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WEAR PROPERTIES OF Fe-C-Al CAST IRON AND CONVENTIONAL CAST IRON –A COMPARATIVE STUDY

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ABSTRACT

The conventional gray cast iron (also known as Fe-C-Si cast iron) exhibitss good properties, such as strength, hardness, corrosion and oxidation resistance but it's properties especially wear and friction detoriorate significantly at higher temperature. In order to improve the wear properties of this conventional cast iron, an attemped has been made to replace Si by Al. In the present study, the wear test was conducted on both conventional cast iron (CI) and Fe-C-Al cast iron using universal pin-on-disk (POD) machine. The wear track profile and damage surface were characterized using optical profilometer and scanning electron microscopy (SEM) respectively. The results showed that the lower wear rate was found for Fe-C-Al CI compared to conventional Fe-C-Si CI and abrasive type wear morphology was observed in both types of cast iron materials. The results also showed that the friction coeficient value of Fe-C-Al CI was lower than conventional cast iron. It can be concluded that the overall wear and friction properties of Fe-C-Al CI was better than conventional cast iron.

***Keywords**:* Sliding; Two-body abrasion; Cast Iron; Surface Analysis; Profilometry.

1. INTRODUCTION

Gray cast iron is one of the oldest cast ferrous products. In spite of competition from newer materials and their energetic promotion, gray iron is still used for those applications where its properties have proved it to be the most suitable material available. Next to wrought steel, gray iron is the most widely used metallic material for engineering purposes including automotive engine component material due to its multi-variety properties such as, good hardness and strength, higher damping capacity and better tribological properties at ambient temperature. The other applications of this material are in the field of machine parts and components such as roller, roller shell, lathe bench, agricultural tools etc. In the recent years, the demand for gray cast iron in different applications are increasing and therefore, there is a need to develop new grades of gray cast iron which can provide better physical, mechanical and wear properties.

Gray cast iron is one of the most easily cast of all metals in the foundry. It has the lowest pouring temperature of the ferrous metals, which is reflected in its high fluidity and its ability to be cast into intricate shapes. As a result of a custom during final stages of solidification, it has very low solid shrinkage so that sound castings are readily obtainable. For the majority of applications, gray iron is used in its as-cast condition, thus simplifying production. Gray iron has excellent machining qualities producing easily disposed of chips and yielding a better surface finish. The resistance of gray iron to scoring and galling with proper matrix and graphite structure is universally recognized (Krause, 1969). However, the mechanical and chemical properties of cast iron can be widely changed by alloy addition, heat treatment or controlling the solidification of the alloy (Bartocha et. al., 2005; Xing et al., 2007). The wear property of gray cast iron mainly depends on the properties of the matrix and hence, by modifying the matrices of the gray cast iron it is possible to change the wear behaviour of the cast iron (Terheci, et al., 1995). Riahi and Alpas (2003) and Prasad (2007) have suggested that addition of aluminium in place of silicon might form fine ferrite or ferrite pearlite which in tern increase the toughness and strength of the cast iron. Low temperature damping behaviour of cast iron with aluminium addition has been studied by Liu et al., (2005). They found that the addition of aluminium in gray iron can modify the matrix with flake which contribute to the improvement in the structure and properties compared to conventional gray iron. Not much information is available in literature on the comparative study of wear properties bewteen conventional gray CI and Fe-C-Al CI. Therefore, the main aim of this work is to study the wear behaviour of Fe-C-Al gray cast iron and conventional gray iron using universal pin-onodisk (POD) machine.

2. EXPERIMENTAL DETAILS

2.1 Casting Process

The moulding materials for casting are: synthetic silica sand, cold set asphalt resin and alpha cure hardener. In order to prepare a mould, first silica sand was mixed with 2% resin for 5 minutes using a blender then added 1% cold set hardener and mix it thoroughly for another 1 minute. Finally, this freshly sand mixture was used to make a mould on wooden pattern.

An induction furnace was used for melting the raw materials such as pig iron, mild steel, limestone and ferrosilicon. Firstly, pig iron and mild steel were charged together in the furnace and heated up to about 1350 ^{0}C. Then, commercially available flux material (limestone) was added into the melt and stirred thoroughly. The slag was removed from the top of the melt and ferrosilicon alloy was added into the melt manually in order to adjust the composition of the cast iron. The above step was repeated by adding the flux material to ensure the removal of slag from melt by keeping the melt in the furnace in order to have the high quality of cast product. Finally, the liquid metal was poured into the cold set resin bonded sand mould at about 1300 ^{0}C and solidified it to room temperature. After casting, the samples were prepared for wear study.

