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Solid Particle Erosion Behavior of SiMo Ductile Cast Iron

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Abstract

SiMo ductile cast iron has been developed to be used at high temperatures as exhaust manifold material. Si and Mo contents in its chemical composition provide high temperature oxidation resistance and high temperature strength. During service, hot corrosive exhaust gas flows through the exhaust manifold and may cause erosion of the manifold surfaces. Thus, in this study, it was aimed to evaluate the performance of SiMo cast iron under severe solid particle erosion conditions, against aluminum oxide particles at 30°, 45°, 60° and 90° impingement angles. Surface degradation of tested alloys were characterized using scanning electron microscope. It was observed that erosion rate increased with increasing impingement angle up to 45°, then decreased as the angle increased, since the mechanism of material removal changed. While ploughing occurred at lower angles, work hardening took place on the worn surface at higher angles.

SiMo Sünek Dökme Demirin Katı Partikül Erozyonu

Anahtar kelimeler:

SiMo sünek dökme demir
Katı partikül erozyonu
Karakterizasyon

Özet

SiMo sünek dökme demir yüksek sıcaklıklarda ekzoz manifold malzemesi olarak geliştirilmiştir. Kimyasal kompozisyonunda bulunan Si ve Mo elementleri yüksek sıcaklık oksidasyon direnci ve yüksek sıcaklık mukavemeti sağlamaktadır. Çalışma koşullarında yüksek sıcaklıktaki korozif ekzoz gazı ekzoz manifoldundan geçer ve manifold yüzeyinde erozyona neden olabilir. Bu çalışmada, SiMo dökme demirin katı partikül erozyon davranışının aluminyum oksit partikülleri ile 30°, 45°, 60° ve 90° çarpma açıları kullanılarak incelenmesi hedeflenmiştir. Yüzeyde meydana gelen bozunmalar tarama elektron mikroskopu kullanılarak incelenmiştir. Erozyon oranı 45° çarpma açısına kadar artış gösterirken, malzeme kaybı mekanizmasındaki değişiklik nedeniyle daha bu oran yüksek açılarda azalmıştır. Düşük açılarda pulluklama etkin mekanizma iken yüksek açılarda yüzeyde deformasyon sertleşmesi meydana gelmektedir.

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1. INTRODUCTION

High silicon molybdenum cast iron, SiMo is a member of ferritic ductile cast iron. It can be used in temperatures up to 850–860 °C due to its Si and Mo content in its composition. Si content stabilizes the ferritic matrix at high temperatures and increases the high-temperature corrosion resistance by forming a Si-rich surface oxide layer. Mo addition increases the high-temperature strength and improves the creep behavior, by forming alloy carbides in the ferritic matrix. By means of these properties developed with the chemical composition, SiMo cast iron is mainly used as exhaust manifold material [1-6].

Exhaust manifolds collect the combustion gases from the cylinders of the internal combustion engine and direct them to the exhaust system [7]. During operation, the surfaces of exhaust manifolds are exposed to the pressure of corrosive hot gas flow causing formation of Fe-based porous oxide scales on top of the manifold surfaces as a product of hot oxidation [5, 6]. This porous scale can be removed due repeated gas flow and behaves like 3D particle causing erosion of the surfaces. Due to erosion, material is removed gradually by repeated deformation and cutting actions caused by solid particle impingement, resulting in both high material loss and high cost [8]. Thus, this phenomenon attracted attention of researchers [9]. Erosion is very much dependent on the counterpart particle properties, target materials, temperature, impingement angle and velocity of abrasive particles [8-15]. If the target material is ductile, erosion causes material loss via cutting and ploughing mechanisms, on the other hand erosion of brittle materials is based on crack propagation and chipping [9, 10, 15]. Literature shows that erosion rates of brittle materials increase with increasing impingement angle and reaches a maximum at 90°. However, erosion rate of ductile materials reaches maximum up to 40° and then declines [8-10, 14].

In this study, solid particle erosion behavior of SiMo ductile cast iron against aluminum oxide particles at 30°, 45°, 60° and 90° impingement angles was investigated.

2. EXPERIMENTAL STUDY

2.1. Material

The studied high silicon and molybdenum ductile cast iron (SiMo) was produced as Y block by sand mold casting according to DIN EN 1563:2012-03 standard in a local company, Turkey. The chemical composition of the SiMo cast iron is given in Table 1.

