

Development of Low-cost Material for Engine Exhaust Valve Seat

Hiroyuki OKETANI*

Ryushi TSUBOTA*

Masao ISHIDA*

ABSTRACT

A low-cost material for engine exhaust valve seats has been developed with the aim of a positive use of an oxide layer. A cost reduction of more than 40% has been attained while maintaining the same or better anti-wear characteristics and machinability as current materials by the optimum designation of density, the optimum addition of secondary hard particles and the special consideration given to the basic iron powder shape for microscopic vacancy without using a special molding method such as repressing and resintering (2P2S), copper infiltration, resin impregnation, nor using a high cost material such as Cr-Mo-Co, Co, or Ni powder to enhance the generation of an oxide layer.

1. Introduction

The main type of engine valve seat in use today is an iron sintered material insert type because of its material flexibility, low cost and abrasion resistance. Additionally, because the practical air fuel ratio is getting closer to the stoichiometric air fuel ratio in order to save fuel and meet ever stricter exhaust emissions regulations, combustion products are unlikely to provide buffering effect, so sintered valve seats (hereinafter referred to as valve seats) should provide enhanced abrasion resistance, which includes tolerance of higher exhaust temperatures⁽¹⁾ and increasing combustion pressure. To achieve abrasion resistance, valve seat materials undergo special production techniques such as repressing and resintering (hereinafter referred to as 2P2S) and copper infiltration as well as the addition of expensive metal powders like Co base alloy powder (Cr-Mo-Co-based) or Co or Ni powder. These are leading to great increases in the cost of valve seats.

In this research, the generation of an oxide layer (triiron tetroxide) that occurs when the engine is running was the focus, and by actively using this layer, an exhaust valve seat material with low cost and excellent abrasion resistance was developed. This paper reports on the content of this research.

2. Development Goals

Figure 1 shows the raw material costs and the abrasion resistance results of a unit rig test of exhaust valve seat materials presently used in Honda motorcycles.

This development was to realize low cost and high abrasion resistance, and the red area shown in Fig. 1 was set as its goal. Specifically, abrasion resistance is equal to current materials, the cost reduction is more than 30% compared with current materials.

3. Establishment of Unit Abrasion Test Correlating with Actual Engine Endurance Test

Before starting the development, a compatibility test was performed to use a valve seat material that had been previously developed for automobiles (herein after referred to as diversion material) as a possible low cost valve seat material for motorcycle engines. As shown in Fig. 2, however, contrary to the unit abrasion results, actual engine endurance result was inferior to current materials.

* Asaka R&D Center

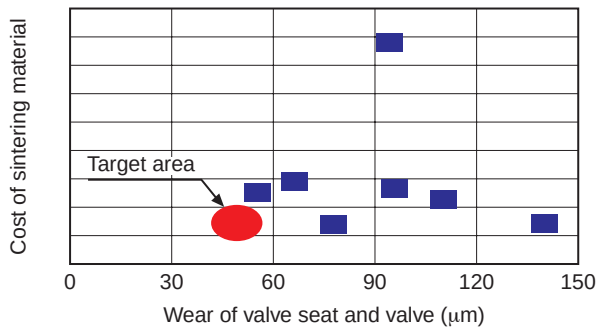


Fig. 1 Target of development

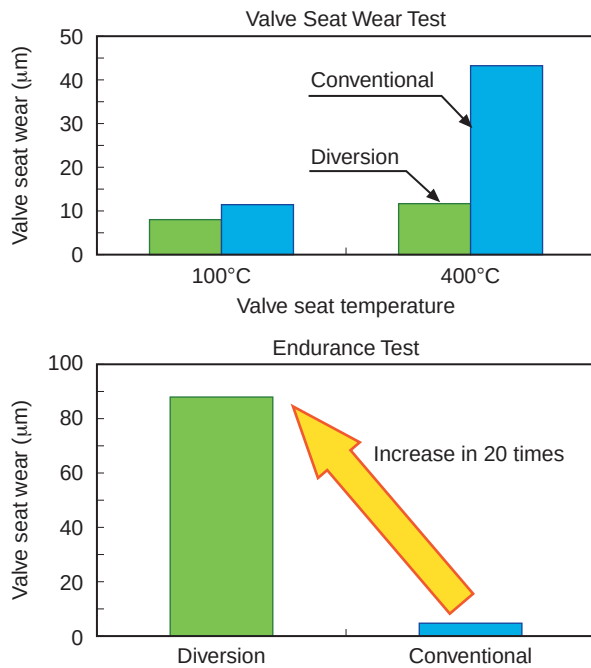


Fig. 2 Result of valve seat wear test & endurance test

3.1. Analysis of Components after Actual Engine Endurance Test

An examination of diversion material components that underwent high speed actual engine endurance testing and in which wear occurred found that, as Fig. 3 shows, there was metal contact, with no combustion products on the valve seat face and no generation of oxide layer. Further, it was found that initial wear occurs at the high running speeds characteristic of motorcycles (10 000 r/min and higher) because of insufficient fit with the valve.

