FRICTION AND WORN SURFACE TOPOGRAPHICAL FEATURES OF AS-CAST, MODIFIED AND HOMOGENIZED ALUMINUM-SILICON ALLOYS

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ABSTRACT

The coefficient of friction was experimentally calculated for aluminum-silicon alloys by connecting a strain gauge to the arm of pin-on-disc wear machine in order to take microstrain readings from the strain-meter. As-cast and modified aluminum-silicon alloys were thermally homogenized for long periods of time (1-40hr) in order to study the effect of homogenization on friction. Scanning electron microscopy was successfully used to build up the mechanism of surface damage during sliding. The results showed that the coefficient of friction was increased with increasing bearing pressure for as-cast, modified and homogenized aluminum-silicon alloys. Thermal homogenization led clearly to remarkable changes in the frictional behavior of as-cast and modified aluminum-silicon alloys. Many mechanisms were responsible for aluminum-silicon alloys surface damage during sliding.

الخلاصة

تم حساب معامل الاحتكاك عمليا لسبائك الالمنيوم-سليكون من خلال ربط مقياس الانفعال بجهاز البلى الالتصاقي لغرض تسجيل قراءات الانفعال المايكروية . اجريت المجانسة الحرارية لسبائك الالمنيوم-سليكون المصبوبة والمحورة لفترات زمنية طويلة (40-1 ساعة) لغرض دراسة تاثيرها على الاحتكاك. استخدم المجهر الالكتروني الماسح بنجاح لغرض دراسة تضرر المنطقة السطحية اثناء الانزلاق. اوضحت النتائج زيادة معامل احتكاك بزيادة ضغط التحميل لجميع السبائك المصبوبة والمحورة والمجانسة. ادت المجانسة الحرارية الى تغيرات واضحة في السلوك الاحتكاكي لسبائك الالمنيوم-سليكون المصبوبة والمحورة. اسهمت العديد من الاليات في تضرر سطح سبائك الالمنيوم-سليكون اثناء الانزلاق.

Key Words: Friction and Worn Surfaces, Al-Si Alloy, Topographical Features, As-Cast

INTRODUCTION

Friction can be defined as a resistance to motion occurring during tangential displacement of contact surfaces in the real area of contact under applied force **(Halling 1979 and Rigney 1981)**. Components used in tribological applications are exposed to friction during their work **(Nayak 2004 and Zhang 2004)**. One of the mostly used alloys in tribological applications is aluminum-silicon because of its good wear resistance, high strength to weight ratio, good corrosion resistance and good castability and machinability **(Granger 1988 and Polmear 1989)**. Many investigators studied the friction property not only for aluminum-silicon alloys but also for other materials. **(Sarkar and Clarke 1980 and 1982)** found that the frictional resistance fluctuated violently for most as-cast and age hardened aluminum-silicon alloys, indicated stick-slip and suggested plastic interaction but correlation between surface damage and magnitude of friction could not be found. **(Sakamoto and Tsukizoe 1978)** found that the metal transfer from the soft metal to hard asperities in contact with it caused significant changes in the shape, size and height distribution of the asperities which led to reduce the effect of the initial surface roughness of the hard metal during friction. Consequently the friction force became less dependent on the surface roughness than it did when no metal transfer occur. **(Mahdavian and Mai 1984)** studied the variation in friction coefficient with sliding distance for similar and dissimilar metals. They found that for similar metals sliding on each other there was a significant contribution to friction owing to severe ploughing while for dissimilar metal, the coefficient of fiction was determined primarily by the way metal transfer occurred between sliding surfaces. **(Prasad and Mecklenburg 1993)** found that no significant differences in the friction behavior of the $Al_2O_3.SiO_2$ and Al_2O_3 fiber-reinforced aluminum metal-matrix composite (MMC) and unreinforced alloy when metallugraphically polished samples were used. They also found that when the surface of the MMC was etched, the friction coefficient dropped to a low value of 0.18 and the stick-slip type behavior disappeared. The addition effect of different lead percentages to aluminum-silicon alloys on friction properties was studied by **(Pathak et al. 1997)**. They found that the addition of lead was reduced the interfacial friction and improved the ability of aluminum-silicon alloys to resist seizure. A lower friction coefficient and higher seizure load were obtained for Al-Si-Pb alloys bearing in semi-dry sliding conditions compared with those observed for dry conditions.

