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Abrasive Wear of Al-Mn Alloys

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ABSTRACT

Aluminum-Manganese alloys are often used as a solution to wear resistance and mechanical behavior problems in industry, where many parts have to exhibit high abrasive wear resistance and considerable mechanical properties. In the present work, the effect of microstructural changes on the wear behavior of Al-Mn alloys was investigated. Cast specimens of Al-Mn alloys were tested using pin-on-disk machine. The effect of wear parameters, such as load, linear speed, surface roughness and sliding time, on wear resistance was investigated. The wear resistance was evaluated by wear rate during certain intervals of time. The results indicate that wear resistance can be improved by increasing the percentage of Mn to 1.5%. The wear surface was studied using optical metallurgical microscope. The results show that polishing wear occurs due to the effect of fine abrasive particles. Work hardening layer (white layer) has appeared on the worn surface of specimens, which means that the wear resistance has been improved.

KEYWORDS: Abrasive wear, Al-Mn alloys, Wear resistance, Polishing wear.

1. INTRODUCTION

Metal matrix composite materials offer exciting possibilities for improving the performance of bulk metals. Improved strength-and stiffness-to-weight ratios, tribological properties and thermal resistance can be realized. The properties of metals and their alloys depend strongly on their processing. For example, the distribution of phases, grain structure, alloy compositional segregation and defects in final commercial products depend on the conditions under which materials are processed and fabricated. These distributions in turn are crucial in determining the alloy strength, ductility, homogeneity and other properties important for industrial applications. The metal processing focuses on measurements and predictive models needed by industry to design improved processing conditions, provide better process control, develop improved alloy and coating properties and tailor material properties for particular applications.

In advanced engineering materials, composites are used in many applications, where high wear resistance is required. Indeed, compared to monolithic materials, wear resistance can generally be enhanced by introducing a secondary phase into the matrix material (Bhansali and Mehrabian, 1982; Dogan and Hawk, 1997; Khruschov, 1974; Axen and Zum-Gahr, 1992).In this fashion the wear properties can be varied substantially through changes in the microstructure, the morphology, volume fraction and mechanical properties of the reinforcing phase and the nature of the interface between matrix and reinforcement (Al-Araji and Sarhan, 2001). In order to obtain optimal wear properties without compromising the beneficial properties of matrix materials, an accurate prediction of the wear of composites is essential. Unfortunately, for abrasive wear, existing models for composites are highly simplified and do not readily predict the role of the composite microstructure (Axen and Jacobson, 1994).

Wear is the loss of material from a surface caused by the interaction with another surface or material. The main mechanisms of interaction are applied loads and relative motion, which can cause adhesion and abrasion or fatigue, all of which can lead to material loss (Ten and Dharan, 1996). The sliding of abrasive on a solid surface results in volume removal of material. The mechanism of wear depends on the mechanical properties of the solid

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(Hutchings, 1992; Zum-Gahr, 1987). In ductile material, the primary wear mechanism is related to plastic deformation; correspondingly, the hardness of the material is a key parameter in governing the amount of material removal. However, the dominant mechanism in a brittle material depends on the fracture nature or the surface toughness of the material.

To improve wear resistance, additional phase can be introduced to either a ductile or a brittle matrix material. However, the required mechanical properties of the reinforcement and the role of the reinforcement will be different in ductile *vs*. brittle materials. For a ductile matrix a hard secondary phase is needed to reduce wear, such that the presence of the hard reinforcement increases the effective hardness of the matrix, thereby reducing the penetration of the abrasive material. Consequently, increasing the effective hardness acts to reduce the amount of material removed Axen and Jacobson, 1999).

Quasicrystalline aluminum-based alloys have become promising due to their high strength- to- weight ratio. This is due to an appropriate combination of the high-strength characteristics of quasicrystals with sufficient ductility by mixing with aluminum as metal matrix component on a nanoscale (Schurack et al., 2001). The aim of this work is to investigate the role of manganese on the wear properties of Al-Mn alloys. Manganese has very limited solubility in aluminum in presence of normal impurities, but remains in solution.