3.2. Verification of Correlation of Unit Abrasion Test and Actual Engine Endurance Test

Figure 4 shows the unit abrasion testing machine and the test conditions. In the past, unit abrasion tests have been performed with an air fuel ratio of 8 - 9, with the results showing much buildup of combustion products on the valve seat face, so that the conditions of the evaluation were favorable for abrasion resistance. After tests, significant combustion product, carbon, was found on the valve seat face. This aspect is very different from what is seen on components after actual engine endurance testing.

The air fuel ratio was, therefore, changed to 13 - 14, and the amount of combustion products on the valve seat face was

decreased. In addition, cam speed was increased from the former 3 000 r/min to 4 500 r/min, to increase valve contact load. This aim achieved a load level similar to that of an actual engine. These changes yielded results similar to those from actual engine endurance tests, as shown in Fig. 5. As shown in Fig. 6, combustion products and surface oxidation on the valve seat face were not detected after actual engine endurance testing by using the diversion material with much wear for the conventional material. These conditions were adopted as the standard conditions for the unit abrasion test.

4. Material Specifications

4.1. Materials Concept

Figure 7 shows the valve seat temperature and amount of wear of valve seat and valve face from the unit rig test performed under the conditions shown in Fig. 4. For the medium temperature range, valve seat wear increases relative to temperature, but the amount

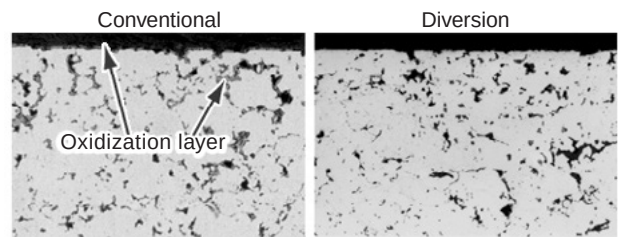
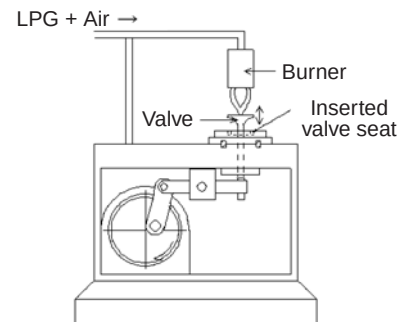


Fig. 3 Microstructure after endurance test



Test conditions		
	Conventional	Improvement
Cam revolution	3 000 r/min	4 500 r/min
Valve revolution	10 r/min	10 r/min
Test time	4.5 hr	9 hr
Valve material	45% Ni	45% Ni
Air fuel ratio	8-9	13-14

Fig. 4 Valve seat and valve wear testing machine

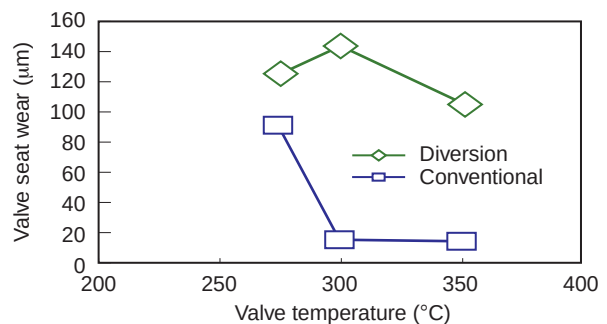


Fig. 5 Result of improvement valve seat wear test

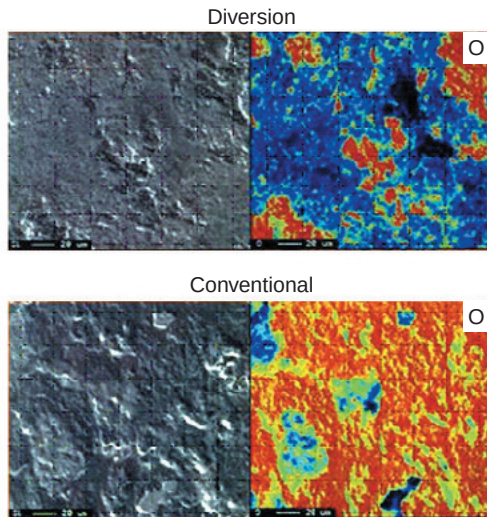


Fig. 6 Surface analysis (EPMA)