The aim of this work is to study the frictional behavior of as-cast and modified aluminum-silicon alloys with titanium. The effect of thermal homogenization with different time periods for aluminum-silicon alloys on frictional behavior is also studied.

MATERIALS AND METHODS

Binary Al-12%Si alloy was prepared by adding small quantity of pure aluminum to Al-13%Si master alloy. Titanium was added to Al-12%Si alloy in different percentages (0.05 and 0.1%Ti) after putting it in an aluminum foil and inserting it to the molten Al-12%Si alloy with good mixing (10 min in time) to ensure solubility and distribution of titanium in the alloy matrix. All alloys were melted in an alumina crucible by using a gas fired furnace. Then these alloys were poured in a preheated carbon steel die (300 C°) to ensure no chilling occurring to these alloys after solidification. The ingots samples produced from casting process have 15 mm diameter and 100 mm length. The chemical composition of pure aluminum, master alloy and prepared aluminum-silicon alloys are illustrated in **Table 1**. All alloys were thermally homogenized at 525 C° with different time periods (1-40 hr) to increase the coherency between silicon particles and aluminum matrix.

Coefficient of friction was measured by taking the microstrain readings from the strain-meter. The strain-meter was connected to the arm of pin-on-disc wear machine through a strain gauge, in which the specimen has been supported. The time of each test was 30 min, in in which the coefficient of friction for each test represents the average value during the test. All specimens were dry slided on a 45 HRC carbon steel disc to make contact with other material.

RESULTS AND DISCUSSION

The frictional behavior of as-cast and modified Al-Si alloys

The relationship between bearing pressure and coefficient of friction (μ) **Fig.1** reveals that the coefficient of friction increases with increasing bearing pressure due to increased interaction and cold welding between the asperities of pin surface and counterface. This means that the surface damage is greater due to tangential traction. Since, strong welds and interaction between the asperities should also mean a high value of friction coefficient because the shear force required to distangle the interaction and cold welding between these asperities is greater in order to make sliding continuous. **Fig.1** also shows that Al-12%Si alloy has a lower coefficient of friction in comparison with the other alloys containing titanium, while the coefficient of friction of the alloy containing 0.1%Ti approached the coefficient of friction of Al-12%Si at high bearing pressure. This approach relies on the wear rate, in which the coefficient of friction increases linearly with wear rate **(Mitchell 1976)**. The wear rate of Al-12%Si alloy is lower in comparison with the other alloys containing titanium **(Subhi 2000)**., therefore Al-12%Si alloy has a lower coefficient of friction. **Fig.2** shows the relationship between sliding distance and coefficient of friction of aluminum-silicon alloys. The figure shows that all alloys have two types of friction coefficient. The first is static and the other is dynamic coefficient of friction. Generally, the static coefficient of friction was greater than the dynamic coefficient of friction for all aluminum-silicon alloys. This is because the asperities are interacted before sliding under applied bearing pressure, and when sliding begins, they need high shear forces to distangle them to make sliding continuous. After increasing the coefficient of friction in the early stage of sliding, its magnitude gradually decreases due mainly to reduction in ploughing action by transfer of material from the aluminum-silicon alloy pin surface to the counter asperities, leading to an increase in the tip angle of the asperities. Under steady state sliding, the dynamic coefficient of friction becomes approximately constant with fluctuation in its magnitude. **(Mitchell and Osgood 1976)** found that this fluctuation depends on the fluctuation in friction force resulted from changes in the number of contacts as well as from changes in the proportion of the welded contacts. **(While Blau 1981)** introduced a comprehensive picture to this fluctuation in which it coincides with the present work. Blau found that the friction depends on many processes as (1) metal transfer (2) film formation and removal (3) debris generation and (4) cyclic surface deterioration. It has bean also shown from **Fig.2** that Al-12%Si alloy has a lower static and dynamic coefficient of friction compared with other alloys containing titanium. This is because the coefficient of friction depends on the wear rate **(Mitchell 1976).**

