DEVELOPMENT OF THE LOW COST FRM PISTON FOR DIESEL ENGINE

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SUMMARY: To develop a cost effective and better performance FRM piston, metal matrix composites reinforced with HTZ (High Temperature Zirconia) ceramic fiber were fabricated by a modified die casting process. Mechanical properties and wear resistance of composites were characterized to find out the effect of composite fabrication conditions, preform sintering temperature and the fiber volume fraction. The HTZ FRM showed tensile and fracture strengths very close to those of the matrix alloy, A336 and less wear volume than the Ni-resist cast iron and other types of composites. Based on the test results, proto type piston was made by the modified squeeze-die casting process and its durability was investigated with the engine dynamometer. The engine test results show that composites with HTZ fiber fabricated by the modified squeeze-die casting can be applied to the cost-effective piston for diesel engine.

KEYWORDS: FRM Piston, HTZ fiber, Modified die castin

INTRODUCTION

Metal matrix composites reinforced with ceramic fibers, due to their improved mechanical properties, economy of fabrication, and ability of near-net shaping are getting attraction for potential applications of engine components, structural automotive and aerospace components. Specially for automotive applications, extensive studies on FRM piston are being carried out, because engine designers are being forced to develop new diesel engine with higher power, better durability and lower emission. Therefore, many piston producers have adopted the FRM to enhance the piston performance by reinforcing the top ring groove and the combustion bowl regions. Although the performances of the FRM pistons were superior to those exhibited by the conventional pistons, the expensive ceramic fibers still limit their wider applications. This initiated us to develop a new type of fiber reinforcement, which not only is cost-effective but also possesses superior material properties good for improving the piston performance. The fiber developed in this paper is termed as the HTZ(High Temperature Zirconia) fiber with chemical composition being 46~54% SiO_2, 26~34% Al_2O_3 and 16~24% ZrO_2 in wt.%. The HTZ fiber produced by Keumkang chemical company in Korea is less expensive compared to both Saffil and Kaowool fibers. In this study, the

mechanical properties and wear resistance of HTZ FRM under the various manufacturing conditions were characterized. The first objective in this study is to determine the best process parameters to fabricate the HTZ FRM piston. The second is to affirm the performance of the HTZ FRM piston via the engine dynamometer test.

EXPERIMENTAL PROCEDURE

1. Preparation of FRM

HTZ fiber preforms having various volume fractions, 7, 11, and 15% were prepared using a conventional preform fabrication technique[1]. Likewise crystallographic structures of most fibers produced by the blowing method, the initial crystallographic structure of the HTZ fiber was also amorphous. However, when fibers are exposed at elevated temperatures for a prolonged time, the amorphous phase becomes crystallized. The 11 vol% preform was heat-treated at various temperatures, such as 1000, 1100, 1200 and 1300°C to evaluate the effect of the sintering temperature on the material properties of FRM. As a matrix, a conventional Al alloy for pistons, A336 was used. The sintered preform was positioned within the die and infiltrated with the molten aluminum 336 alloy.

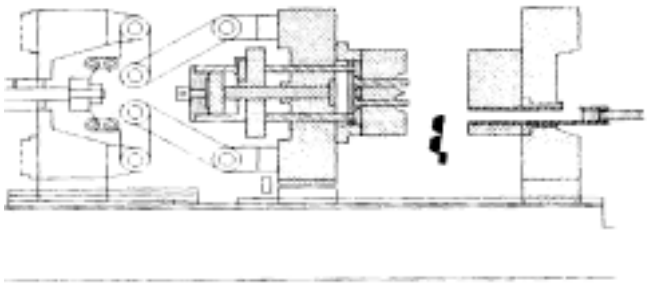


Fig. 1: A schematic illustration of the modified die casting machine.

Fig. 1 is a schematic showing the side view of the modified squeeze-die casting machine used to fabricate FRM specimens and proto parts. The modified die casting machine having a 250 ton clamping force was used and all test pieces were T6 heat treated. The designs of gate, runner and controller are greatly modified from the conventional die caster but the operation cost of this machine is much cheaper than that of the conventional squeeze casting machine.

