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Feasibility Study of Ferrous Powder Thermal Spray Coatings on Cylinder Bores in Diesel Engines†

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KEY WORDS: (Plasma) (Thermal Spraying) (Corrosion) (Wear) (Diesel Engine) (Al Alloy)

Aluminum alloy is being gradually utilized in cylinder blocks instead of ferrous casting material for weight reduction in the automobile industry these days. In order to achieve more weight reduction for automobile diesel engines, aluminum cylinder blocks without cast iron liners (liner-less) are expected to come into practical use soon. Yet, diesel fuel's impurity element "sulfur" introduces the corrosive attack possibility, since sulfuric acid generated on the liner surface is higher than with gasoline fuel[1), 2)].

For that reason, wear and corrosion resistances on the inner surface of cylinder-bores are required so that liner-less aluminum cylinder blocks perform effectively. At present, coating technologies for cylinder-bores have been investigated from the material and method point of view[3)-5)]. This research is intended to examine both wear and corrosion performances using plasma thermal spray technology and to verify the feasibility of application to actual engine bores. A newly-developed ferrous powder (Fe-C-Ni-Cr-Cu-V-B alloy) revealed extremely excellent corrosion and wear resistances, compared with currently used bulk casting materials such as Fe-C-Si-B alloy and Fe-C-Si-Mo-B alloy for cylinder liners. The new ferrous alloy powder was applied to actual engine bores by using Rota-Plasma spray coating. The experimental results with engine bores showed a presented potential equivalent to current engine bores.

Al-11.1mass% Si-2.1mass% Cu-0.8mass% Fe-0.7mass% Zn-0.3mass% Mn-0.3mass% Mg alloy casting was used for the cylinder block. As the spray material, a newly-developed ferrous powder, Fe-C-Ni-Cr-Cu-V-B alloy, was used in our experiments. The chemical composition of the powder is shown in **Table 1**. Two types of cast iron liner bulk materials, Fe-C-Si-B alloy (ST) and Fe-C-Si-Mo-B alloy (GT), were also used for comparing wear and corrosion performances. The chemical compositions of these bulk materials are shown in **Table 2**.

Atmospheric Plasma Spraying (APS), Rotaplasma®, was utilized in the experiments. Before the spraying process, a blast treatment was performed on the aluminum alloy substrate with alumina and titania using particle sizes of 600-800 μm. The bore diameter and height of the test engine are 93.7 mm and 126.7 mm, respectively.

Test pieces for evaluating wear and corrosion performances were prepared in rectangular parallelopiped shape with sizes of 17mm×15mm × 70mm. The target coating thickness is 250-300 μm, and the spray conditions are shown in **Table 3**.

Wear resistances of coatings were examined by using a reciprocation motion type testing equipment under the wet condition of engine oil mixed with sulfuric acid water solution (3.6 vol%). A chromium-plated pin with a coating thickness of 100-150 μm was used as a counterpart. Wear tests were performed at 240m/min sliding speed, 50 mm per stroke, and 98 N load. The test pattern is 10 hours wear test followed by 14 hours stop/hold and then 10 hours wear test again, so the actually total wear testing time is 20 hours. The maximum wear depth was measured using "Talysurf S5C" picture image analyzing method by

Table 1 Chemical composition of newly-developed spray powder for cylinder blocks.

Chemical composition (mass %)										
C	Si	Mn	P	S	Ni	Cr	Cu	V	B	Fe
3.10	2.89	0.08	0.004	0.004	8.95	2.46	4.80	0.74	0.075	Bal.

Table 2 Chemical composition of current liner bulk materials.

	Chemical composition (mass %)							
	C	Si	Mn	P	S	Mo	B	Fe
ST	3.09	2.31	0.73	0.23	0.117	–	0.093	Bal.
GT	3.27	2.32	0.74	0.21	0.124	0.44	0.051	Bal.

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Table 3 Rota-Plasma spray parameters.