2.2 Wear and Friction Test

The dry sliding wear test was performed using a universal wear testing machine (CSM High Temperature Tribometer) as shown in Fig. 1. Both Fe-C-Al and conventional CI samples were used as a rotating disk, whereas a 6 mm diameter alumina ball pin (with the hardness value of ~1500, Vickers kgf.mm^{-2}) was used as a counter-part material. The hardness of Fe-C-Al CI and conventional CI are 240 BHN and 190 BHN respectively. The disk dimension was 30×30×10 mm and finely polished before test. All the tests were carried out at 5 N load and at a fixed sliding spped of 25 cm/s at 56% humid atmosphere. The test duration for each test was 5 min and the test was performed according to ASTM G 99-95a standard. Before placing the sample into the specimen chamber, it was cleaned with acetone to remove oil, grease or dust from the surface for each test. The wear and friction data are sent directly to a personal computer via data acquisition system. After test, worn surfaces were cleaned lightly using acetone solution for surface characterization.

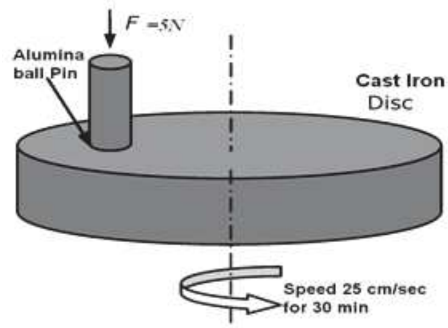


Figure 1 A schematic diagram of pin on disc wear tester under dry sliding condition.

2.3 Surface Characterization

Surface analysis on wear track after wear test of Fe-C-Al CI and conventional CI were performed using “Veeco Wyko NT1100” optical profilometry and presented in both 2D and 3D profiles of the wear track. The wear worn surface was studied using SEM (Philips model XL20) in order to understand the wear morphology and identify the nature and the mechanism of wear after wear and friction test.

3. RESULTS AND DISCUSSION

3.1 Wear Properties of Fe-C-Al and Conventional Cast Irons

The wear rate of both Fe-C-Al and conventional (Fe-C-Si) cast irons is shown in Fig 2. From figure, it is noticed that the conventional cast iron showed higher wear rate compared to Fe-C-Al cast iron. On the contrary, the increase rate of wear for Fe-C-Al cast iron was minimum with R^2 value of 0.9997 which indicate the steady state and uniform wear rate with higher slope. In fact, the wear rate of conventional (Fe-C-Si) cast iron varies from 12.42×10^{-5} mm^3/m/N to 98.88×10^{-5} mm^3/m/N, whereas the wear rate of Fe-C-Al cast iron varies only from 3.3203×10^{-5} mm^3/m/N to 8.1550×10^{-5} mm^3/m/N. However, the Si containing cast iron has more graphite flakes and hence matrix will get more chance to be separated than less graphite flaky cast iron which is Fe-C-Al CI. The highly dense graphite flakes in presence of higher Si finally concentrated the stress during wear test (Hatate et al., 2001) resulting peeling off the Fe-C-Si cast iron materials as shown in Fig 5 (a). Therefore, it can be concluded that the Fe-C-Al cast iron is more wear protective than conventional Fe-C-Si cast iron.

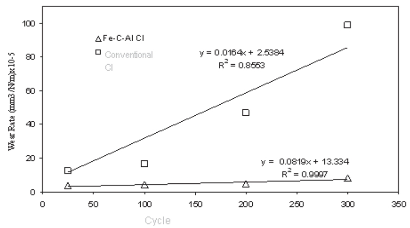
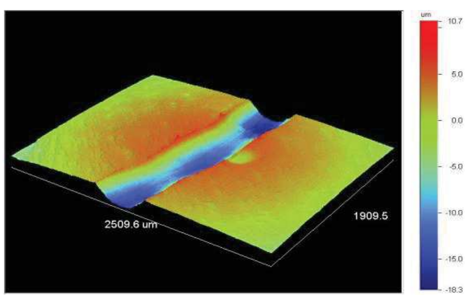


Figure 2 Wear rate of Fe-C-Al and conventional Fe-C-Si cast irons under dry sliding condition. The speed is 25 cm/s; load 5N; duration 5 min.

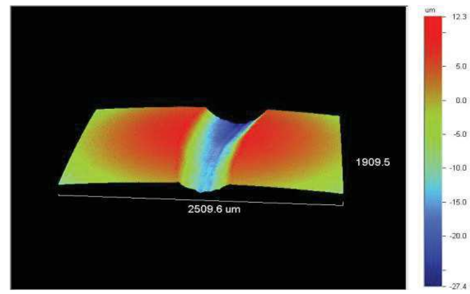


(a)

(b)

Figure 3 Wear tracks of Fe-C-Al cast iron at room temperature under optical profilometer: (a) wear track profile and (b) corresponding depth of wear track.