The frictional behavior of homogenized Al-Si alloys

Thermal homogenization affected the magnitude of friction coefficient and this effect is dependent on the thermal homogenization time. The relationship between bearing pressure and coefficient of friction of homogenized aluminum-silicon alloys **Figs.3-5** showed that the homogenization for 1 hr led to increasing the coefficient of friction for all homogenized aluminum-silicon alloys in comparison with its magnitude in the as-cast and modified aluminum-silicon alloys. This is because the ductility of homogenized aluminum-silicon alloys for 1 hr was increased as a result of internal stresses relief, led to increase the interaction and cold welding between the asperities of pin surface and counterface. Since, the wear mechanism appeared with increasing bearing pressure as interaction between the asperities, and galling as a result of incomplete cold welding during sliding [Subhi 2000]. This demonstrates our explanation in which the increasing coefficient of friction accompany with increasing bearing pressure. With increasing thermal homogenization greater than 1 hr (5-40 hr), the coefficient of friction decreased. This is because the coefficient of friction depends on the wear rate **(Mitchell 1976)**. Decreasing in the wear rate occurred with increasing thermal homogenization time greater than 1 hr **(Subhi 2000)**, therefore, coefficient of friction decreases with increasing thermal homogenization time in comparison with its magnitude at 1 hr. The frictional behavior of homogenized alloys was similar to that of as-cast and modified aluminum-silicon alloys in which the two types of friction coefficient were present regardless of its magnitude, therefore, there is no need to re-explain the frictional behavior during sliding of homogenized alloys at constant bearing pressure.

The study of worn surface

Fig.6 shows the worn surface of as-cast and modified aluminum-silicon alloys where different mechanisms contributed in surface damage during sliding. The predominant mechanism is dependent on the alloy composition and bearing pressure. The worn surface of Al-12%Si alloy revealed that there were many mechanisms responsible for material removal. It has been shown that there was spalling in the worn surface, leading to a large pit formation, as well as there were many subsurface cracks sheared to the surface which were responsible for wear particles formation. These wear particles can be recognized clearly in the worn surface of the alloy containing 0.05%Ti. It has been shown that there were many wear small particles on the surface removed from the surface during sliding. The same wear particles can be shown in the worn surface of the alloy containing 0.1%Ti. These small particles were removed by secondary delamination. Secondary delamination is distinguished by craze cracking. (**Clarke and Sarkar 1981)** found that this secondary delamination may be a function of surface forces only and may have nothing to do with probable subsurface cracking responsible for primary delamination.

The wear mechanisms remained the same for homogenized aluminum-silicon alloys, but in different degrees. The worn surface of homogenized Al-12%Si alloy **Fig.7** shows that there were many surface cracks due to surface traction. These surface cracks were responsible for material removal by secondary delamination. The worn surface of homogenized alloy containing 0.05%Ti shows advanced stage in subsurface crack growth sheared to the surface. There are many surface cracks in the worn surface of homogenized alloy containing 0.1%Ti, as well as many small particles compacted on the surface due to the action of bearing pressure in which these small particles delaminated by secondary delamination.

CONCLUDING REMARKS

1-The coefficient of friction was increased with increasing bearing pressure for as-cast, modified and homogenized aluminum-silicon alloys.

2-Two types of friction coefficient were present, static and dynamic regardless of the magnitudes of these two coefficient types.

3-Thermal homogenization at 1 hr led to an increase in the coefficient of friction in comparison with its magnitude for as-cast and modified aluminum-silicon alloys, while increasing thermal homogenization time greater than 1 hr (5-40 hr) led to a decrease in the coefficient of friction in comparison with its magnitude at 1 hr.

4-Many mechanisms were responsible for surface damage during sliding. The predominant mechanism was dependent on the alloy composition, bearing pressure and thermal homogenization time.

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Table.1 Chemical composition of pure aluminum, master alloy and prepared aluminum-silicon alloys.