2. Experimental Procedure

Ingots were produced by pouring the molten metal of Al-Mn alloy into a steel mold with inner diameter of 25mm and 40mm length. Wear specimens of 5mm diameter and 25mm length were machined out from the middle portion of the ingots. Microstructural examination was made to check the homogeneity of the structure. Specimens containing different percentages of Mn were studied. Their chemical compositions are shown in table 1. Commercial aluminum was used as a matrix material. Its chemical composition is given in table 2. Wear tests were carried out at room temperature using pin-on-disc machine.

To determine the resistance against pure two-body abrasion, most of the Al-Mn specimens were abraded dry against ϕ 230mm SiC paper with a particle size of 15-60 μm. In this test specimens were mounted in a holder placed in relation to the rotating SiC paper. The press force on the specimens varied from 0.5-2.5N. The rotational speed of the SiC paper was 50-450rpm. Each test embodied three test runs of 120s duration with an exchange of SiC paper after each run and the average wear rate has been taken into consideration. Commercial aluminum was used as reference. The wear rate in g.s^{-1} was calculated by the following equation:

$$\text{Wear rate} = \frac{w_1 - w_2}{s_t}$$

where w_1 is the initial weight of specimen before test in g, w_2 is the final weight of specimen at the end of test in g and s_t is the sliding time in s. The experimental conditions of wear tests are given in table 3.

3. Results and Discussion

3.1 Effect of sliding time on the wear rate

The wear rate in Al-Mn alloys and commercial aluminum as a function of sliding time is shown in Fig. 1. It is clear that the wear rate decreased with increasing the sliding time. This decrease was pronounced at the beginning of the test, and then steady-state was reached due to the work hardening. Most of the specimens show three stages of wear behavior. Specimen with 1.5% Mn shows good wear resistance as compared with the others at the same test conditions. This is due to the effect of crystalline solid solutions in Al-Mn composite (Grushko, 1999).

3.2 Effect of load on the wear rate

The effect of load on the wear rate is shown in Fig. 2. In all specimens the wear rate increased with increasing the applied normal load at constant linear speed. The wear rate in commercial aluminum specimen under 2.5N load was five times higher than in 1.5% Mn alloy specimen. This means that 1.5% Mn alloy is more wear resistant than commercial aluminum (Schurack et al., 2001). Also the specimen with 1.5% Mn shows a steady state wear rate with increasing the applied load from 1N to 2N. This means that the alloy experienced work hardening during the test, and this leads to the increased wear resistance. This result can be observed from Figs. 3 and 4, which show a typical microhardness exploration of Al-Mn alloys and commercial aluminum. There is a considerable increase in hardness in 1.5% Mn alloy. This is probably caused by work hardening during service. The work hardening zone of the worn surface of this alloy is shown in Fig. 5, where the thin zone resists the plough action of abrasives.

3.3 Effect of linear speed on the wear rate

Fig. 6 shows the effect of linear speed on the wear rate. The wear rate increased with the increase of linear speed until a critical speed, at which softening of the worn surface starts. This effect is due to the increase of the contact surfaces temperature which leads to softening of the worn surface, causing decrease of the wear resistance (Bryggman et al.). The test results of Fig. 6 show that specimen of 1.5% Mn is subjected to higher degree of softening as compared with other alloys, so it exhibits better wear resistance.

3.4 Effect of microstructure on the wear rate

Test specimens were divided into three groups according to the content of Mn percentage. The first group contains 0.5% Mn, the second group contains 1% Mn and the third group contains 1.5% Mn. Fig. 7 shows the microstructure of 0.5% Mn alloy, where a solid solution of aluminum and manganese Al_6Mn can be recognized. This fact explains the high wear rate of this alloy. Fig. 8 shows the microstructure of 1% Mn alloy, where a heterogeneous distribution of solid solution of Al_6Mn can be seen. This phenomenon explains the intermediate wear rate of this alloy. Fig. 9 shows the microstructure of 1.5% Mn alloy, where a homogeneous solid solution of Al_6Mn can be seen. This increases the wear resistance of this alloy.