2. Material property characterization

Mechanical properties such as strength, fracture toughness and wear resistance were characterized using the fabricated composites and the heat conductivity of the composite was also measured. Tensile test was carried out at room temperature using the tensile test machine, Shimadzu AG-25TA, under the cross-head speed of 1mm/min. Fracture energy was measured using a Charpy impact testing machine. Heat conductivity of 11% HTZ FRM was also measured using HVS-40-300SDS(Tokyo meter Co.) and compared with other materials. Wear tests were conducted using the pin-on-disc type FALEX multi specimen wear tester. Since the wear property is one of the most critical factor for selecting materials suitable for the top ring groove region of the diesel piston, the wear tests using various materials were performed to compare the wear property of the HTZ FRM under the two different test conditions. The details of these conditions are as follows.

Table 1 : The details of wear test conditions

Item	Test condition (A)	Test condition (B)	Comments
Counter Material	Carburized S45C	Gas-nitrided SUS440	Disc
Wear Distance	30 km		
Pressure	100 kg/cm^2	150 kg/cm^2	
Speed	2 m/s	2.5 m/s	
Lubrication	Engine oil dipping		

3. Prototyping and Engine test of FRM piston

Based on the test results, we have selected 11 vol% preform with a sintering temperature higher than 1100 and fabricated pistons using a 250 ton die casting machine. Preliminary engine tests were conducted on proto pistons at full load for 50 hours to check the performance and the wear states of the piston, especially top land and skirt regions. After preliminary checking for dimension and performance of FRM piston, we conducted the full load engine test for 500 hour duration. The power and the torque were measured from the engine during the test run and the top ring groove width was measured at the end of the test.

RESULTS AND DISCUSSIONS

1. Effect of fiber volume fraction on the mechanical properties of FRM

The test results are shown in the table 2.

Table 2: The test results of mechanical properties at various vol%

Properties	HTZ 7 vol%	HTZ 11 vol%	HTZ 15 vol%	336
Tensile strength(MPa)	280 ±20	280 ±20	290 ±10	270 ±20
Fracture toughness (J/cm^2)	0.52	0.51	0.48	0.55
Hardness(HB)	129	128	128	120
Wear volume(mm^3)*	0.029	0.018	0.018	1.136

* Tested under the wear test condition (A)

As shown in Table 2, tensile strength of FRM was slightly improved with a fiber addition. The fracture toughness of the HTZ FRM decreased gradually with increasing the volume fraction of the fiber, which indicates that small change in fiber volume fraction has minor effect on the resultant mechanical properties of the FRM.

2. Effect of preform sintering temperatures on mechanical properties of the FRM

The results, obtained using the same test conditions as those in Table 2, are summarized on the Table 3.

Table 3: Mechanical properties of composites fabricated with preforms sintered at various temperatures

Properties	1000 °C	1100 °C	1200 °C	1300 °C	Ni-resist
Fracture toughness (J/cm^2)	0.51	0.51	0.53	0.58	-
Hardness(HB)	129	128	128	128	150
Wear volume(mm^3)*	0.024	0.018	0.019	0.0059	0.045

As can be seen in Table 3, mechanical properties of composites were not observed to change significantly with the sintering temperature. The tensile strengths of all FRM specimens were about 280 MPa. However, there was a significant improvement in the wear resistance especially when the HTZ preforms were sintered above 1100 °C. Such a wear property shown by the HTZ FRM was better than the Saffil FRM or Ni-resist cast iron, which showed the wear volume in the range of 0.045~0.055 mm^3 under the same test conditions. Heat conductivity of 11% HTZ FRM was also measured and the results are shown in Fig. 2.

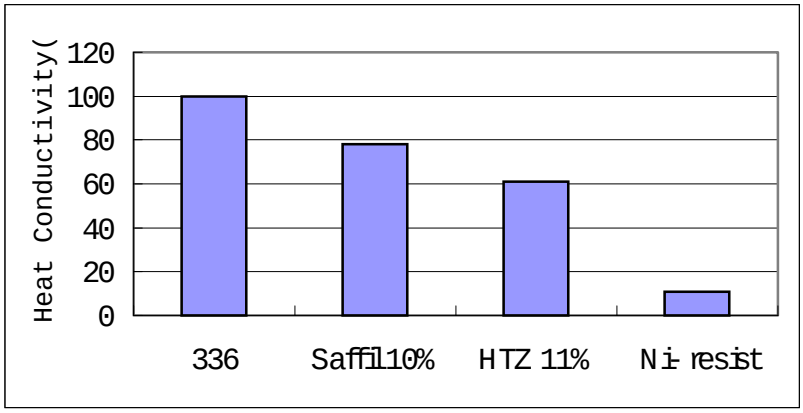


Fig. 2 : Heat conductivities of various materials.