Materials	*Composition (%)*				
	Si	**Cu**	**Mg**	**Ti**	**Al**
Al	0.113	0.008	0.008	0.008	Remainder
Al-13%Si	13.00	0.02	0.007	0.004	Remainder
Al-12% Si	12.23	0.02	0.005	0.035	Remainder
Al-12% Si-0.05% Ti	12.10	0.02	0.007	0.045	Remainder
Al-12% Si-0.1% Ti	13.33	0.02	0.007	0.108	Remainder

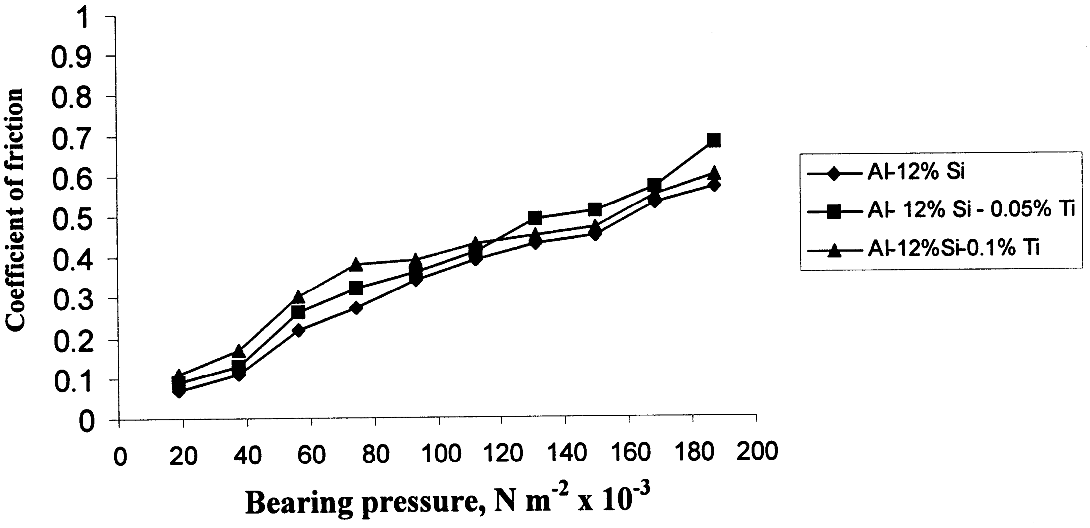
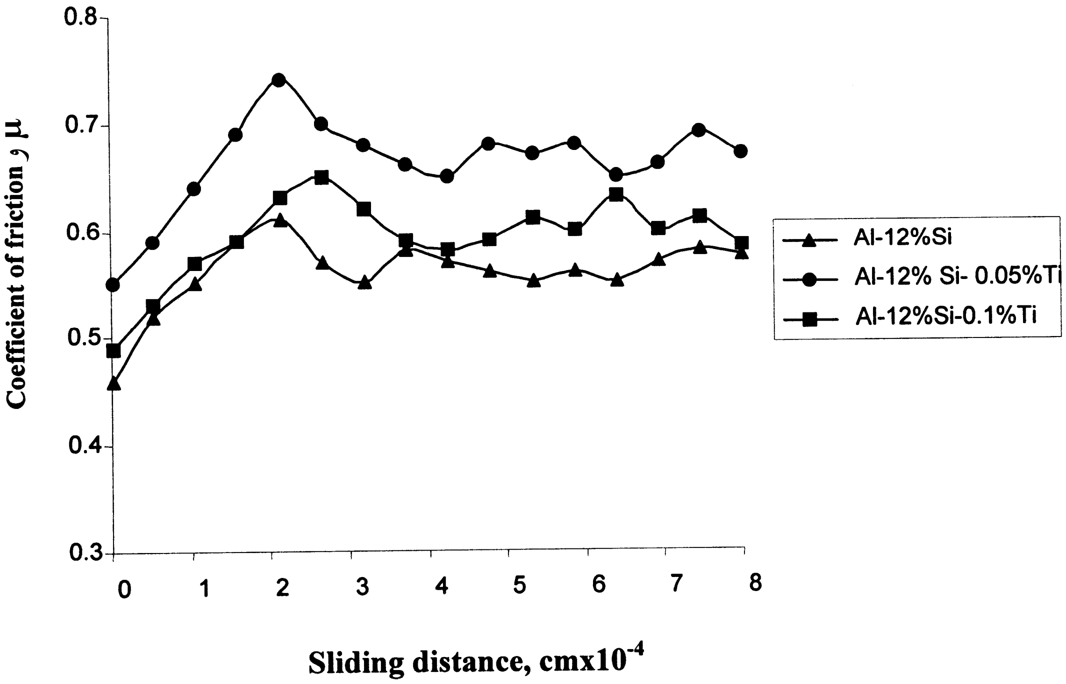


Fig.(1). The relationship between bearing pressure and coefficient of friction of as-cast and modified aluminum-silicon alloys.



