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Wear Studies of Aluminum-Silicon Alloys

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Abstract

Aluminum-Silicon (Al-Si) alloys are extensively used in industrial applications due to better tribological properties. In the present work, an attempt has been made to study the tribological properties of aluminum-silicon alloys. Addition of silicon to aluminum gives high wear resistance, low thermal expansion coefficient, and high strength to weight ratio. The wear was found to be higher at increased velocity at increased normal load. Also it was found to be increasing with decreasing Silicon content. Under lubricated condition wear was found to be higher due to the interaction of Silicon platelets at the Al-Si boundary.

Keywords

Tribology; Wear; Aluminum; Silicon

I. Introduction

Aluminum and its alloys are extensively used in transportation (automobiles and aerospace), engine parts and structural applications [1]. Thus it becomes necessary to study the tribological characteristics of aluminum and its alloys. Addition of silicon to aluminum gives high wear resistance, low thermal expansion coefficient, and high strength to weight ratio. These alloys also show improved strength and wear properties as the silicon content is increased beyond eutectic composition. Such properties warrant the use of these materials as structural components in automotive industries [2]. Brittle fracture problems do not occur with aluminum. Aluminum alloys are suitable for low temperature applications because as the temperature is reduced, aluminum alloy increases in strength without loss in quality [3].

A. Aluminum-Silicon Eutectic and Hypoeutectic Alloys

Alloys with Silicon as a major alloying element are by far the most important casting alloys. Binary Aluminum-silicon alloys combine the advantages of good weldability, high corrosion resistance, high wear resistance and low specific gravity. Castings of these alloys are more difficult to machine than the aluminum-copper or aluminum-magnesium alloys, all types of machining operations are routinely accomplished using tungsten carbide tools and appropriate lubricants and coolants.

Alloy 443 (5.3% Si) may be used for all casting processes for parts in which good corrosion resistance, pressure tightness and good ductility are more important than strength. For die casting, alloys 413 and A 413 (12% Si) also have good corrosion resistance but are superior to alloy 443 in terms of castability and pressure tightness. Alloy A444 (7%Si - 0.2% iron) also has good corrosion resistance and has especially high ductility when cast in permanent mold and heat treated to a T4 condition. This alloy has good impact resistance. Alloy 319 (6% Si - 3.5% copper) is a preferred general purpose alloy for sand foundries that may also be used in permanent mold casting.

B. Hypereutectic Aluminum-Silicon Alloys

Al-Si alloys with greater than 12% silicon are called hypereutectic alloys. These Al-Si alloys have excellent wear resistance, good casting characteristics and a lower thermal expansion coefficient. These alloys have outstanding fluidity and excellent machinability in terms of surface finish and chip characteristics. A typical example is alloy 390 (17% silicon-4.5% copper-0.5% magnesium). It is used in small engines, master brake cylinders, pistons for air conditioning compressors, pumps and other components in automatic transmission [4].

II. WEAR

Wear is defined as a process of removal of material from one or both of two solid surfaces when they are in contact. It is also defined as the damage to a solid surface involving the progressive loss of material due to relative motion between two moving surfaces [5].

A. Types of Wear

Following are the various types of wear processes based on the types of wearing contacts.

(i) Single-phase wear: In which a solid moving relative to a sliding surface causes material to be removed from the surface. The relative motion for wear to occur may be sliding or rolling. (ii) Multi-phase wear: In which a solid, liquid or gas acts as a carrier for a second phase that actually produces the wear [6].

B. Wear Mechanisms

Types of wear mechanisms are listed below as:

(i) Abrasive wear (ii) Solid particle erosion (iii) Sliding and adhesive wear (iv) Fretting wear (v) Corrosive wear (vi) Impact wear

1. Abrasive Wear

American Society for Testing and Materials (ASTM) defines it as the material loss due to hard particles that are forced against and move along a solid surface. Many mechanisms have been proposed to explain how material removal takes place during abrasive wear. These mechanisms include fracture, fatigue and melting. Fig. 1 shows some of the processes which are possible when a single abrasive tip slides across a surface. They include plowing followed by wedge formation, cutting, micro-fatigue and micro-cracking [7].