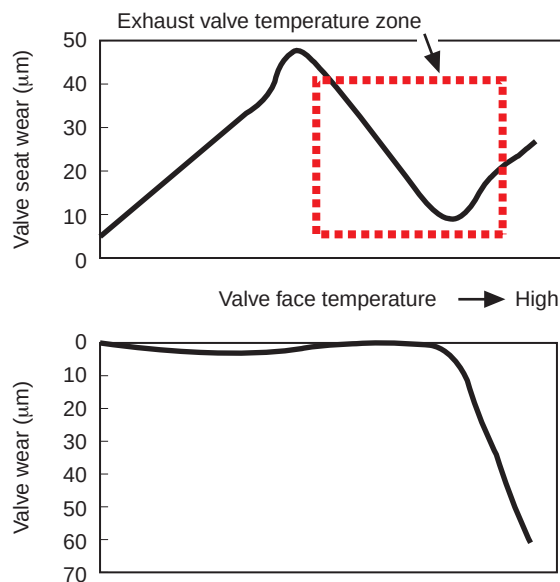


Fig. 7 Valve seat wear of temperature dependability

of wear tends to decline from a certain temperature. It is believed that the amount of wear decreases due to the low coefficient of friction and adhesion proof effect of the oxide layer (triiron tetroxide). As the temperature continues to increase, the high temperature hardness balance between the valve seat and valve face starts to decay, resulting in wear of the valve face.

In motorcycle engines, it has been identified from past data that the area within the broken red line of Fig. 7 is the range of temperatures at which exhaust valve seats are used.

Since running conditions in actual vehicles vary and the atmosphere around the valve seat varies greatly by driving conditions, it is believed that an early generation of a good oxide layer is important to ensure stable abrasion resistance. The concept of this developed material was to realize a low cost production method and to ensure a generation of oxide layer by using metal powders.

4.2. Examination and Selection of Base Material

Heteromorphic iron powder that has irregular shape with large surface area was used instead of spherical iron powder as the base iron powder in order to promote oxidation of the base material. Results of an oxidation test by heating showing oxidation properties is shown in Fig. 8, and a photograph of the internal microstructure after the test is shown in Fig.9. The developed material using heteromorphic iron powder has many microscopic cavities compared to the spherical iron powder. By above-mentioned reason, it is believed that good results of oxidation test by heating were shown.

Next, the alloying for the base material was examined to enhance heat resistance under high temperatures. Co powder, which is in heavy usage, is widely beneficial for generating good oxide layers, but its cost as a powder is high. Furthermore, it was excluded as an addition metal powder candidate for environmental reasons. Ni powder has similarly been removed as a candidate because of cost increases and environmental issues, so an addition metal powder was selected from the various steel alloy powders. Oxide layer generation and diffusion during sintering properties were emphasized, powder cost, hardness, and machinability were considered for steel alloy powder selection. Ultimately, Ni-Cu-Fe partial diffusion iron alloy powder was chosen.

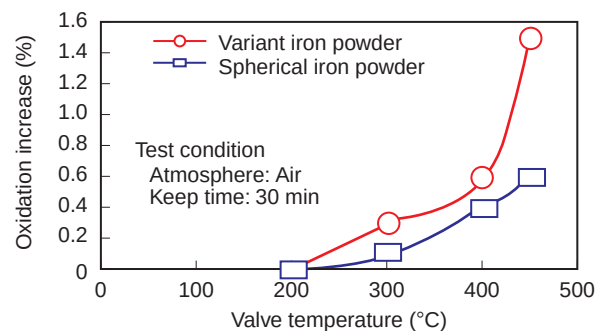


Fig. 8 Oxidation test of base iron powder

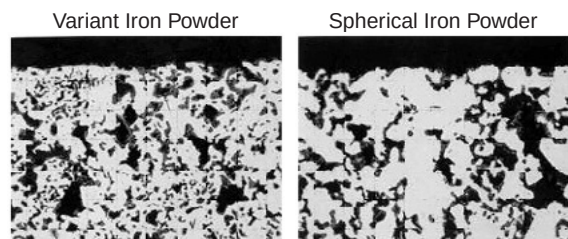


Fig. 9 Microstructure after oxidation test

4.2.1. Selection of hard particle material

Hard particles, which greatly affect the abrasion resistance of valve seat, are the base constituent of iron sintered valve seat material. In order to select materials for hard particles, coefficient of friction, oxide layer generating property, diffusion with the base material, fracture toughness, and powder cost were examined. Figure 10 shows results of lubricity tests of major hard particles.

In terms of the coefficient of dynamic friction and scuff load assessment, Mo-Ni-Cr-Co hard particle powder proved better than C-Cr-W-Co stellite powder and Fe-Mo ferroalloy powder and had characteristics next to Co base alloy powder Cr-Mo-Co.

