

The Effect of Surface Morphology of Cylinder Bore Surface on Anti-Scuffing Property made by High Pressure Die-Casting Process using Hyper-Eutectic Al-Si Alloy

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ABSTRACT

A monolithic type aluminum (Al) cylinder made of hypereutectic Aluminum-Silicon alloy has been widely used for motorcycle applications. It has a lightweight structure and a superior cooling ability owing to its material property and surface finishing.

Usually the cylinder bore surface of the monolithic Al cylinder is finished by an etching process or a honing process in order to expose silicon (Si) particles from aluminum (Al) matrix for the improvement of the tribological properties. The morphology of the cylinder bore surface including the exposure of Si particles is supposed to make an important effect on its tribological properties, especially on the anti-scuffing property.

In this research, the anti-scuffing property of three kinds of cylinder bore finishing, an etched surface, a Si exposure honed surface and a conventional plateau honed surface is evaluated with using a reciprocated type wear tester. The experimental results are analyzed by using Weibull analysis. It is shown that the experimental data of the anti-scuffing property can be evaluated quantitatively by Weibull analysis. It is revealed that the etched surface shows superior anti-scuffing property rather than the Si exposure honed surface and the conventional plateau honed surface.

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INTRODUCTION

In recent years, the improvement of engine efficiency is required for not only automobiles but also motorcycles from the viewpoint of global demands for energy conservation. For meeting the demands, an improvement of combustion efficiency, a reduction of friction loss and a weight reduction of engine components are increasingly important.

Among engine components, an engine cylinder plays a quite important role on the generation of power, because the engine cylinder constitutes a combustion chamber together with a head cylinder and a piston, it guides the reciprocating movement of a piston, and also it releases the heat generated in a combustion chamber during an engine operation. So, the material of the engine cylinder is required for high strength, sufficient wear and scuff resistance, high heat conductivity, high corrosion resistance and lightweight. And also high productivity, lower cost and good recycling efficiency are required as an industrial product. In order to meet the above

mentioned requirement, a lot of cylinder block designs have been proposed and tried to put into practical use. Figure 1 categorizes the cylinder block design according to the cylinder bore materials and its structure.

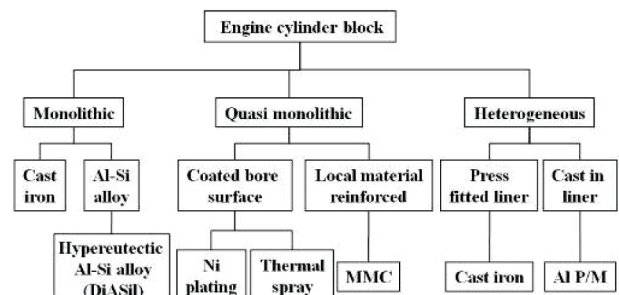


Figure 1. Categorized cylinder block design according to the cylinder bore material and its structure.

Among these cylinder block design, the monolithic type Al cylinder, which is named DiASi cylinder, has been

widely applied for single cylinder motorcycles mainly used in Asian countries (1). An appearance of DiASil cylinder is shown in Figure 2. Until now, more than 1 million units of DiASil cylinders are launched to the market, and these motorcycles are used not only for the transportation of daily life but also the enjoyment of motorcycle riding.



Figure 2. Appearance of DiASil cylinder.

The monolithic type Al cylinder which is made by high pressure die casting process using hyper eutectic Al-Si alloy has a lightweight structure and superior cooling ability. The cylinder bore surface is required for tribological properties such as an anti-scuffing property, an anti-wear property, and a low friction. Among these tribological properties, the anti-scuffing property is quite important to assure the reliability and the safety of the motorcycles.

Usually the cylinder bore surface of the monolithic type Al cylinder is finished by an etching process or a honing process in order to expose Si particles from the Al matrix for the improvement of the tribological properties (2). The morphology of the cylinder bore surface such as the exposure of Si particles is supposed to make an important effect on its tribological properties. Regarding the anti-wear property, it has been already shown that the Si exposure height makes an effect on its wear resistance (3). However, the studies dealing with the relationship between the morphology and the anti-scuffing property of the monolithic type Al cylinder have not ever been seen.