Table 1. Chemical composition of the SiMo alloy (wt. %)

Specimen	C	Si	Mo	Mg	Mn	P	S
SiMo	3,32	3,52	0,81	0,049	0,13	0,031	0,008

2.2. Metallographic Sample Preparation and Microscopic Examinations

Before erosion tests, four SiMo cast iron specimens (30x20x15 mm) were ground using grinding papers of 120, 320, 600 and 1000 mesh, respectively, and polished with 3 μm diamond paste in order to reduce the roughness of the surfaces. For microscopic examinations, one more specimen was prepared metallographically using the same sequence and polished surface was then etched chemically with Nital (% 3 HNO_3) solution to obtain phase contrast. The etched specimens were investigated using both light microscope (LM, Olympus BX41RF-LED) and scanning electron microscope (SEM, Jeol JSM-6060) equipped with energy dispersive spectrometer (EDS, IXRF). After the solid particle erosion tests, surface degradation of tested alloys were characterized by using SEM.

2.3. Solid Particle Erosion Test

Solid particle erosion tests were performed based on the ASTM G76–95 test standard at room temperature, on polished and cleaned surfaces, using a home-made solid particle erosion test setup (Figure 1). The parameters used in the solid particle erosion tests are given in Table 2. Al_2O_3 particles were accelerated from nozzle to the sample surface using dry compressed air at four different impingement angles. Specimens were weighed prior and following erosion tests, in order to determine weight losses.

The erosion rate was calculated using the formula given in Eq. (1):

$$\text{Erosion rate} = \Delta W_m / W_p \quad (1)$$

where ΔW_m is the weight loss of the target material and W_p is the weight of the counterpart particle impinged on the target surface [15].

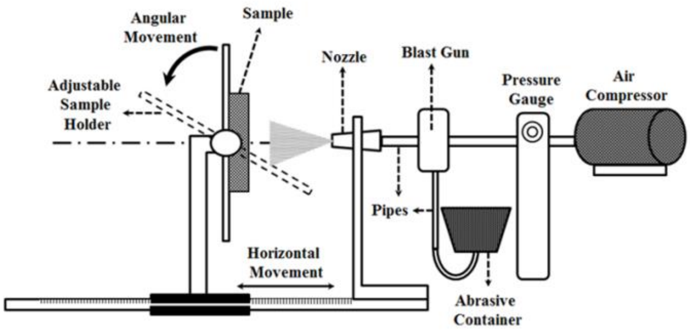


Figure 1. A schematic illustration of the setup used in erosion tests [15].

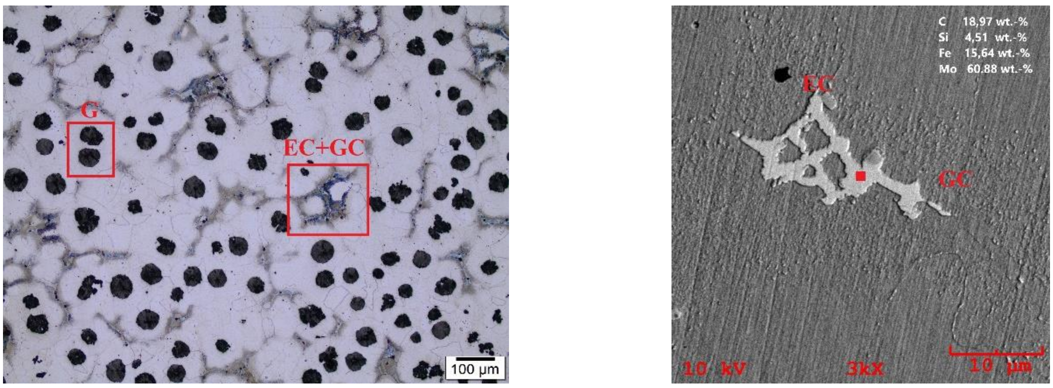
Table 2. Parameters of solid particle erosion tests.

Counterpart particle	Size of counterpart particle (mesh)	Impact angle (°)	Pressure (bar)	Time (second)
Al_2O_3	120	30	2	10
		45		
		60		
		90		

3. RESULTS AND DISCUSSION

3.1. Microstructural Characterization

LM micrographs showing the general structure of SiMo cast iron is given in Figure 2a. The micrograph shows that cast microstructure of SiMo has globular graphite (G), eutectic carbide (EC), and granular cementite (GC) in ferritic matrix. SEM image given in Figure 2b shows the eutectic carbide, surrounded by granular cementite, and EDS result given in the inset indicates that this eutectic carbide is Mo-rich M_6C carbide. Studies show that this microstructure is a typical microstructure of SiMo cast iron with Mo-rich M_6C eutectic carbide [1-6].