The diffusion to the base is also an important factor for preventing defluxion of hard particles and for forming a high alloy phase of base material. Mo-Ni-Cr-Co powder showed better diffusion properties than stellite powder or ferroalloy powder, as shown in

Fig. 11. Mo-Ni-Cr-Co powder was selected by combined judgment, including fracture toughness and powder cost, as the hard particles for this developed material. Although Cr-Mo-Co powder has excellent abrasion and adhesion resistance, it is also costly and was excluded from application to the developed material, because

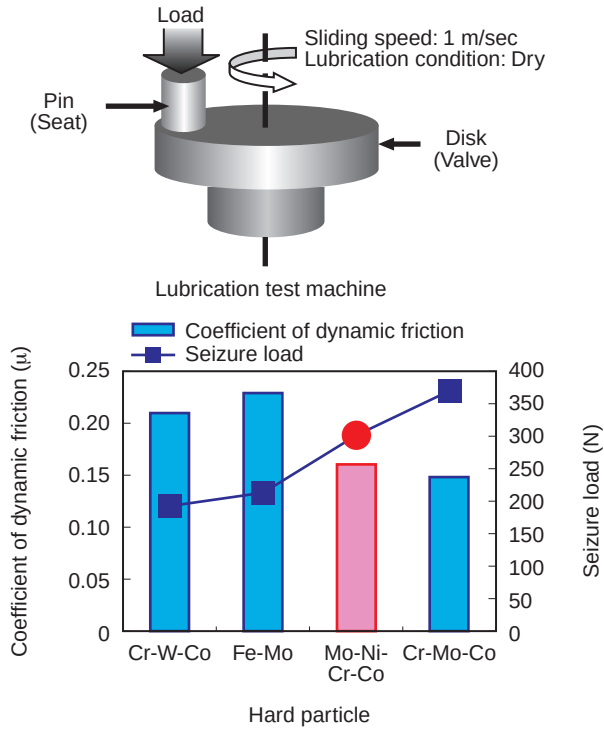


Fig. 10 Lubricity of hard particle

cost reduction was the aim. Figure 12 shows the relative cost of hard particles, where the cost of Cr-W-Co material is defined as 1.

4.2.2. Examination of hard particle additive amount

The optimum addition amount of Mo-Ni-Cr-Co powder was examined. Figure 13 shows the results of unit abrasion tests in actual engines and under simulated conditions on the relationship between the amount of hard particles added and the amount of wear. The amount of valve seat wear decreases as the amount of hard particles increases, but this effects tends to saturate when amount of hard particle additive exceeds 20%. On the other hand, the amount of valve face wear tends to increase from 20% in addition amount. Based on the above test results and the cost consideration, the amount of hard particles to add in the developed material was set at 20%.

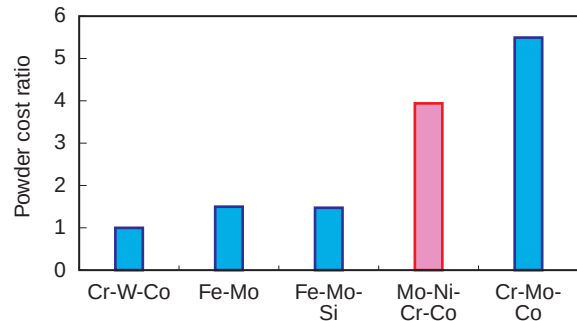


Fig. 12 Cost of hard particle

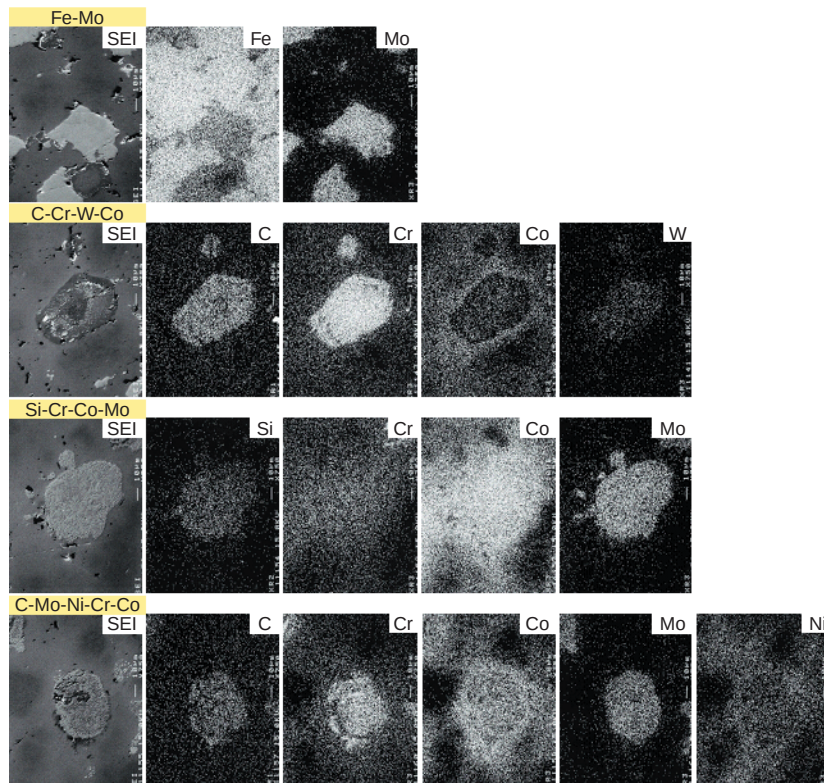


Fig. 11 Surface ultimate analysis development (EMPA)