`Fig.2 The relationship between sliding distance and coefficient of friction of as-cast and modified aluminum-silicon alloys.

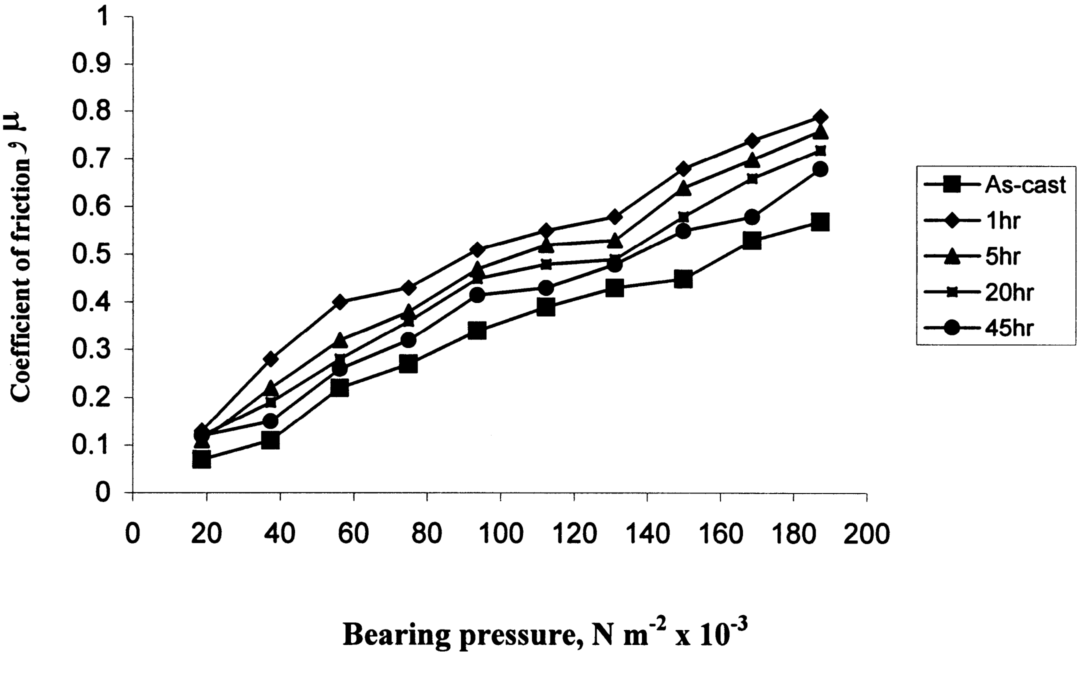


Fig.3 The relationship between bearing pressure and coefficient of friction of homogenized Al-12%Si alloy.

