys.

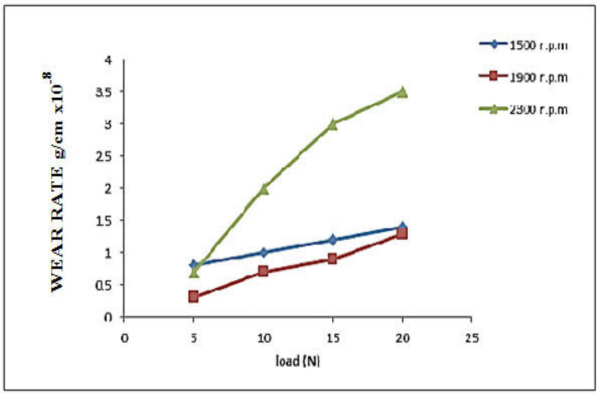

Fig. 6. Effect of load on the wear rate of 392 Al alloy at different mould rotation speeds.

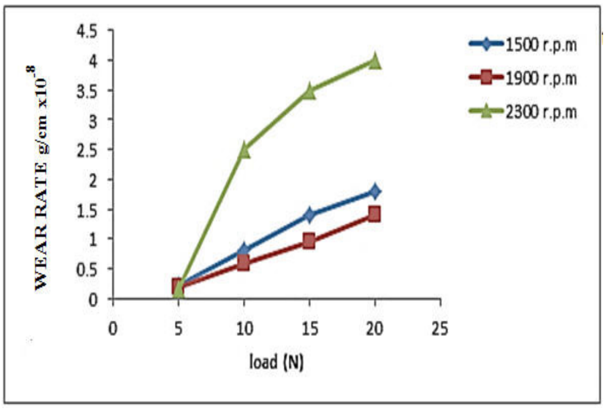

Fig. 7. Effect of load on the wear rate of Al-19%Si-3%Mg alloys at different mould rotational speeds.

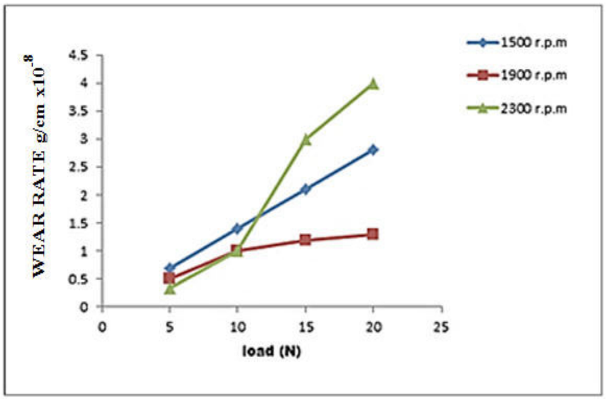

Fig. 8. Effect of load on the wear rate of Al-19%Si-5%Mg alloy at different mould rotational speeds.

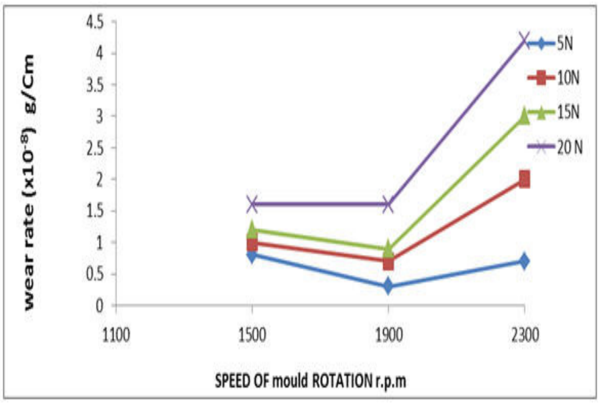

Fig. 9. The relation between wear rate and speed of mould rotation of 392Al alloy.

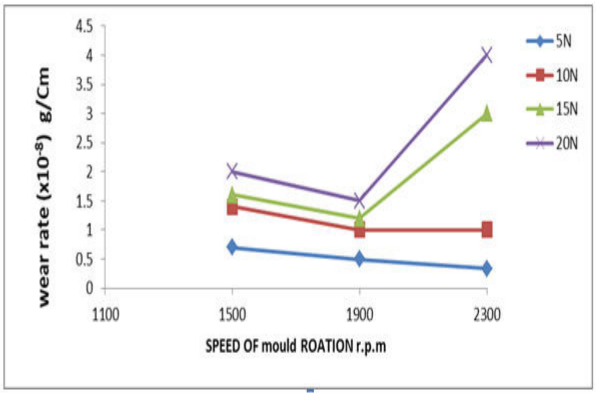

Fig. 10. The relation between wear rate and speed of mould rotation of Al-19%Si-3%Mg alloy.