3.5 Effect of abrasive particles on the wear rate

Fig. 10 shows the effect of silicon carbide SiC particles size on the wear rate. The wear rate increased with increasing of the abrasive particles size. The effect of abrasives can clearly be seen as raised, unscratched areas, while micro-spalls are often seen in conjunction with the small particles and larger scratches, as shown in Figs. 11 and 12. Severe plastic deformation associated with the abrasive wear of 1.5% Mn alloy and some cracking and surface fragmentation associated with sliding tracks in commercial aluminum were observed.

4. Conclusions

Based on the results of this study, the following conclusions can be made:

(1) Al-Mn alloys are more wear resistive than commercial aluminum.
(2) The addition of 1.5% Mn to aluminum improves its wear resistance and makes it suitable for many engineering applications.
(3) The wear resistance to abrasion of Al-1.5Mn alloy can reach five times that of commercial aluminum.
(4) The presence of homogeneous solid solution of Al_6Mn in Al-Mn alloys increases the wear resistance.
(5) Under abrasive conditions, the wear rate increased with increase of abrasive particles size.
(6) The degree of work hardening of Al-1.5Mn alloy is much higher than that of other Al-Mn alloys.
(7) A white layer was formed on the worn surface due to the polishing wear in Al-1.5Mn alloy, and this leads to a good wear resistance of this alloy.

Table 1. Compositions of Al-Mn alloys.

Alloy No.	Al (wt %)	Mn (wt %)	Si (wt %)	Mg (wt %)	Fe (wt %)
1	97.89	0.5	1.03	0.45	0.13
2	97.39	1	1.03	0.45	0.13
3	96.89	1.5	1.03	0.45	0.13

Table 2. Chemical composition of commercial aluminum.

Element	(wt %)
Si	1.03
Mg	0.45
Fe	0.13
Al	balance

Table 3. Experimental wear test conditions.

Wear test No.	Load (N)	Linear speed (m/s)	Particles size of SiC paper (μm)	Time (s)
1	2	0.679	40	60, 120, 180, 240
2	0.5, 1, 1.5, 2, 2.5	0.679	40	120
3	2	0.138, 0.407, 0.950, 1.222	40	120
4	2	0.670	15, 20, 30, 60	120

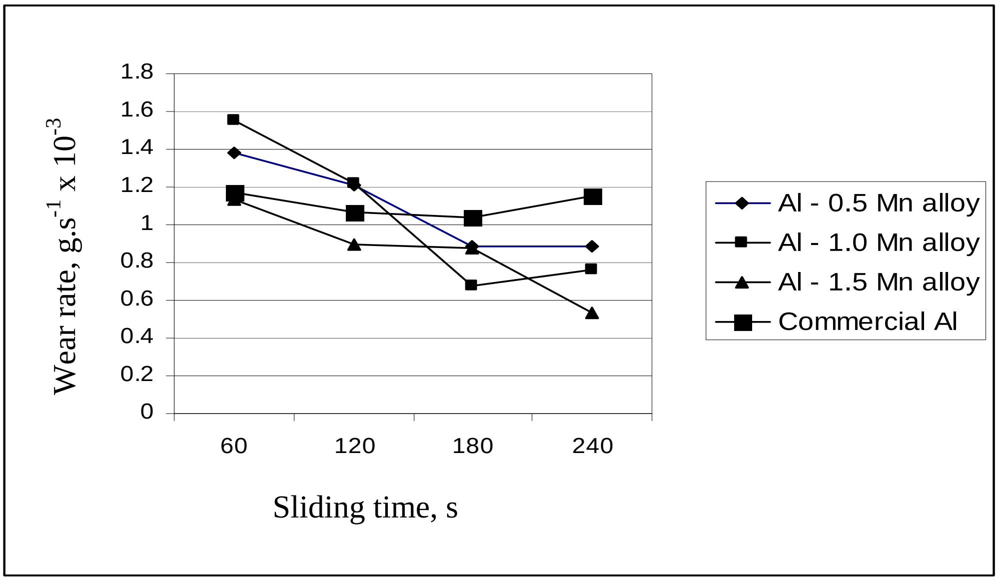


Fig. 1 Effect of sliding time on wear rate.