In this research, the anti-scuffing property of three kinds of cylinder bore finishing, an etched surface, a Si exposure honed surface and a conventional plateau honed surface is evaluated with using a reciprocated type wear tester. The experimental results are analyzed by using Weibull analysis. The relevance of the application of the Weibull analysis is discussed. Then the effect of surface morphology on the anti-scuffing property is discussed by comparing the Weibull analysis, surface observation and also surface roughness measurement results.

EXPERIMENTAL PROCEDURE AND ANALYSIS METHOD

Reciprocated Type Wear Tester

The scuffing phenomenon of the cylinder bore surface usually occurs on a top dead center. So, the reciprocating type wear tester was chosen for the evaluation of the anti-scuffing property. Figure 3 schematically illustrates the testing system.

For the scuffing tests, specimens of a piston ring and a cylinder bore which are cut out from actual components are used. The piston ring specimen clamped with an upper specimen holder is attached to a reciprocating arm. On the other hand, the cylinder bore specimen is set in a lower specimen holder. The normal load is applied on the piston ring specimen. And also the piston ring specimen moves back and forth on the cylinder bore specimen.

During the test, the temperature around the contact point is kept constant by a heater installed under the lower specimen holder. The sliding amplitude of the piston ring specimen is feedback controlled with an amplitude sensor installed in the reciprocating arm. Friction force is monitored by a friction sensor which is also installed in the reciprocating arm.

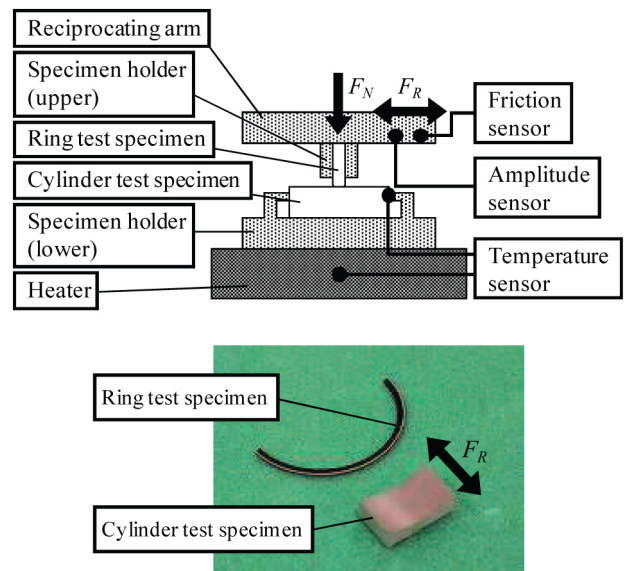


Figure 3. Schematic illustration of the test system and appearance of test specimen.

Prior to testing, 5 μ l of engine oil is supplied at the contact point of the lower cylinder bore specimen. The oil is not supplied during the scuffing test. Then 5N as a preload is applied on the piston ring specimen and also the temperature is increased to the testing temperature. After the temperature is reached at the determined temperature, the reciprocating movement of the piston ring specimen is started. At the same time the normal load is increased continuously until the scuffing signal is detected by the wear testing machine. The

detailed way of scuffing detection is described later. The experimental conditions are shown in [Table 1](#).

Table 1. Experimental conditions

Test temperature at a cylinder test specimen	230 ± 5 °C
Amplitude of a piston ring oscillation	2 mm
Frequency of a piston ring oscillation	10 Hz
Lubrication	20W-40 Base oil x 5μl
Increase rate of normal load	1N/sec

Test Specimen

Top rings and oil rings used for the monolithic type Al cylinders are usually treated several surface treatments, for example, Cr plating, CrN and/or DLC, on the sliding surface against the cylinder bore. These surface treatments have a superior tribological property, so it is considered that the probability of tribological problems in the actual usage would be small. On the other hand, second rings are usually made of cast iron or steel without any special coatings. So, the anti scuffing property of second rings is needed to be evaluated quantitatively. Because these reason, for the upper piston ring specimen, an actual second ring for motorcycle is used. The outer diameter is 42mm and the thickness is 1mm. The second ring is made of conventional cast iron, JIS-FCD700. Phosphate coating is treated on the outer surface.