Parameter \ Substrate	Cylinder Block
Powder Name	ISUZU selected powder
Powder Chemical Composition	Fe-C-Ni-Cr-Cu-V-B
Plasma Gun	SM-F210
Current	250 (A)
Recorded Voltage	30 (V)
Argon (Ar)	40 (L/min)
Hydrogen (H_2)	1 (L/min)
Powder Carrier Gas	Ar 3.8 (L/min)
Powder Feed Rate	30 (gr/min)
Spray Distance	45 (mm)
Rotation Speed	200 (rpm)
Forward Speed	6 (mm/rev)
	20 (mm/sec)
Gun Jet Cooling	Ar 6 (bar)
No. of passes	24

scanning the surface of the test pieces with a 2 µm radius of stylus tip.

No cracking was found in the coating and no peeling was observed at the interface between coating and substrate in all of the coatings. A cross-section of coating is shown in **Fig. 1**.

Fig.2 shows external appearance of the cylinder block and sprayed bore after honing finishing. Coating thickness satisfied the target of 250 µm at every position of the bore. The range of coating thicknesses is between 258 µm minimum and 280 µm maximum.

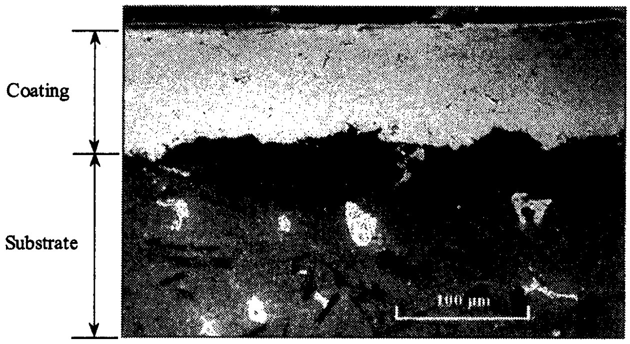
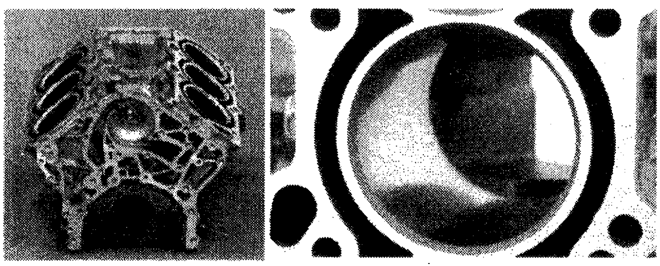


Fig. 1 Representative spray coating section with newly-developed powder.



(a) External appearance (b) Sprayed bore after honing finishing

Fig. 2 Thermal sprayed aluminum cylinder block.

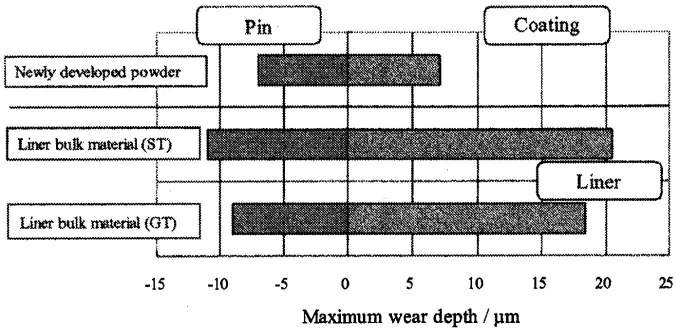


Fig. 3 Anti-wear property of coatings and counter pins tested in engine oil with 3.6 vol% sulfuric acid water solution.

Figure 3 shows the wear test results in engine oil lubricant conditions mixed with sulfuric acid water solution (3.6 vol %). The maximum wear depths of spray coating, counter pins, and bulk materials are compared between the newly-developed powder and two types of liner bulk materials. The newly-developed powder coating showed excellent wear performance compared to liner bulk materials currently used in actual engines. Maximum wear depth of coating was less than half compared to liner bulk materials. Maximum wear depths of counter pin against the spray coating also showed less than these of liner bulk materials.

As summarizing remarks, it can be confirmed that spray coating bores with the newly-developed spray coating material by using the Rotaplasma® method fills all the performances required for practical use in actual diesel engine.

Acknowledgment

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