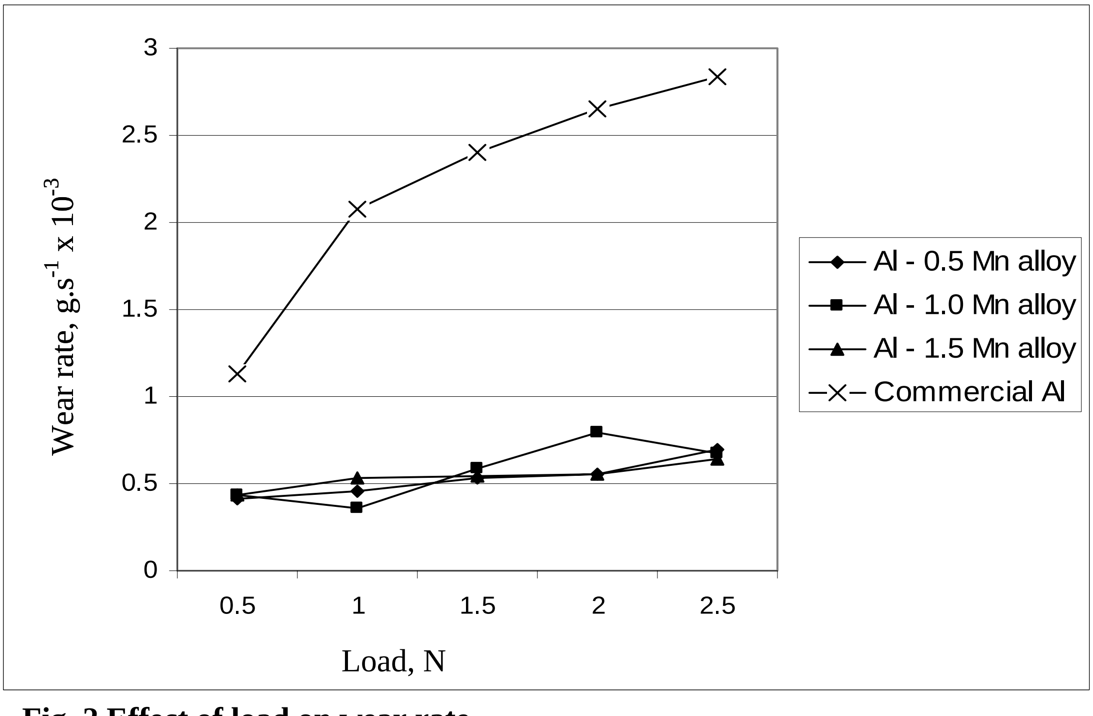


Fig. 2 Effect of load on wear rate.
(linear speed= 0.679m/s, sliding time=60s, abrasive particles size=50 μ m).