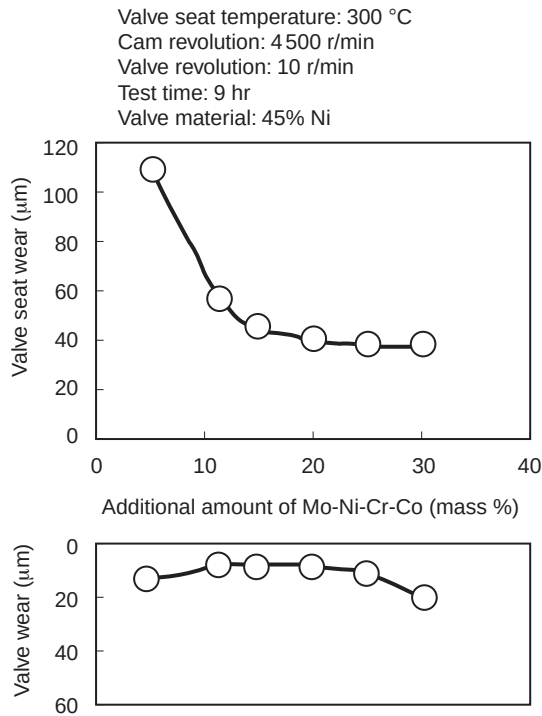


Fig. 13 Effects of hard particle amount for wear amount

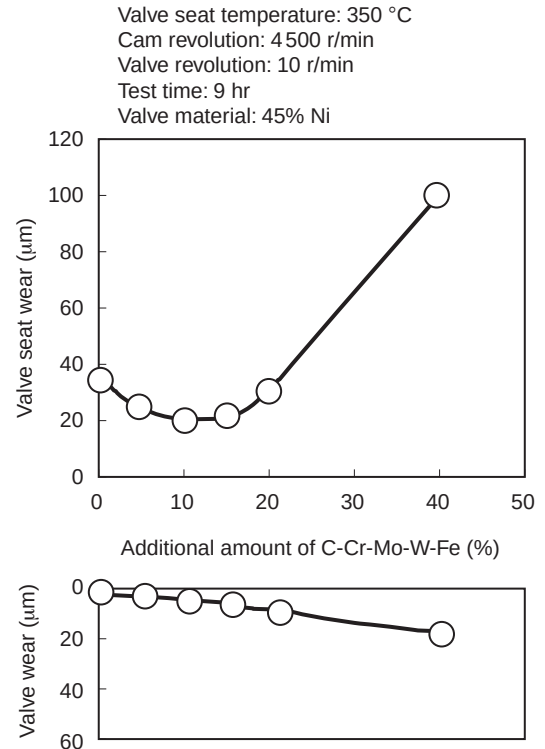


Fig. 14 Effects of fine carbide amount for wear amount

4.3. Examination of Secondary Hard Particle Additive Amount

In order to control initial wear before generating an oxide layer, in addition to the main hard particles, the optimum amount of secondary hard particles made of microscopic powder was examined. The type of hard particle selected was C-Cr-Mo-W-V-Fe powder, used in high-speed tool steels, by considering hardness, powder cost, and overseas availability. The amount of this additive was decided based on generation properties of oxide layer and abrasion resistance. Heteromorphic iron powder and Ni-Cu-Fe partial diffusion iron alloy powder were used for the base material iron powder. The addition amount of secondary hard particles was changed variously based on valve seat material that included the 20% addition of the main hard particle powder, Mo-Ni-Cr-Co. Figure 14 shows result of unit abrasion test on the relationship between the amounts of secondary hard particles added and the amount of wear. Wear was lowest at 10% and tended to increase even when increasing and decreasing the amount of additive.

Figure 15 shows the result of a valve seat material oxidation test by measuring the oxidation increase, and Fig. 16 shows the result of a radial crushing strength test. The oxidation increase tends to decline in inverse proportion to the amount of C-Cr-Mo-W-V-Fe powder added. In contrast, radial crushing strength tended to increase in proportion to the amount added. Based on these results, it is conjectured that excessively adding C-Cr-Mo-W-V-Fe powder reduces the generation of oxide layer and affects abrasion resistance. Considering the radial crushing strength and the oxide layer generation property, the amount of high-speed tool steel powder (secondary hard particles) to add was set at 10%.

4.4. Examination of Optimum Density

An abrasion resistance test with varying densities was performed; the results are shown in Fig. 17. Regarding the abrasion resistance of valve seat materials, it is generally known that abrasion resistance increases as density increases, but it was identified that an optimum density for abrasion resistance exists in the developed material.