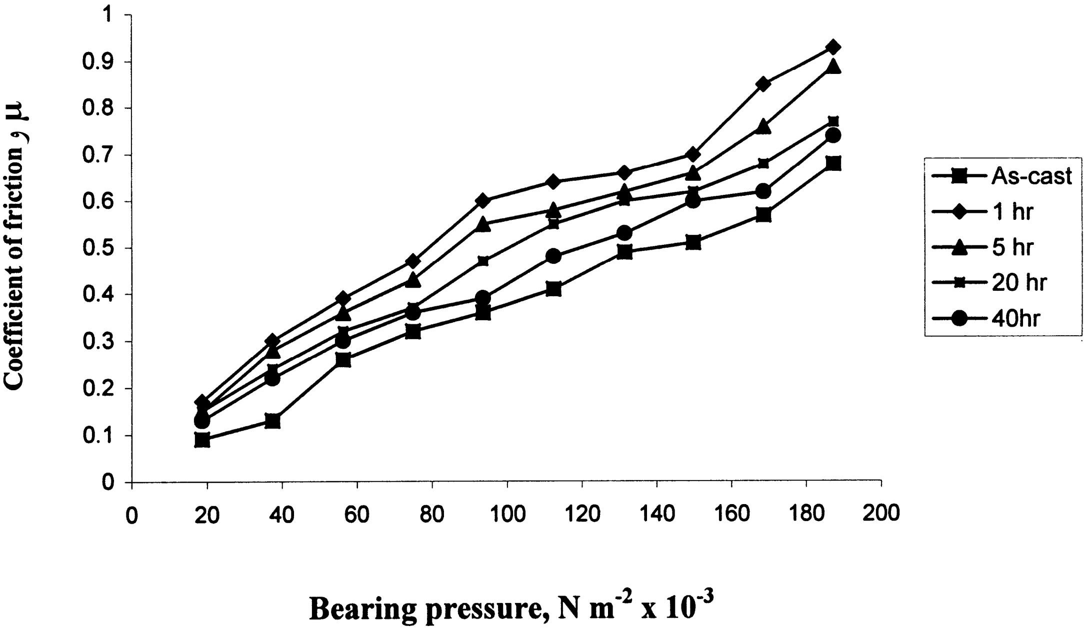


Fig.4 The relationship between bearing pressure and coefficient of friction of homogenized Al-12%Si-0.05%Ti alloy.

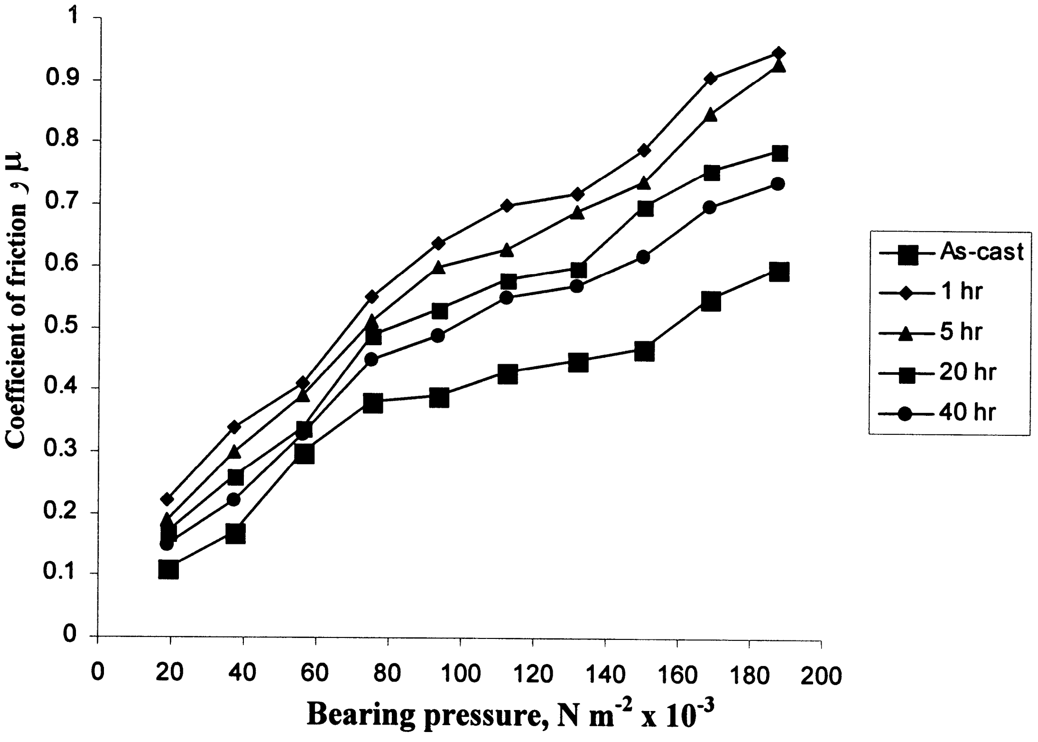
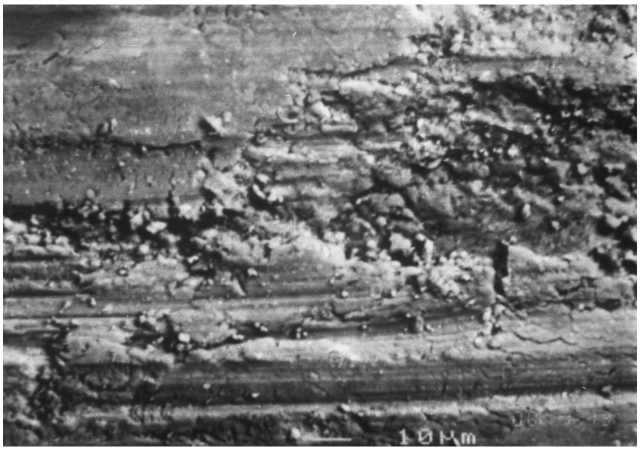
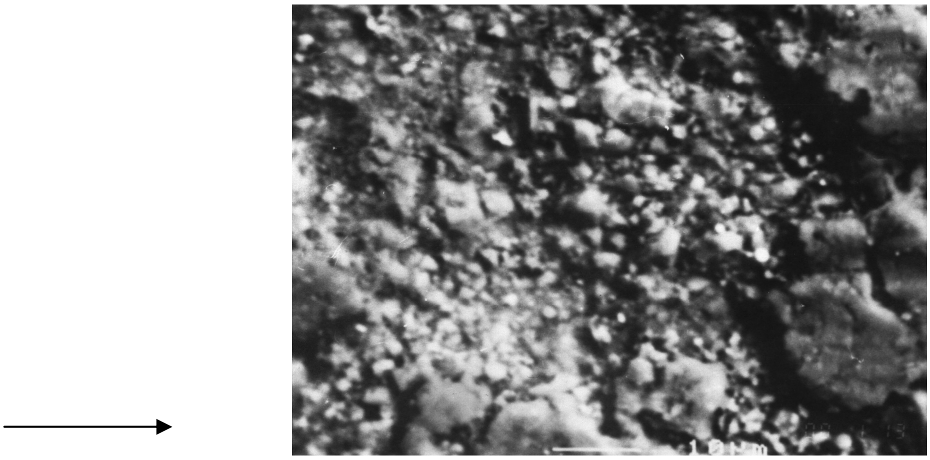