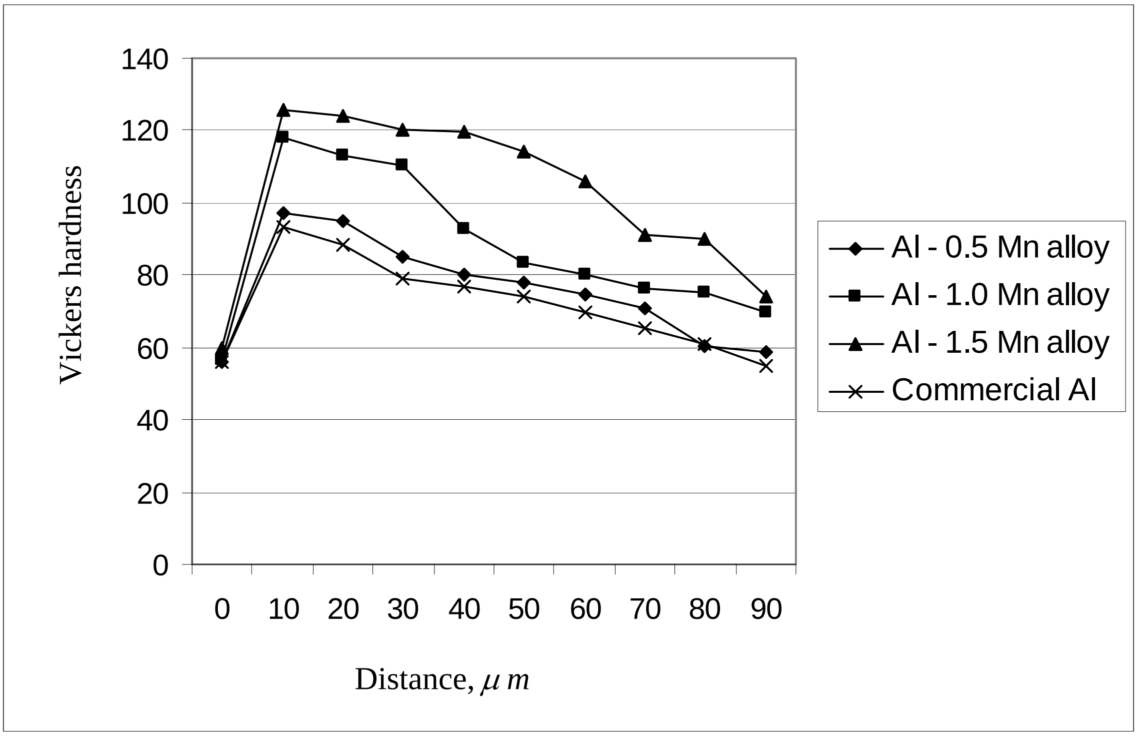


Fig. 3 Vickers hardness (from surface to center) at maximum load 2.45N and time 120 s.

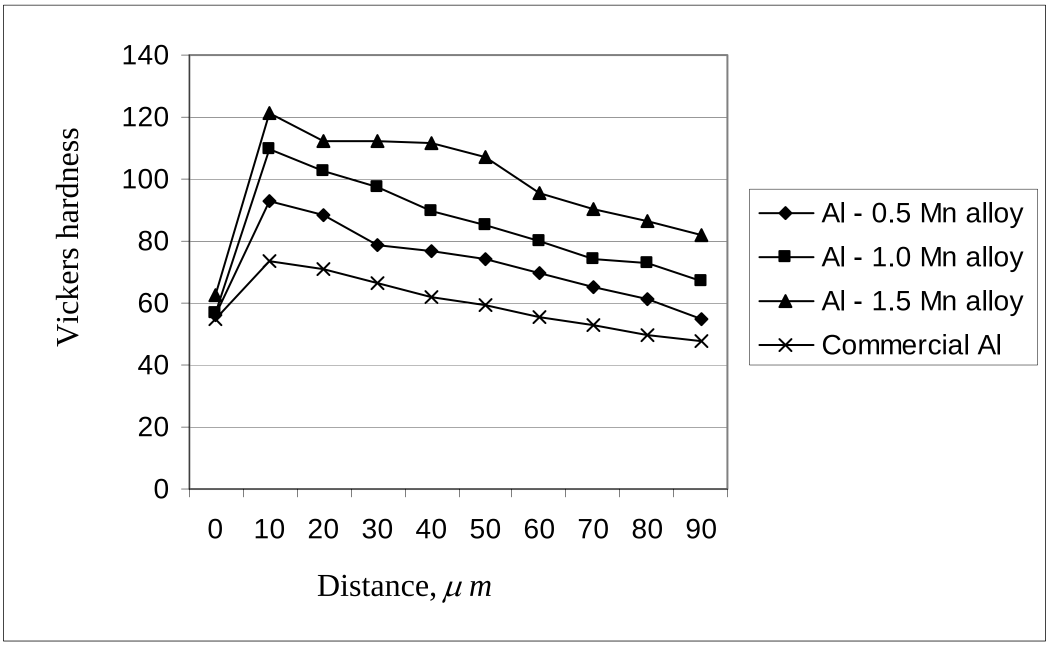


Fig. 4 Vickers hardness (from surface to center) at minimum load 0.45N and time 120s.

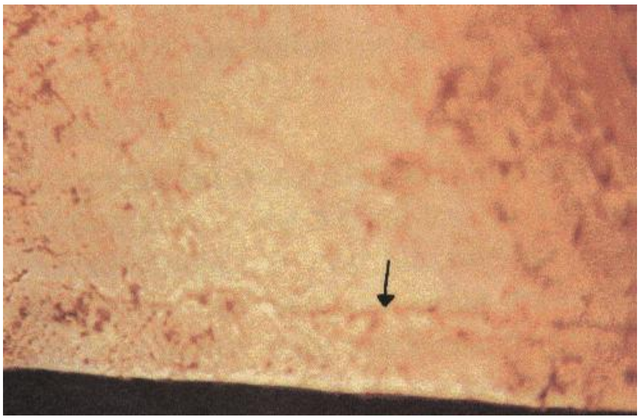


Fig. 5 Effect of maximum load on surface damage and layer of material removal of Al-1.5Mn alloy (40X).