Shown in Fig. 2 is the relative heat conductivity compared with that of the 336 alloy. Although the heat conductivity of the HTZ FRM is approximately 60% that of the 336 alloy and slightly lower than the Saffil FRM, it still has much larger heat conductivity than that of the Ni-resist cast iron. Therefore, if the Ni-resist cast iron could be replaced with the HTZ FRM for the diesel engine piston, the cooling efficiency of the component would be improved.

3. Comparison of wear properties of various materials under the wear test condition(B)

Fig. 3 and 4 are the test results. The notations used in Fig. 3 and 4 are defined in the Table 4.

Table 4: Notations in the Fig. 3~4

Notation	Meaning	Comment
Ni-resist	Ni-resist cast iron	Conventional Reinforcing material for top ring groove of pistons
HTZ	Chemical composition of fiber = Alumina+Silica+Zirconia	11 vol% FRM (F) : as cast (T6) : T6 heat treatment
AS	Chemical composition of fiber = Alumina+Silica (= Kaowool fiber)	
336	Base Al alloy for FRM	Material for piston
Alborex	Alborex whisker reinforced material	24 vol%, 336 matrix
F3D.20S	SiCp 20% reinforced composite	Commercial product produced by Duralcan

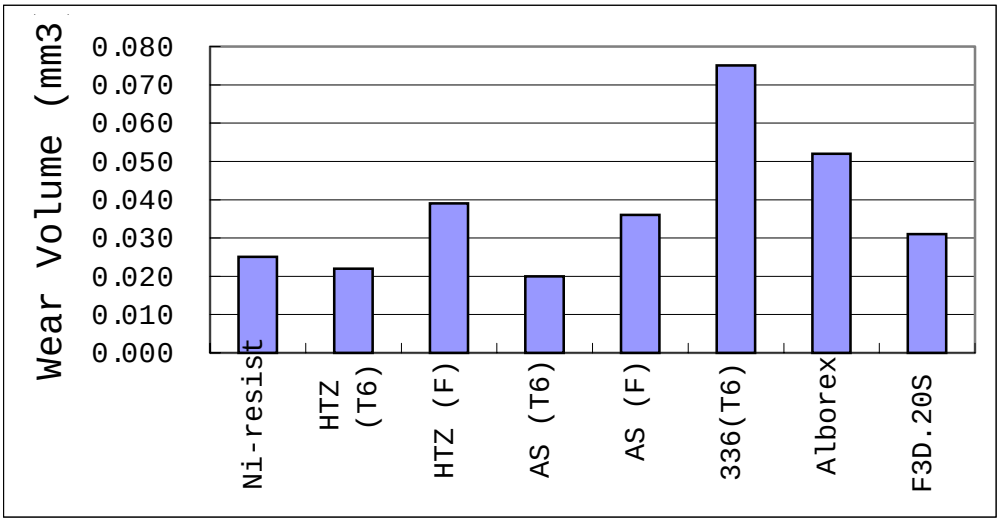


Fig. 3 : Wear test results of various materials.