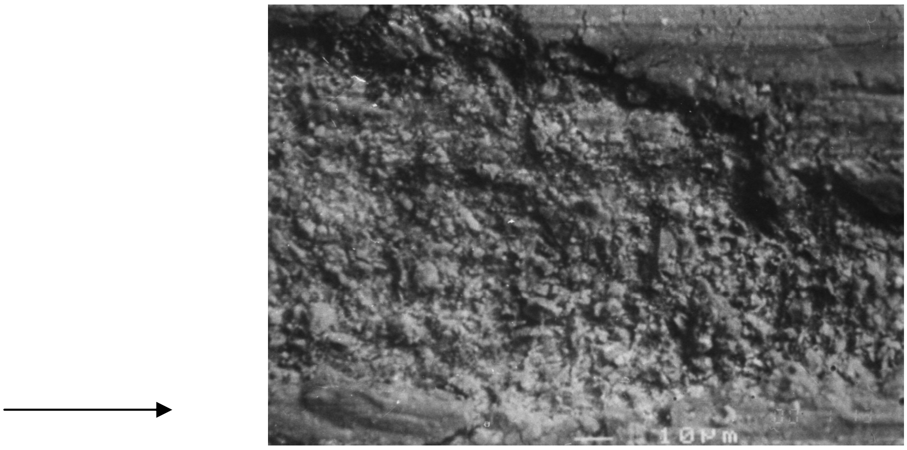
Fig.5 The relationship between bearing pressure and coefficient of friction of homogenized Al-12%Si-0.1%Ti alloy.