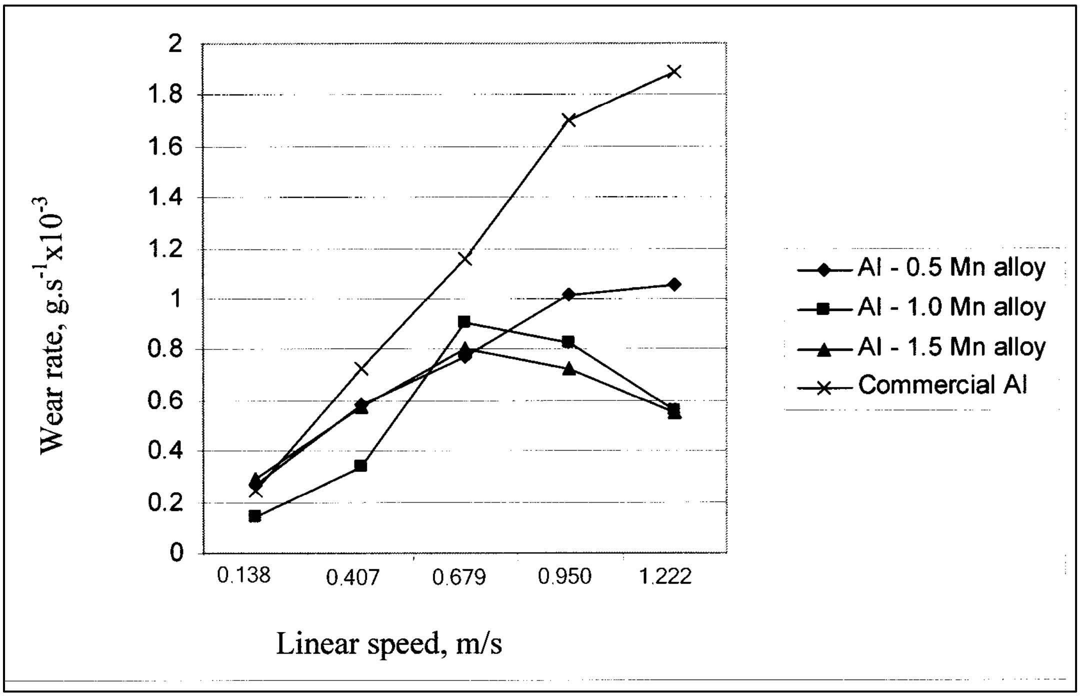


Fig. 6 Effect of linear speed on wear rate.
(abrasive particles size=40 μm, load=2N, sliding time=120s).

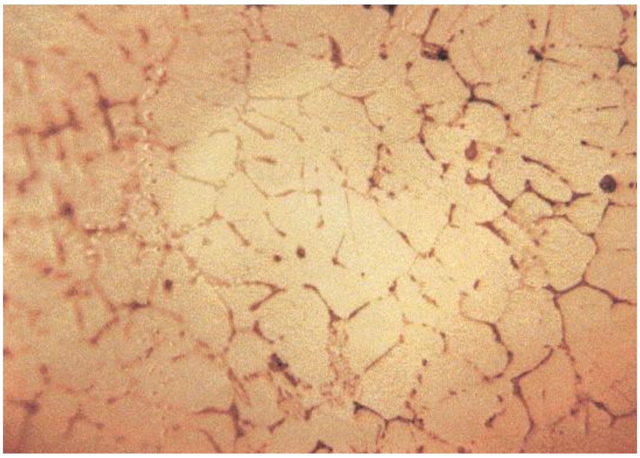


Fig. 7 Microstructure of Al-0.5Mn alloy (20X).