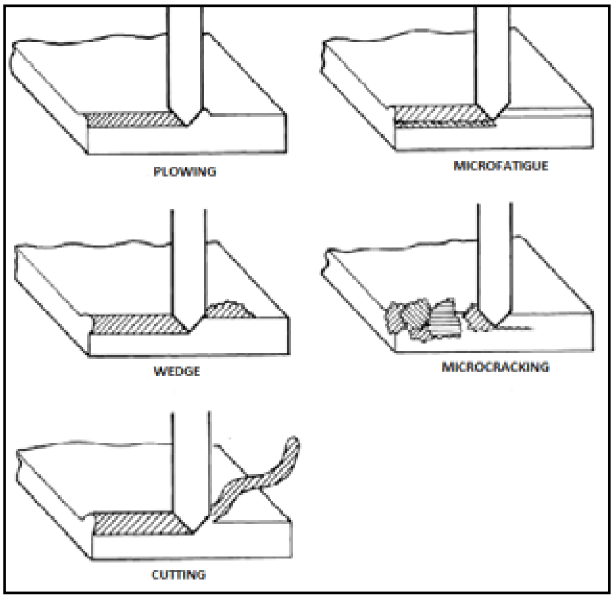

Fig. 1: Five Processes of Abrasive Wear [7]

2. Solid Particle Erosion (SPE)

It is the loss of material that results from repeated impact of small, solid particles. Solid particle erosion is to be expected whenever hard particles are entrained in a gas or liquid medium impinging on a solid at any significant velocity (greater than 1 m/s). The difference between erosion and abrasion should be clear, because the term erosion has been used in connection with situations that might be better classed as abrasion. Solid particle erosion refers to a series of particles striking and rebounding from the surface while abrasion results from the sliding of abrasive particles across a surface under the action of externally applied forces. In erosion, the force applied by the particles on the material is due to their deceleration, while it is externally applied and approximately constant in case of abrasion [8].

3. Sliding and Adhesive Wear

It is a type of wear generated by the sliding of one solid surface against another. Apparently, sliding wear is a type of wear that is “left over” when all other types of wear have been identified under separate headings.

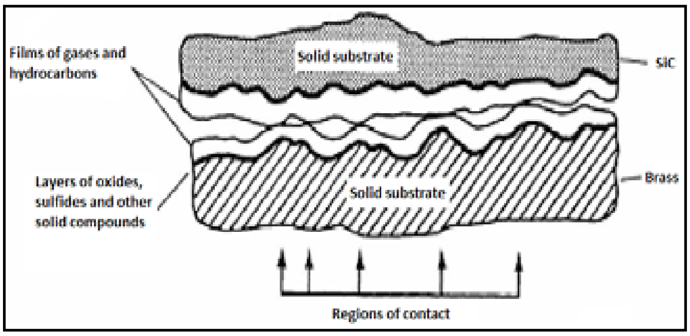

Fig. 2: Schematic of a bond bridge produced when two solid surfaces are in contact with each other [9].

Although sliding wear and adhesive wear are not synonymous, Adhesive wear is said to occur if no abrasive substances are found, also amplitude of sliding is greater than that in fretting wear and oxidation is not taking place.

4. Fretting Wear

Fretting can be defined as the small-amplitude oscillatory movement that may occur between contacting surfaces which are usually nominally at rest. Oxide debris production is one of the immediate consequences of this phenomenon. Hence, the terms “fretting wear” and “fretting corrosion” are applied to this process. In several cases, one of the members of the contact is subjected to a cyclic stress (fatigue). This gives rise to the initiation of fatigue cracks. This is called “fretting fatigue” or “contact fatigue” [10].

5. Corrosive Wear

In case of corrosive wear, thin films are assumed to form through tribochemical reactions between contact surface materials and surrounding media, such as air or a liquid lubricant [11] and wear occurs through a combination of wear and corrosion can result in total material losses that are much greater than the additive effects of each process taken alone, which shows synergism between the two processes. The wear process accompanies with the Corrosion to some extent in all environments except in inert atmospheres [12].

6. Impact Wear

It is defined as wear of a solid surface due to percussion. Percussion is a repetitive exposure to dynamic contact by another solid body. Several industries employ processes that lead to impact wear. Machine components, cams, and gears mate with a certain dynamic component. Typical applications occur in electromechanical printers [13].

III. Literature Survey

The literature survey is carried out to study and evaluate the wear properties of Al-Si alloys. The work of researchers in this respect has been carried out and their conclusions are as follows:

Alias et al. [14] have studied the wear behavior of Al-Si heat treated and as-cast eutectic alloys. Tests on the alloys were performed on a pin on disk apparatus and parameters taken as shape and size of the pin, load, speed and the material pairs. Increase in the rotational speed of the disk leads to the increase in the mass loss of the heat treated and as-cast alloys. The wear rate is higher for as-cast samples. High speed leads to wear rate reduction. This reduction is pronounced in heat treated samples. This is because heat is developed during sliding and the material becomes softer and weaker.

