

Effect of Surface Roughness and Lubrication on Scuffing for Austempered Ductile Iron (ADI)

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ABSTRACT

This paper describes the scuffing tests performed to understand the effect of surface roughness and lubrication on scuffing behavior for austempered ductile iron (ADI) material. As the scuffing tendency is increased, metal-to-metal interaction between contacting surfaces is increased. Lubrication between sliding surfaces becomes the boundary or mixed lubrication condition. Oil film breakdown leads to scuffing failure with the critical load. Hence, the role of surface roughness and lubrication becomes prominent in scuffing study. There are some studies in which the influence of the surface roughness and lubrication on scuffing was evaluated. However, no comprehensive scuffing study has been found in the literature regarding the effect of surface roughness and lubrication on scuffing behavior of ADI material. The current research took into account the inferences of surface roughness and lubrication on scuffing for ADI. The effect of various surface roughness values and two types of lubricants were evaluated based on the experimental data using ball-on-disc rig to better understand scuffing behavior affected by surface roughness and lubricants.

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INTRODUCTION

Scuffing failure is usually accompanied by abrupt increase in coefficient of friction, noise, vibration, temperature, material removal, and film thickness breakdown. This failure usually occurs in engineering components, such as gear, crankshaft, piston, and bearing. The damage components are not self-healing, which need to be replaced. Austempered Ductile Iron (ADI) offers greater mechanical properties and wear resistance because the high austempering temperatures produce a unique matrix of acicular ferrite and carbon stabilized austenite, called ausferrite. Therefore, ADI has recently appeared as a significant engineering material.

There have been many studies in which the influence of the surface roughness on scuffing was evaluated. Two measures of topography, the RMS roughness σ and the correlation distance β^* , were used by W. Hirst et al. [1] in 1973 to evaluate the scuffing behavior of isotropic stainless steel surface under low-speed and boundary lubricated sliding conditions. K. Nivatvongs et al. [2] in 1991 experimentally validated the work of W. Hirst using a low-speed ball-on-flat test apparatus. The results agree with W. Hirst's hypothesis which stated that failure is caused by plastic deformation at the asperity tips. Robert Wolff [3] in 1991 evaluated the influence of the surface roughness on scuffing with transverse and longitudinal roughness. In the work by Jeng Haur Horng et al. [4], the roughness pattern and asperity height were investigated under four types of roughness patterns. Experimental results proved that the surface roughness

pattern had a considerable effect on tribological performance under various lubrication states. It is well-known that the transversely-oriented roughness pattern can help increase the scuffing load and have a high scuffing resistance. In 1995 O. Jinno et al. [5] stated that the smaller surface roughness values resulted in lower scuffing load. Amplitude, spatial, hybrid and functional parameters of surfaces were used in the scuffing tests by Allison Y. Suh et al. [6] to examine and quantify changes in topography.

On the other hand, Scuffing failure generally occurs in the boundary or mixed lubrication condition owing to the breakdown of lubricant films. The property of lubricant is an important parameter to prevent scuffing. Many researchers have related the effect of lubricants on scuffing for steel materials. A. Begelinger et al. [7] studied boundary lubrication and wear in slow moving concentrate contacts using SAE 10W base oil and HD SAE 20W crankcase oil. Under conditions of oxygen depletion the use of HD SAE 20W crankcase oil leads to a more favorable friction characteristic and less wear. The effect of stearic acid in reducing friction was carried out by M.C. Shen et al. [56] in 1991 using the pure mineral oil and poly- α -olefin (PAO). The experimental results revealed that the stearic acid in PAO exhibits better resistance against scuffing. In 1994 three additional test series were made by S. Andersson et al. [8] with different viscosities. The mineral oils used were ISO VG32 oil, ISO VG100 oil, and ISO VG220 oil. The results showed that the effect of the oil viscosity on the transition load was clearly noticeable with the ISO VG 220 oil in which the transition loads

were significantly higher than the corresponding results with other oils. W. F. Bowman et al. [9] investigated the effect of base oil oxidation on scuffing. It was found that the greater the oxidation the larger scuffing resistance. Increasing the viscosity of the base oil improved the average scuffing failure load.

Although there has been considerable research on the effect of surface topography and lubrications on scuffing, no comprehensive scuffing study has been found in the literature which is related to ADI materials considering the effect of roughness and lubrications. The current research takes into account the inferences of roughness and lubrications on scuffing of ADI. Scuffing tests were carried out with three types of roughness surfaces and two different lubricants in order to investigate the effect of roughness and lubricants on scuffing behavior of ADI material. The surface and subsurface of specimens after scuffing were examined by an optical microscope and X-ray photoelectron spectroscopy (XPS) in order to study the scuffing mechanism.