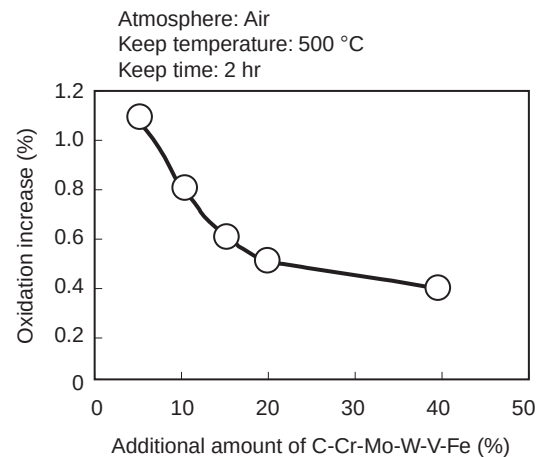


Fig. 15 Effects of fine carbide amount for oxidation increase

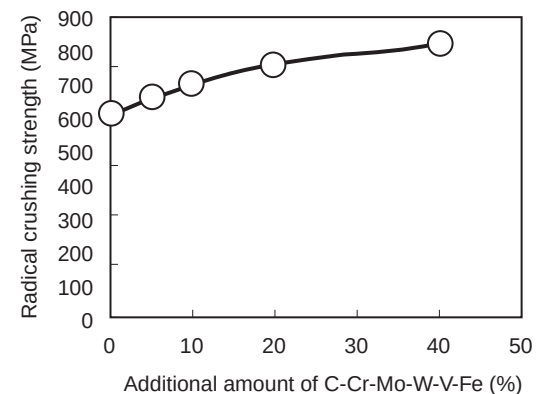


Fig. 16 Effects of fine carbide amount for radical crushing strength

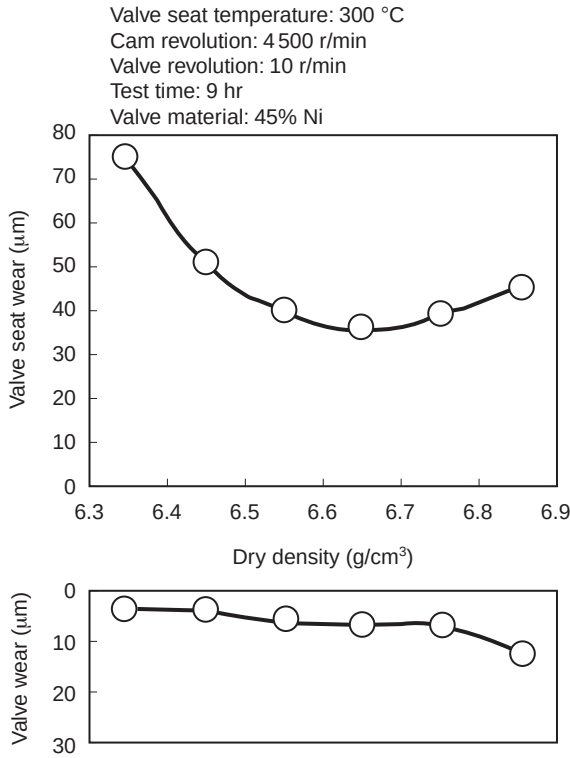


Fig. 17 Effects of dry density for wear amount

The above phenomenon was examined on the oxide layer generation property and the radial crushing strength. Figure 18 shows the result of radial crushing strength test. Figure 19 shows the result of oxidation test. The oxidation increase test was also performed as a comparison using Co powder base material. In the radial crushing test, radial crushing strength tends to increase as density increases.

However, in the results of oxidation test, fluctuations in mass gain to changes in density by oxidation of the base material that used Co powder are few and stable. On the other hand, the developed material without Co powder tends to increase mass gain with density decrease. These facts indicate that increasing density in the powder's composition does not necessarily contribute to an increase in abrasion resistance, and therefore conditions where the density of the developed material is set at 6.55 - 6.75 g/cm³. This density can be achieved by the compressing once and sintering once (1P1S) method.