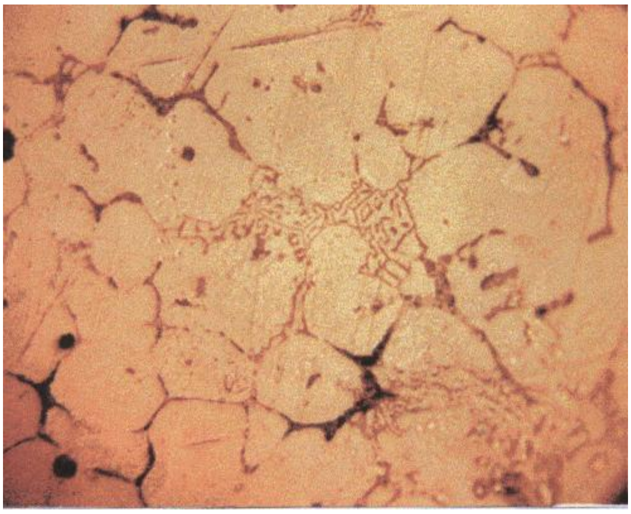


Fig. 8 Microstructure of Al-1.0Mn alloy (40X).

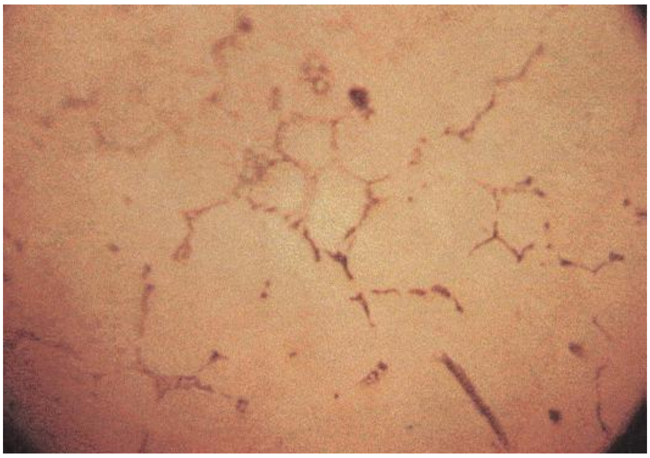


Fig. 9 Microstructure of Al-1.5Mn alloy (40X).

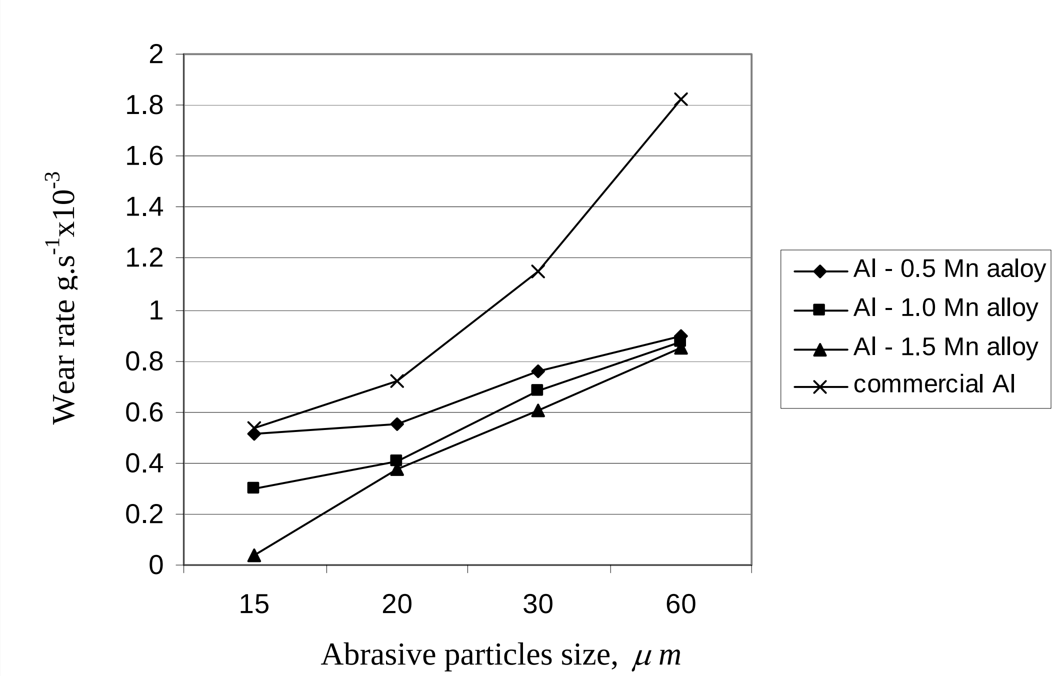
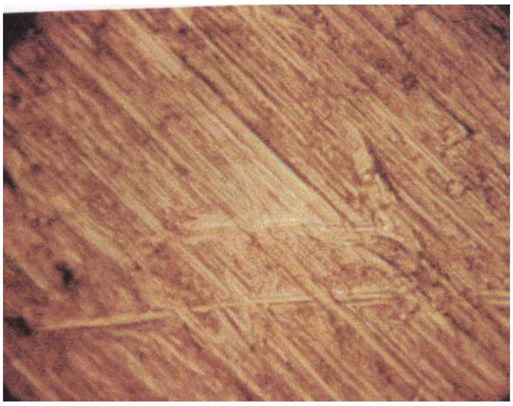