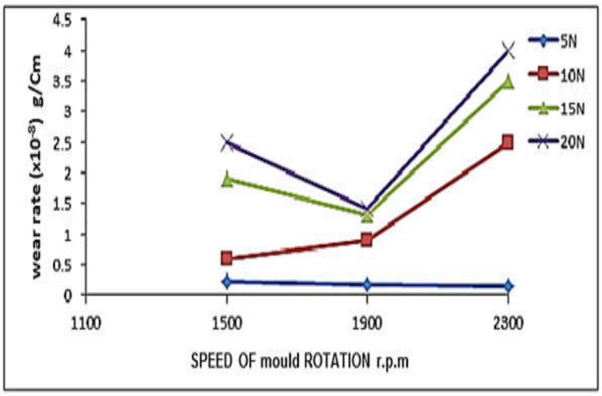

Fig. 11. The relation between wear rate and speed of mould rotation of Al-19%Si-5%Mg alloy.

4. Conclusions

1. Gradual distribution of primary Si and Mg_2Si from inner layer to the outer region has been performed using centrifugal casting.
2. Mg addition has an important effect on increasing the hardness of Al-19%Si-%Mg alloy in which with increasing Mg percentage, hardness will increase.
3. Increasing Mg percentage of Al-Si-Mg alloy results in a decrease in the wear rate.
4. The highest hardness value and lowest wear rate can be observed in Al-19%Si-5%Mg at mould rotational speeds of (1900) r.p.m.

5. Refrenens

[1]Metals Handbook, 9 th ed., Vol.2,“ Properties and selection : non ferrous alloys and pure metals”, American Society For Metals , Metals Park (Ohio), 1979.

[2]E. Panda, S. P. Mehrotra, D. Mazumdar, "Mathematical modeling of particle segregation during centrifugal casting of metal matrix composites", Metall. Mater. Trans.A , 37 (2006) 1675.

[3]W. Chen, Q. Wang, C. Zai, C. Ma, Y. Zhu, W. He, "Functionally graded Zn-AI-Si in-situ composites fabricated by centrifugal casting" J. Mater. Sci. Lett, 20 (2001) 823.

[4]S. Put, J. Vleugels, O. Van der Biest, "Microstructural engineering of functionally graded materials by electrophoretic deposition", J. Mater. Proc. Technol., 143 (2003) 572.

[5]B. Zhou, "Functionally graded Al/Mg2Si in-situ composites, prepared by centrifugal casting", J. Mater. Sci. lett., 17 (1998) 1677.

[6]G. Chirita., D. Soares, F.S Silva., "Advantages of the centrifugal casting technique for the production of structural components with Al-Si alloys", Mater. & Design, 29 (2008) 20.

[7]Y. Xie, C. Liu, Y. Zhai, K. Wang, X. Ling, "Centrifugal casting processes of manufacturing in-situ functionally gradient composite materials of Al-19Si-5Mg alloy", Rare Met., 28 (2009) 405.

[8]Y. Zhai, X. Ma, Z. Mei, “Centrifugal forming mechanism of Al gradient composites reinforced with complementary primary Si and Mg2Si particles”, Rare Met. Mater. and Eng., 43 (2014) 769.

[9]S. Das, D. Mondal, S. Sawla and N. Ramkrishnan, " Synergic effect of reinforcement and heat treatment on the two body abrasive wear of an Al–Si alloy under varying loads and abrasive sizes", Wear, 264 (2008) 47.

[10] J. G. Kaufman, E. L. Rooy, “Aluminum alloy castings: properties, processes, and applications”, ASM International, Materials Park (Ohio), (2004).

تحسين خواص البلى لسبيكة المنيوم 392 باستخدام السباكة بالطرد المركزي

عقيل ظاهر صبحي*　　　عدنان محيسن عبد**

*،** *قسم هندسة الانتاج والمعادن/ الجامعة التكنولوجية/ بغداد*

* البريد الالكتروني: 70071@uotechnology.edu.iq

** البريد الالكتروني: mhsnd8500@gmail.com

الخلاصة

□م في هذا البحث دراسة التركيب المجهري وخواص البلى لسبيكة المنيوم ٣٩٢ والتي□حتوي على نسب مغنسيوم مختلفه باستخدام سباكة الطرد المركزي. اذ□م صهر جميع السبائك في درجة حراره ٨٠٠ م° وصبت في قالب الطرد المركزي اللذي سخن مسبقا ضمن مدى حراري يتراوح بين ٢٠٠-٢٥٠ م° بسرع دورانية مختلفة (١٥٠٠، ١٩٠٠ و٢٣٠٠) دوره/دقيقه. اوضحت النتائج ان معدل البلى والصلاده يعتمدان على محتوى المغنسيوم والحمل المسلط علاوة على السرعه الدورانيه للقالب. اضافة لذالك فان اختبار البلى اظهر ان اقل معدل للبلى لللطبقه الداخليه للحلقات المنتجه كان عند سرعة دورانية للقالب ١٩٠٠ دوره/دقيقه، وعند نسبة مغنسيوم 5%.