(a) (b)

Figure 2. (a) LM and (b) SEM micrographs showing the microstructure of SiMo cast iron

3.2. Evaluation of Solid Particle Erosion Tests

The results of erosion tests indicating the effect of impingement angle on erosion rate of specimens are shown in Figure 3. The diagram shows that erosion rate increases up to 45° and then decreases with increasing impingement angle. According to the literature this is a typical behavior for ductile materials [8-10, 14]. Erosion rates of brittle materials increase with increasing impingement angle reaching a maximum at 90° whereas erosion rates of ductile materials reaches maximum at about 40° and then start to decline [8]. This is because the counterpart particles produce a ploughing effect and cause material loss at low impingement angles [9].

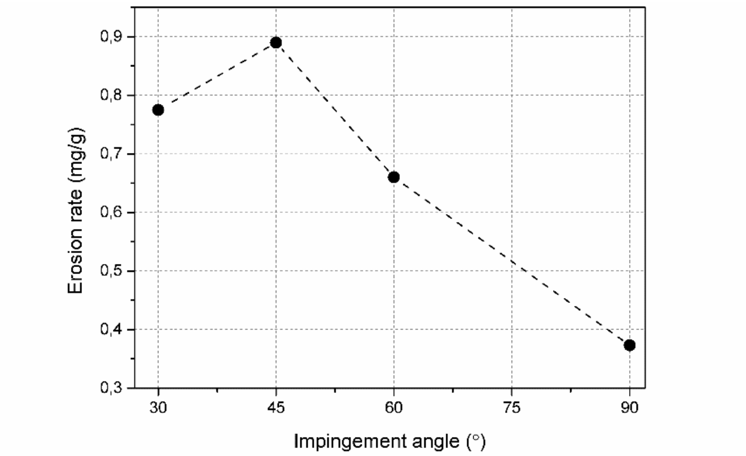
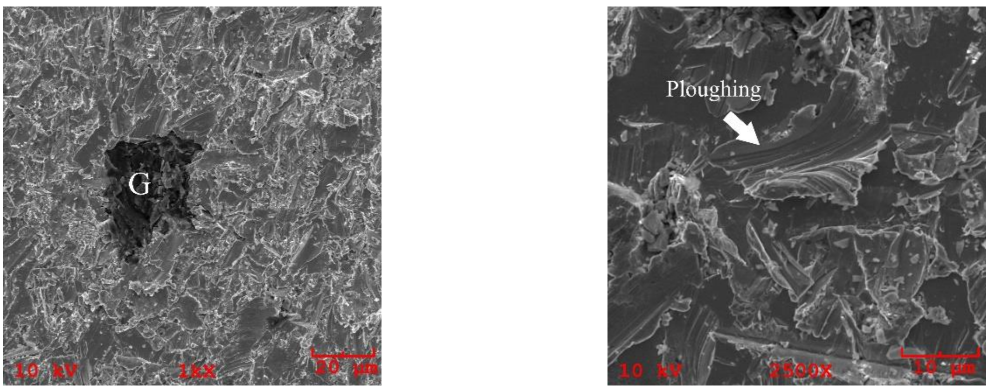


Figure 3. Erosion rates of specimens subjected to solid particle erosion test.