EXPERIMENT SETUP AND SPECIMEN PREPARATION

A ball-on-disk apparatus (see Figure 1) was used to carry out the tests. A 52100 steel ball with a diameter of 7.94 mm and a hardness of 66 HRC was held stationary and loaded by step load against a rotating ADI disc specimen with a diameter of and a hardness of 27.6 HRC submerged in the lubricant. The disc specimen material was austempered NiMoCu ductile iron (ADI). ADI specimen has a composition of 1.61% Ni, 0.11% Mo, 0.78%Cu, 3.76% C, 0.24% Mn, 2.51% Si, 0.057% Mg, and traces of S and P. This NiMoCu ductile cast iron initially was heat treated in a salt bath at 890°C for 20min for austenitization, then quenched directly in another salt bath down to the austempering temperature of 375°C for periods of time 150min. After austempering, the samples were immediately cooled in air. Figure 2 shows the initial microstructure of ADI which includes graphite nodular with ausferrite matrix.

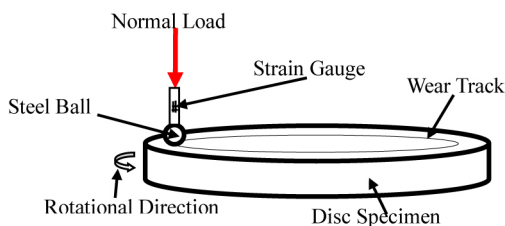


Figure 1. Schematic of ball-on-disk rotational test

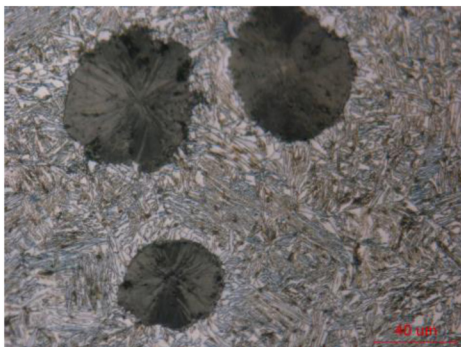


Figure 2. Microstructure of cast iron and 1050 steel specimens

EFFECT OF ROUGHNESS

Operation Conditions

Roughness surface scuffing tests were performed using a step-load that was increased 22N every 120 seconds until scuffing occurred. The linear sliding speeds were 1.885m/s, 1.550m/s and 1.215m/s. White mineral oil with a viscosity of 33.5cSt at 40°C was used as the lubricant. The specimens were machined by finish grinding, medium grinding, and milling processes. The surface roughness was measured by WYKO 3D surface profiler. Three locations on both sides of the specimen were measured and the average roughness values were calculated. The surface roughness parameters are shown in Table 1.

Table 1. Roughness of specimens

	Fine (Grinding)	Medium (Grinding)	Rough (Milling)
Ra(μm)	0.24	0.54	1.12

Coefficient of Friction and Scuffing Load

Figure 3 shows the results of the coefficient of friction (COF) versus the number of cycle for different surface roughness specimens under three sliding speeds. The COF remains stable until scuffing occurs and the COF abruptly increases. It was observed that the ADI specimen with Ra 1.12μm scuffed quickly at the sliding speed of 1.885m/s. It indicated that rough surface was very sensitive to scuffing under higher sliding speed. A much smaller effect of surface roughness on scuffing was observed under the sliding speeds of 1.550m/s and 1.210m/s.

The relationship among scuffing load, roughness and sliding speed is shown in Figure 4. It was observed that scuffing load decreased with the increase of surface roughness at all testing speeds. Similarly, scuffing resistance decreased with the increase of sliding speed for all roughness values. ADI with roughness of Ra 1.12μm has the lowest scuffing load of 44N at a sliding speed of 1.885 m/s, while ADI with a roughness of Ra 0.24μm at a sliding speed of 1.210 m/s has the highest scuffing load of 154N. This suggests that ADI with a fine surface roughness at low sliding speed has higher scuffing resistance than that of a rougher surface at high sliding speed.

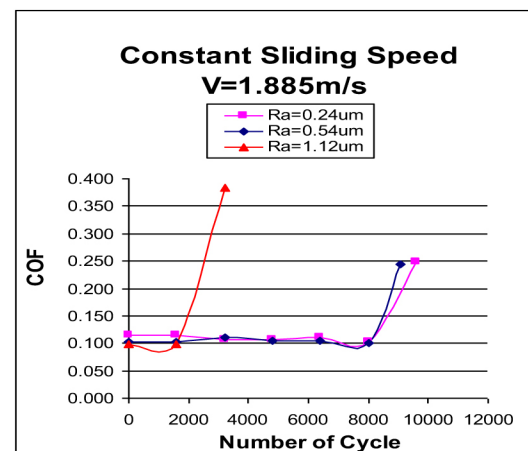


Figure 3. Coefficient of friction vs. sliding speed with different surface roughness