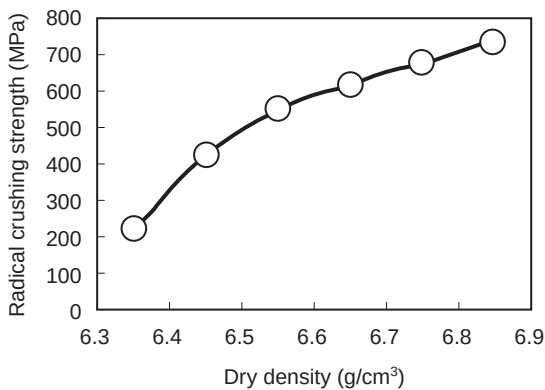


Fig. 18 Effects of dry density for radical crushing strength

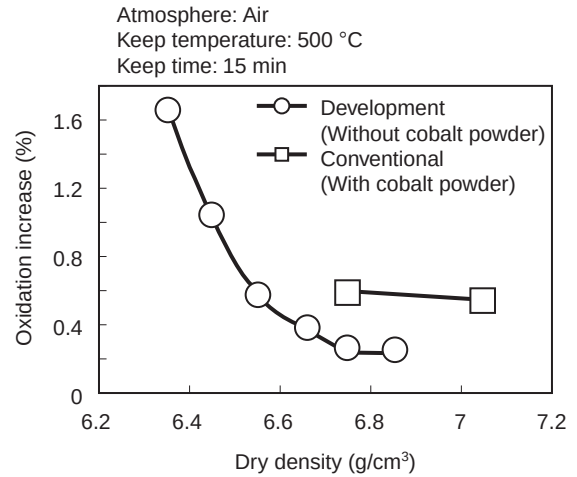


Fig. 19 Effects of dry density for oxidation increase

4.5. Specifications of Developed Material

Table 1 shows the chemical composition, density and hardness of the developed material. Figure 20 shows the internal microstructure. The developed material's structure consists of a mixture of Mo-Ni-Cr-Co hard particles, C-Cr-Mo-W-V based fine carbide and microscopic cavities in a pearlite layer and high alloy phase base.

5. Performance Evaluation of Developed Material

5.1. Unit Abrasion Test Results

Figure 21 shows the abrasion resistance properties of the developed material and comparison material from a unit abrasion test in which the valve seat temperature and air fuel ratio were controlled. A composite material of stellite hard particles with highest wear resistance, which is the exhaust valve seat material currently used by Honda; Fe-Mo hard particles, Co powder, and 2P2S material, was used as a comparison material. The developed material demonstrates abrasion resistance better than or equal to the comparison material.

Table 1 Chemical composition, density and hardness of developed material

Chemical composition (mass %)									
C	Ni	Cr	Mo	Co	W	V	Cu	S	Fe
1.2	3.6	5.2	5.5	8.0	0.6	0.2	0.6	0.2	Bal.
Density (g/cm³)					Hardness (HRB)				
6.65					97				

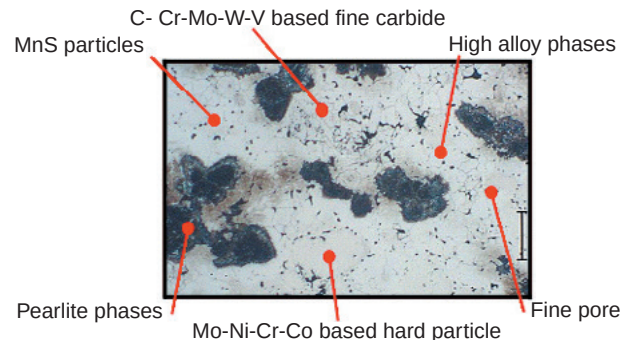


Fig. 20 Microstructure of developed material

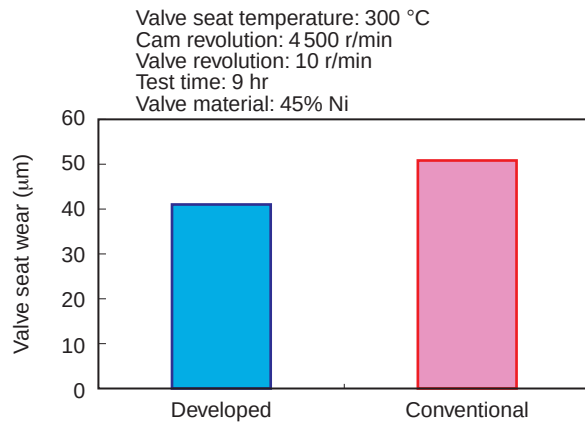


Fig. 21 Wear test result of developed material

5.2. Machinability of the Developed Material

Valve seats also require good machinability in conjunction with abrasion resistance. Figure 22 shows measurement results of cutting resistance value by using a cutting test machine. Figure 23 shows surface roughness profile for valve seats produced on a mass production line. The developed material's cutting resistance value and surface relative roughness after cutting were about the same as those of the present material, and even without post-processes, like resin impregnation for enhanced machinability, the developed material has as much machinability as the present material.

5.3. Cost of Developed Material

Figure 24 shows the powder cost ratio of the developed material and current material, and the raw material cost of which the developed material prior to machining is defined as 100. The powder cost ratio shows that the developed material is more than 40% less costly than the current material.