Al-12%Si

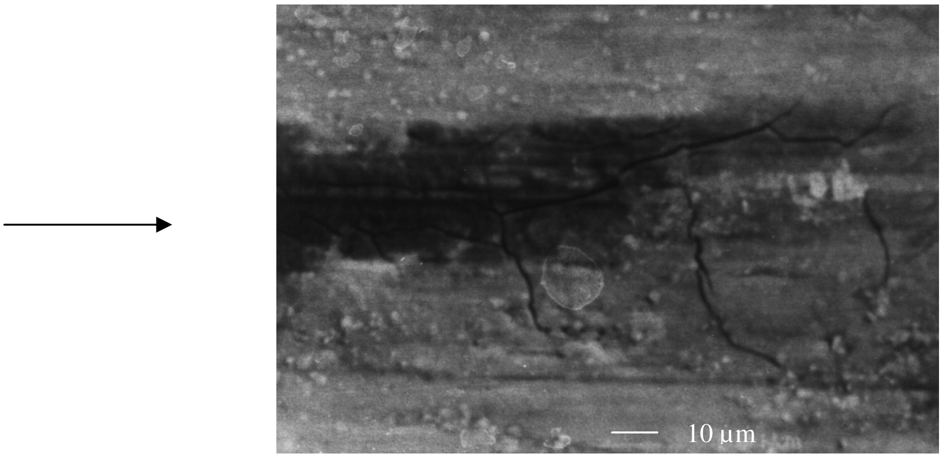


Al-12%Si-0.05%Ti

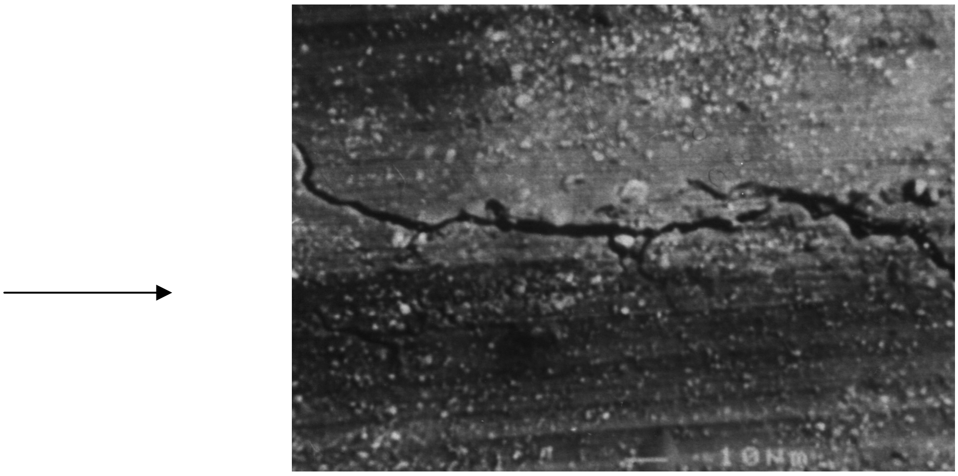


Al-12%Si-0.1%Ti

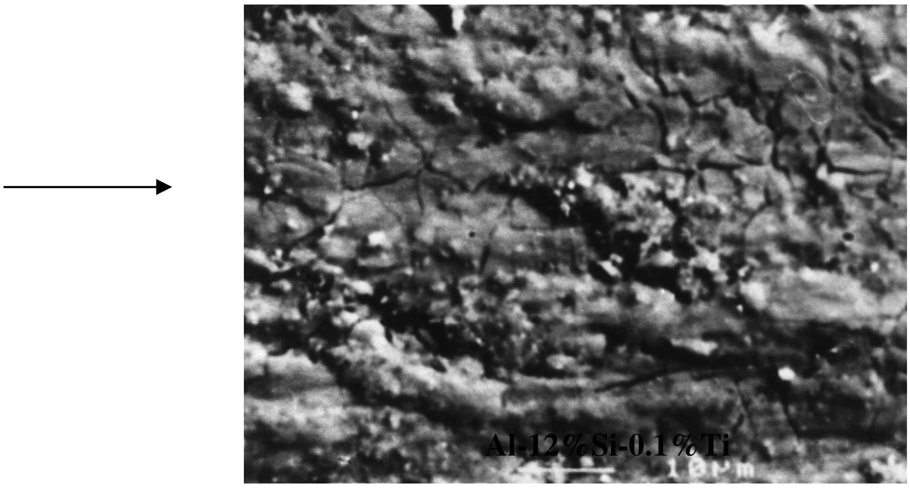
Fig.(6). Secondary electron images of freshly worn surfaces of as-cast and modified aluminum-silicon alloys. Bearing pressure, 168.6 kPa; sliding speed, 160.2 m min^{-1}. Arrow indicates sliding direction.



Al-12%Si



Al-12%Si-0.05%Ti



Al-12%Si-0.1%Ti

Fig.(7). Secondary electron images of freshly worn surfaces of homogenized aluminum-silicon alloys at 40 hr. Bearing pressure, 168.6 kPa; sliding speed, 160.2 m min^{-1}. Arrow indicates sliding direction.