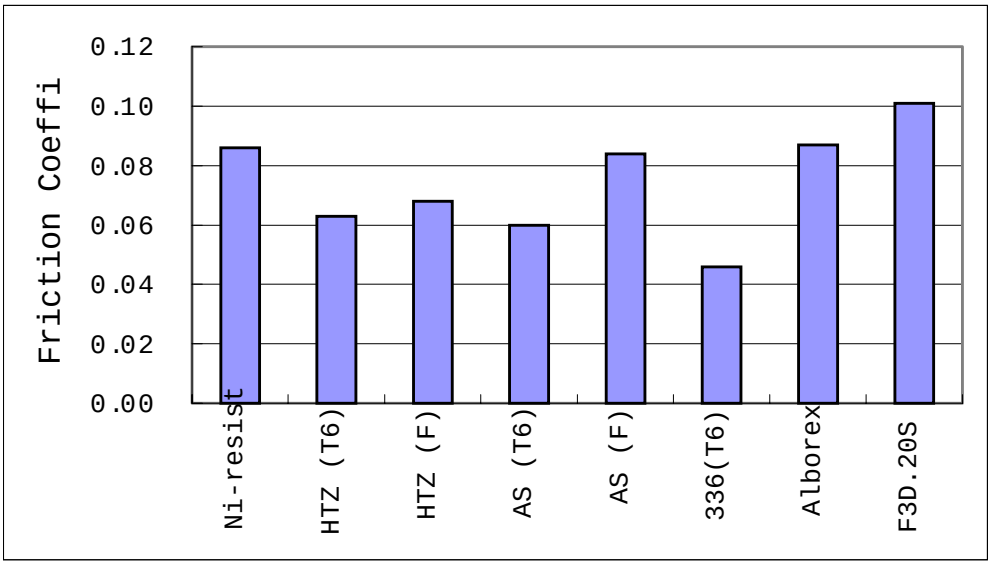


Fig. 4 : Friction coefficient of various materials.

As can be seen in Fig.3~4, the T6 heat treated HTZ FRM showed less wear volume and friction coefficient than the Ni-resist cast iron and other types of composites.

4. Fabrication and Engine tests of proto piston

FRM diesel pistons, of which ring groove region was locally reinforced with the HTZ fiber preform, were prototyped. Fig. 5 and 6 are the photos of HTZ fiber preform insert used for piston and the corresponding microstructure of HTZ FRM at the top ring groove. Fig.7 and 8 are the matrix microstructures of the incumbent gravity cast piston and the modified die cast piston. As can be seen in the micrographs, the secondary dendritic arm spacing was reduced by approximately 40% in the die cast piston.

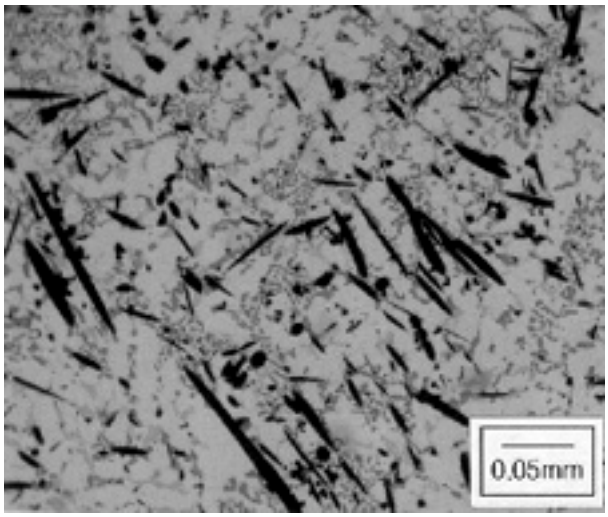


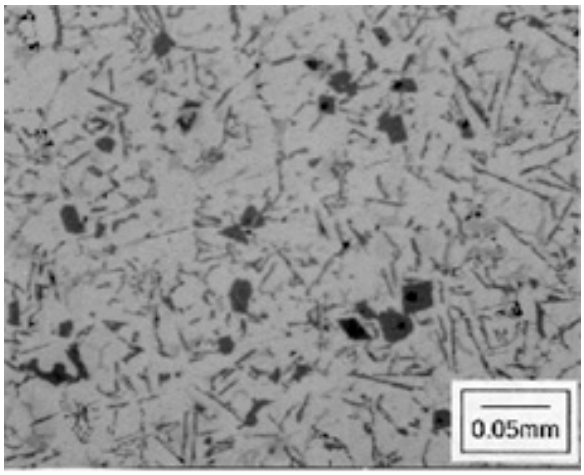
Fig. 5 Preform for IDI diesel piston. *Fig. 6 Microstructure of HTZ FRM.*

Preliminary engine test at full load for 50 hours

Fig. 9 shows the actual shape of the squeeze cast proto piston. Wear states of the composite piston were satisfactory compared to those shown by the incumbent gravity cast piston. It is also noted that large reduction in the blow-by gas could be achieved especially at high RPM.(Fig. 10)

Full load engine test for 500 hours

As can be seen in Fig.11, the power, the torque and the top ring groove width were measured to be equivalent when FRM pistons were assembled to the engine. The wear amount of top ring groove was found to be equivalent to that of the incumbent piston and the carbon deposit at top ring groove region was slightly reduced.