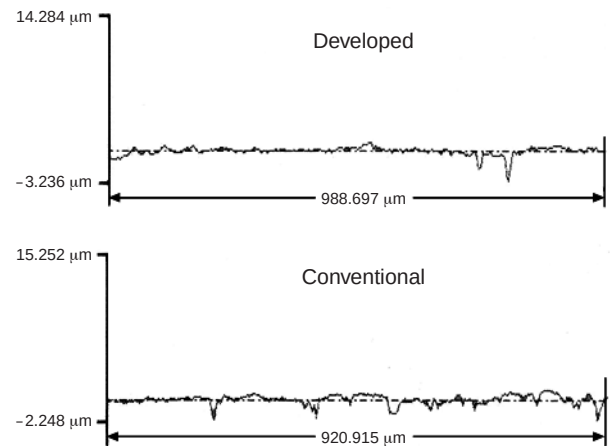


Fig. 23 Surface roughness profile of valve seats

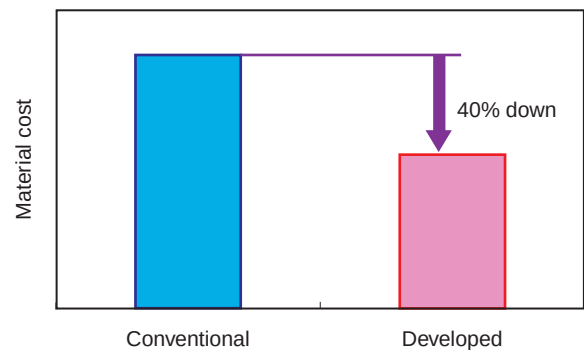


Fig. 24 Cost of developed material

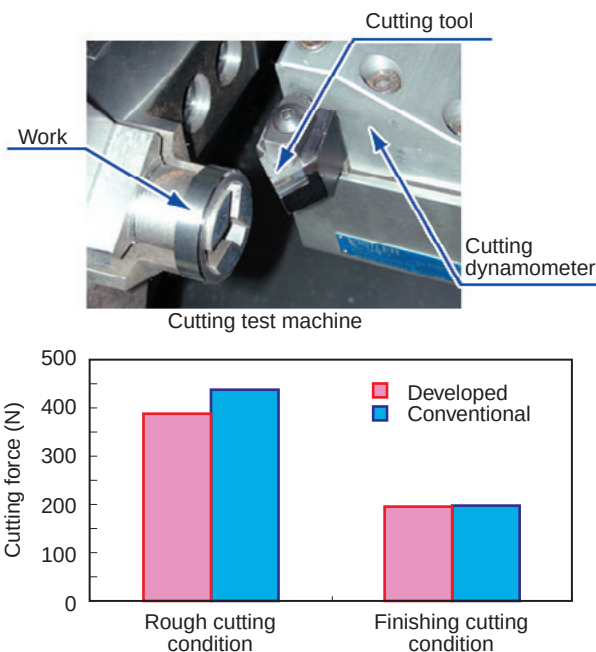


Fig. 22 Result of machining test

6. Actual Engine Endurance Test Results

Figure 25 shows the bench endurance test results with a super-sports motorcycle from Honda. In both high revolution endurance mode and long life endurance mode, the amount of wear in the developed material was about the same or less than the current material. Actual engine endurance results using different valve materials in other models likewise showed about the same or less wear than in current material.

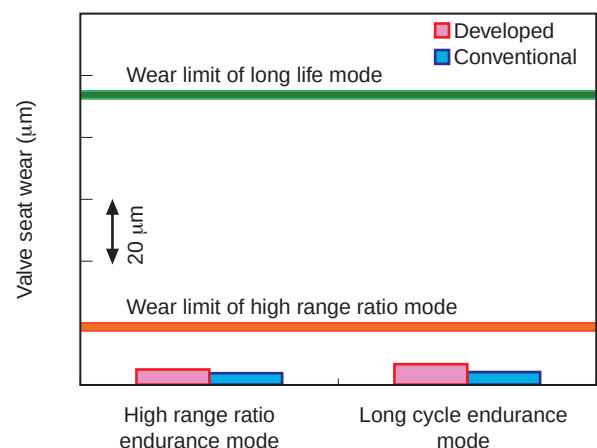


Fig. 25 Endurance test result of developed material

7. Conclusion

An exhaust valve seat material was developed that, while not needing 2P2S (repressed and resintered) processing, infiltration, impregnation or other post-processing, provided abrasion resistance as well as or better than current material while costing 40% less.

- (1) An optimal density for abrasion resistance was selected for seat materials not containing Ni or Co powders by balancing oxidation increase and radial crushing strength.
- (2) Because excessively adding fine hard particles inhibits oxide layer generation and decreases abrasion resistance, the amount added was optimized.
- (3) Heteromorphic iron powder was used instead of spheroidal iron powder as the base powder material in order to produce microscopic cavities.
- (4) Less expensive hard particles with low coefficient of friction and high base diffusion were added at optimal levels.

The developed material is being used in the mass produced 2004 model year CBF600F and its use is to be expanded in succession to other mass produced models.

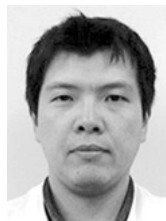
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■ Authors ■



Hiroyuki OKETANI



Ryushi TSUBOTA



Masao ISHIDA