The lower test specimen is cut out from an actual cylinder for motorcycle having 50mm diameter. The cylinder is made of T5 treated hyper-eutectic Al-Si alloy (Al-17wt %Si-4.5Cu-0.4Fe-0.5Mg), so-called A390 alloy. The size of the specimen is 12mm × 20mm and the thickness is 4mm on the minimal position. A typical microstructure of Al-17%Si alloy is shown in [Figure 4](#). Coarse primary Si and fine eutectic Si particles are dispersed in an aluminum matrix.

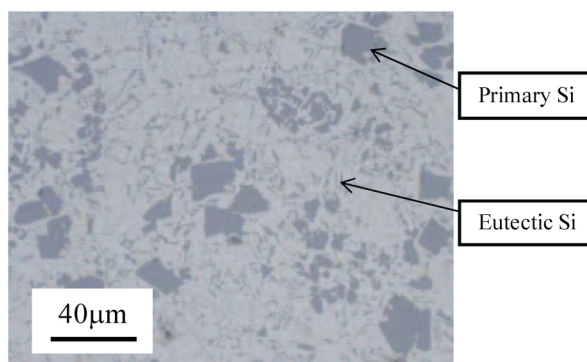


Figure 4. Microstructure of the cylinder bore material.
Al-17%Si hyper-eutectic alloy is used.

In this research, three kinds of cylinder bore finishing are evaluated, an etched surface, a Si exposure honed surface and a conventional plateau honed surface.

Process flow of cylinder bore finishing is shown in [Figure 5](#). The first step is fine boring process by which the cylindricity can be kept. Then rough honing is processed to

get an accurate cylinder bore diameter. And then, fine honing process makes the surface smooth.

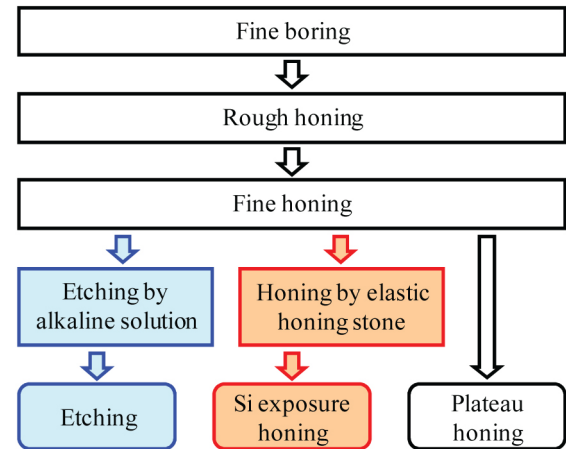


Figure 5. Process flow of cylinder bore finishing.

In case of the etching process, the fine honed cylinder bore is etched with alkaline solution for predetermined time. In this process, only the Al matrix dissolves into the alkaline solution, so primary and eutectic Si particles still remain. As the result, these Si particles are exposed from the Al matrix.

In case of the Si exposure honing process, the fine honed cylinder bore is honed with an elastic honing stone made of polyurethane. In this process, the Al matrix is mechanically recessed. The Si exposure height is controlled by the time of processing, and also the maximum Si exposure height is determined by the elastic modulus of honing stone (2).

In case of the conventional plateau honing, the recessing volume of the fine honing process is carefully controlled to remain grooves which are made during the rough honing process. These grooves act as an oil retention volume.

The contact surfaces which are observed with an optical microscopy (OM) and analyzed using an energy dispersive spectroscopy (EDS) installed in a secondary electron microscopy (SEM) are shown in [Figure 6](#). The surface roughness measurement results are shown in [Figure 7](#).

On the surface roughness of the etched cylinder bore surface, a lot of asperities can be clearly visible. On the etched surface, microstructure of Al-17%Si alloy in which primary Si particles are dispersed is observed. The asperities correspond to the exposure of not only primary Si but also eutectic Si particles remain on bore surface by the alkaline etching in which process only an Al matrix is effectively etched.

On the other hand, on the Si exposure honed surface, the height of asperities is lower and the number is much smaller than that of the etched surface. Fine scratch marks are visible on the surface but the microstructure is not visible.

On the plateau honed surface, there are no asperities on the bore surface, but several deep grooves are observed.