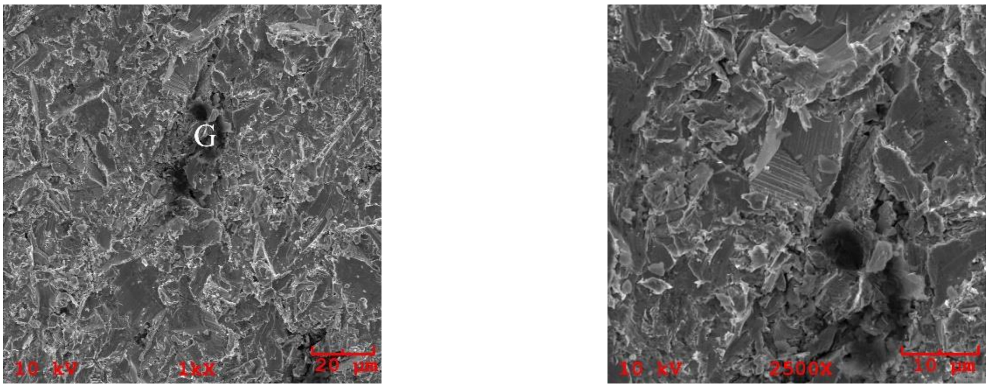
3.3. Worn Surfaces Investigations

In order to understand the dependence of solid particle erosion on impingement angle, SEM studies are carried out and images showing the worn surfaces of tested samples are given Figure 4-7. General view of the worn surface is shown at low magnification for all samples (Figure 4a, 5a, 6a and 7a). According to these images, globular graphites fractured at all angles. In order to understand the change in erosion mechanisms with changing impingement angle, high magnification SEM images are also given (Figure 4b, 5b, 6b and 7b). According to the literature, erosion causes material loss via cutting and ploughing mechanism in ductile materials whereas erosion of brittle materials is based on crack propagation and chipping. However, counterpart particles cause plastic deformation on the surface by forming craters and lips [8-15]. As impingement angle increases, formation of craters due to plastic deformation becomes the dominant mechanism as shown in Figure 5. At 60° impact angle, ploughing is lower and formation of craters is higher than for both 30° and 45 °case (Fig. 6). The erosion occurred by the platelet mechanism rather than ploughing at 90° impingement angle as seen in Fig. 7.



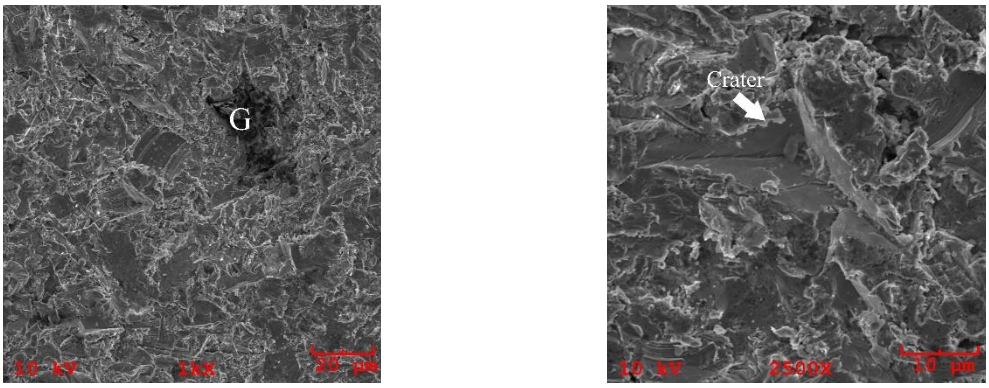
(a) (b)

Figure 4. SEM micrographs showing the worn surfaces at 30°



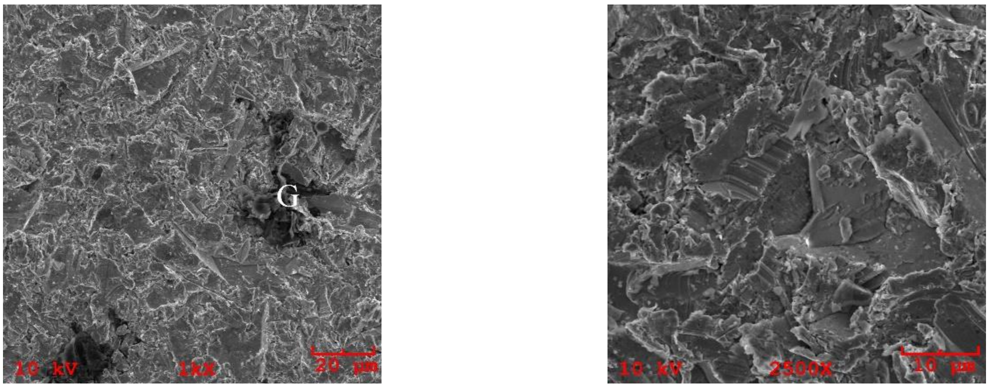
(a) (b)

Figure 5. SEM micrographs showing the worn surfaces at 45°



(a) (b)

Figure 6. SEM micrographs showing the worn surfaces at 60°



(c) (d)

Figure 7. SEM micrographs showing the worn surfaces at 90°

4. CONCLUSION

In this study, solid particle erosion behavior of SiMo ductile cast iron was investigated and it was concluded that (i) SiMo had globular graphite, Mo-rich M_6C carbides and globular cementite in ferritic matrix, (ii) erosion rate increased up to 45° impingement angle and then decreased with increasing angle, (iii) while ploughing was the main mechanism at 30° impingement angle, plastic deformation and platelet mechanism became dominant as the angle increased.

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