Kori et al. [15] have studied the effect of grain refiner and or modifier on the wear behavior of hypoeutectic (Al–0.2, 2, 3, 4, 5 and 7Si) and eutectic (Al–12Si) alloys using a Pin-On-Disc apparatus under dry sliding conditions. It is important that Al-Si alloys solidify with fine equiaxed α-Al in hypoeutectic/fine primary Si particles in hypereutectic and fine eutectic Si. The former can be achieved by grain refinement treatment/solidification processing the later can be achieved by a suitable grain modification. Fine grain size ensures good tribological properties. Al-Ti-B was used as grain refiner and Al-10%Sr was used as modifier. Addition of grain refiner and modifier to Al-Si alloys resulted in less specific wear rate. An increase in sliding speed led to the decrease of specific wear rate both in the case of grain refined/modified and grain unrefined/unmodified alloys. Addition of grain refiner and modifier led to decrease in wear rate at longer sliding distances.

Rajaram et al. [16] have studied the tensile and wear properties of Al-Si alloys fabricated by stir-casting technique at temperatures ranging from ambient to 3500ºC. It is observed that the wear rate decreases with increasing temperature. Continuous sliding action removes this layer which facilitates direct contact of the alloy with the abrasive which results in decrement of wear rate at high temperature (~3000ºC).

Dwivedi [17] has studied the effect of alloying elements on binary Al - 17wt%Si alloy and multi-component (Al – 17Si – 0.8Ni – 0.6Mg – 1.2Cu – 0.6Fe) cast alloy. A reduction in wear rate at high sliding speed was observed. This is due to the formation of an oxide layer on the sliding interface. The increase in sliding speed leads to an increase in interface temperature. Temperature rise increases the ability of soft aluminum matrix to accommodate the hard and brittle Silicon.

Torabian et al. [18] have studied the effects of sliding distance, alloy composition, sliding speed and load on the wear rate of Al-Si alloys. The wear rate is strongly dependent on the applied load. It increases linearly with load in three distinct regions in all the alloys i.e., Mild wear, Intermediate wear and severe wear. Mild wear takes a longer duration and takes place under low loads. The intermediate wear and severe wear regions are distinguished from the mild region by higher rates of increase in the wear rate per unit weight. The wear rate is found to decrease with increasing Silicon content.

Anasayida et al. [19] have studied the effect of addition of cerium on the wear behavior of as cast Al-4Si-4Mg alloys. Test results confirm that the wear rate decreases with the addition of cerium in the alloy. The microstructures of the alloy samples reveal that Si in the as cast alloys is finely distributed in the interdendritic region. Silicon being harder than aluminum increases the wear resistance of the alloys. Addition of Ce resulted in the formation of intermetallic phases like Al-Ce and Al-Si-Ce which leads to hardness and wear resistance.

Odabas et al. [20] worked on the comparison of reciprocating and continuous two body abrasive wear behavior of solution-treated and age-hardened 2014 Al alloy. Reciprocating and continuous abrasive wear have been performed on solution treated 2014 Al alloys under similar conditions of speed, load, sliding distance and nominal area of contact. Conclusions can be drawn for continuous and reciprocating wear. Wear loss is greater in the continuous wear. The abrasive wear coefficient is higher in the continuous wear. The values of average roughness of the worn surfaces are greater in reciprocating wear.

IV. Results and Discussion

It is found that, with increase in silicon percentage in the alloy, the microstructure is different for hypo-eutectic compositions than of the hyper-eutectic composition. With the addition of Silicon content, the hardness of alloys increases (Table 1).

Table 1: Hardness of Some Silicon Based Aluminum Alloys

Alloy	composition	Hardness (HV)
Al	7wt% Si	54.4
Al	11wt% Si	55.3
Al	15wt% Si	56.2

With increase in silicon content in the alloys i.e. 11% and 15% silicon, reveals different micrographs. It can be observed that although deeper grooves/abrasive tracks are observed but are smooth in dry condition; and at lubricated condition the separation of groove line is reduced. This may be due to the fact that at dry condition the wear debris might have flown off, but in lubricated condition some particles are embedded in the matrix which is the reason for deep grooves.

V. Conclusions

From this piece of various studies following conclusions can be made:

1. With increase in silicon percent, the wear rate decreases.
2. Wear is seen to increase at higher sliding speed and at higher applied load.
3. Wear behavior is dependent on applied load, sliding speed mainly. However, a steady state is attained after a sliding distance of about 1000 meters.
4. In case of lubricated condition, the Alloys shows higher amount of material loss. The precipitated silicon platelets have been easily removed from the material due to interaction at the inter boundary zone of Al-Si eutectic and silicon platelets (i.e. pro-eutectic silicon) and has enhanced the material loss.

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