The surface area of wear track profiles under optical profilometer for Fe-C-Al CI and conventional gray cast iron materials are shown in Figs 3 and 4 respectively. From both wear track (3D view) and depth of wear track (2D view) profiles it can be seen that the depth of the wear track increases for the conventional Fe-C-Si CI compared to Fe-C-Al CI. This again shows the highrer wear protection of Fe-C-Al CI compared to conventional CI and also well agreed with the previous explanation on wear rate in Fig. 2.



(a)

(b)

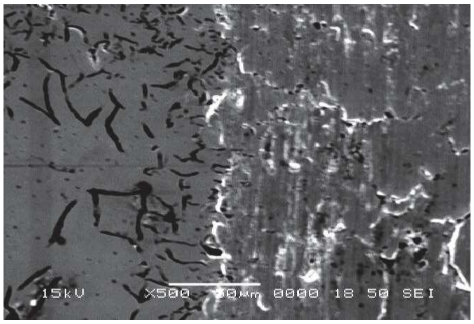
Figure 4 Wear tracks of Fe-C-Si cast iron under optical profilometer: (a) wear track profile and (b) corresponding depth of wear track.

3.2 Wear Mechanism of Damage Surface

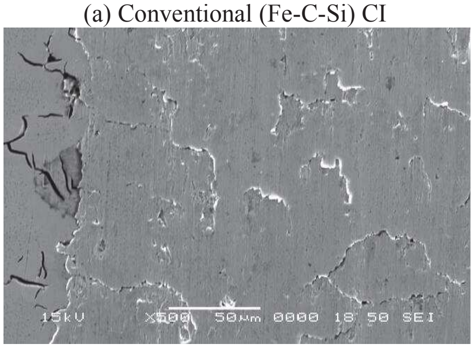
The wear worn or damage surface of both cast iron materials under SEM are shown in Fig 5 represent the morphology of the wear. It shows that conventional Fe-C-Si cast iron has larger plastic flow, scar, more debris and cutt-off or peel-off surface resembling delamination on the surface indicating severe wear of the Fe-C-Si cast iron material.

However, worn surface of Fe-C-Al CI shows less plastic flow and wear scar indicating less severe wear on the damage surface. When hard asperity on the surface of a material or a hard particle is entrapped between two surfaces, plastically deformed or cut off surface may occur due to the sliding motion, resulting abrasive wear. In this study, both cast iron materials surface were cut off due to sliding motion and thus abrasive type of wear occurred in this investigation.

Abrasive wear property also depends on oxidation characteristics of the materials. When debris forms during wear test, it is clear that oxidation occurs in that place and every moment virgin materials are exposed. If the formation of more debris and scar are higher, the wear rate will also be higher. The conventional Fe-C-Si cast iron shows larger scar and debris which indicates higher wear as can be seen in Fig. 2 as well.



(a) Conventional (Fe-C-Si) CI



(b) Fe-C-Al CI

Figure 5 Wear damage surface of (a) Conventional Fe-C-Si CI and (b) Fe-C-Al CI under SEM.

3.3 Friction Coefficient

Friction coefficients of both conventional Fe-C-Si and Fe-C-Al cast irons at room temperature are plotted with respect to time in Fig 6. It shows that there are three stages of friction. In first stage, the friction coefficient is increased due to formation of tribochemical film; in the second stage is steady state where the film remains stable and finally, the friction coefficient increases when the film breaks down. The same trend was also reported by Keller (2007). The friction coefficient for both types of cast iron shows the same trend and their values are slightly different from each other. This may be due to the same operating speed and ambient room temperature. In a fixed speed, the same amount of graphite was smeared on the worn track to keep the coefficient of friction almost similar. The similar phenomena was also reported by Ghaderi and his coworkers (2003).

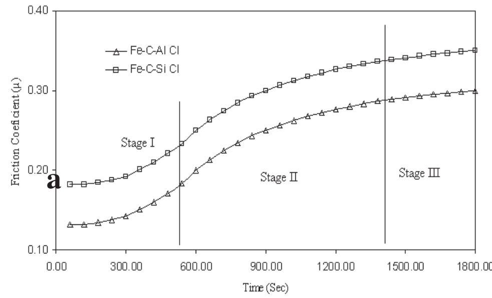


Figure 6 Friction coefficient of both conventional Fe-C-Si CI and Fe-C-Al cast iron.

4. CONCLUSIONS

The wear properties of Fe-C-Al cast iron and conventional (Fe-C-Si) cast iron were investigated and the following conclusions can be drawn from this study:

(i) The wear rate of Fe-C-Al CI is lower that Fe-C-Si CI.
(ii) The depth of wear track for Fe-C-Al CI is lower than Fe-C-Si CI material.
(iii) Abrasive type of wear morphology was observed in both types of cast iron material, however, Fe-C-Si CI shows more plastic flow and dilamination compared to Fe-C-Al CI.
(iv) The friction coeficient of both type of cast irons increase with increasing the time showing three regime of frictional behaviour.
(v) Overall results advocate to use Fe-C-Al cast iron material where wear and friction reristance properties are required.

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