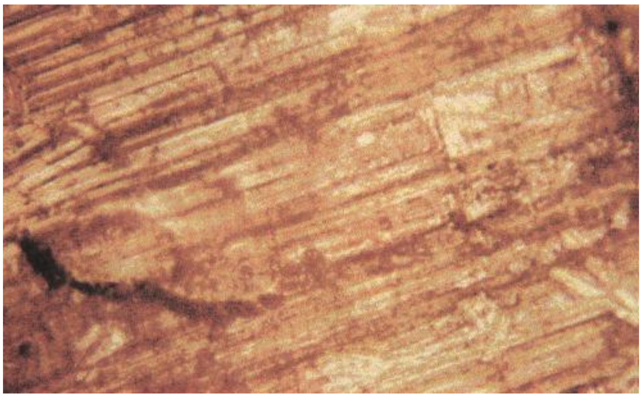
Fig. 10 Effect of abrasive particles size on wear rate.
(linear speed=0.679m/s, load=2N, sliding time=120 s).



(a)

(b)

Fig. 11 Effect of abrasive particles size (μm) on surface roughness of alloys.
(a) Al-0.5Mn alloy, (b) Al-1.0Mn alloy.



(a)

(b)

Fig. 12 Effect of abrasive particles size (μm) on surface roughness of alloys. (a) Commercial aluminum, (b) Al-1.5Mn alloy.

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التآكل بالحك في سبائك الألومنيوم – المنغنيز

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ملخـص

كثيراً ما تستخدم سبائك الألومنيوم- المنغنيز لحل المشكلات المتعلقة بمقاومة التآكل والسلوك الميكانيكي في الصناعة، حيث يتعين على العديد من الأجزاء أن تبدي مقاومة عالية للتآكل بالحك وخصائص ميكانيكية معتبرة.

في هذا البحث، تم استكشاف أثر التغيرات في البنية المجهرية على السلوك الخاص بالتآكل في سبائك الألومنيوم-المنغنيز؛ فقد درس أثر عدد من العوامل ذات العلاقة بالتآكل لعينات من هذه السبائك، مثل: الحمل، والسرعة الخطية، وخشونة السطح، وزمن الانزلاق على مقاومة التآكل. وقد جرى تقييم مقاومة التآكل بواسطة معدل التآكل في فترات زمنية معينة.

وبينت النتائج أن تحسين مقاومة التآكل لهذه السبائك أمر ممكن من خلال زيادة نسبة المنغنيز إلى (1.5%).

لقد تمت دراسة سطح التآكل باستخدام المجهر الضوئي الخاص بالمعادن.

وأوضحت النتائج أن تآكل الصقل يحدث بسبب أثر الحك للجسيمات الدقيقة. وقد ظهرت طبقة التقسية البيضاء على سطوح العينات المتآكلة الأمر الذي يعني أن مقاومة التآكل قد تحسنت.

الكلمات الدالة: التآكل بالحك، سبائك الألومنيوم-المنغنيز، مقاومة التآكل، تآكل الصقل.

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