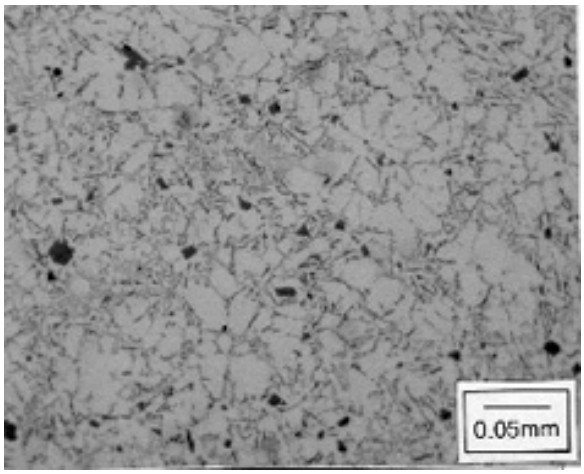


Fig. 7 Microstructure of the incumbent piston. *Fig. 8 Microstructure of the modified Diecast piston.*

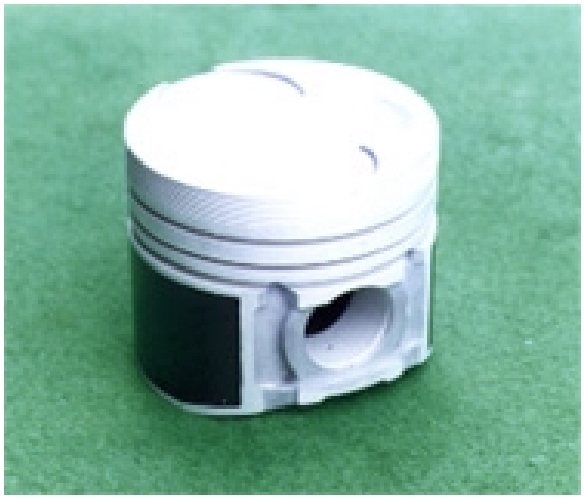


Fig. 9 Indirect injection HTZ FRM piston.

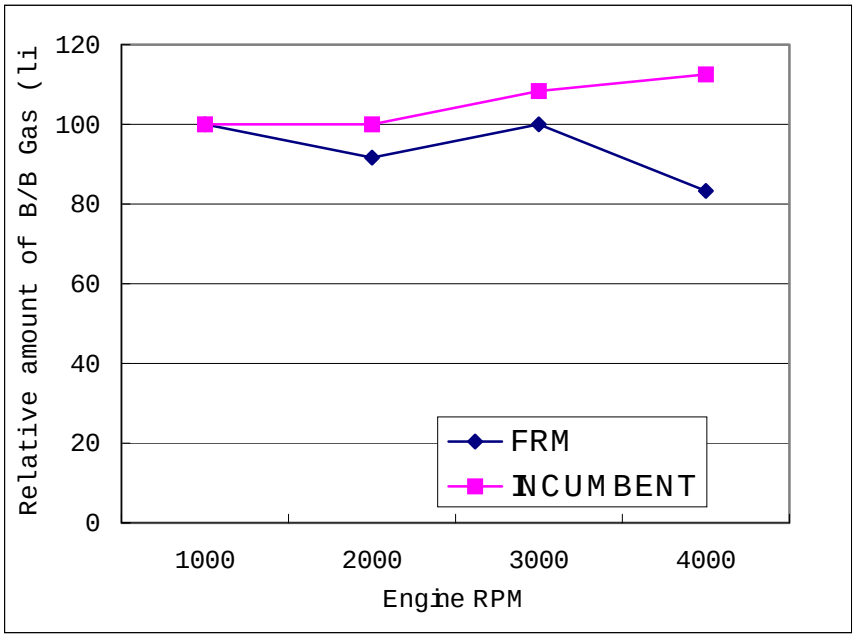


Fig. 10 : The comparison of blow-by gas between the engines using the incumbent and the FRM piston.

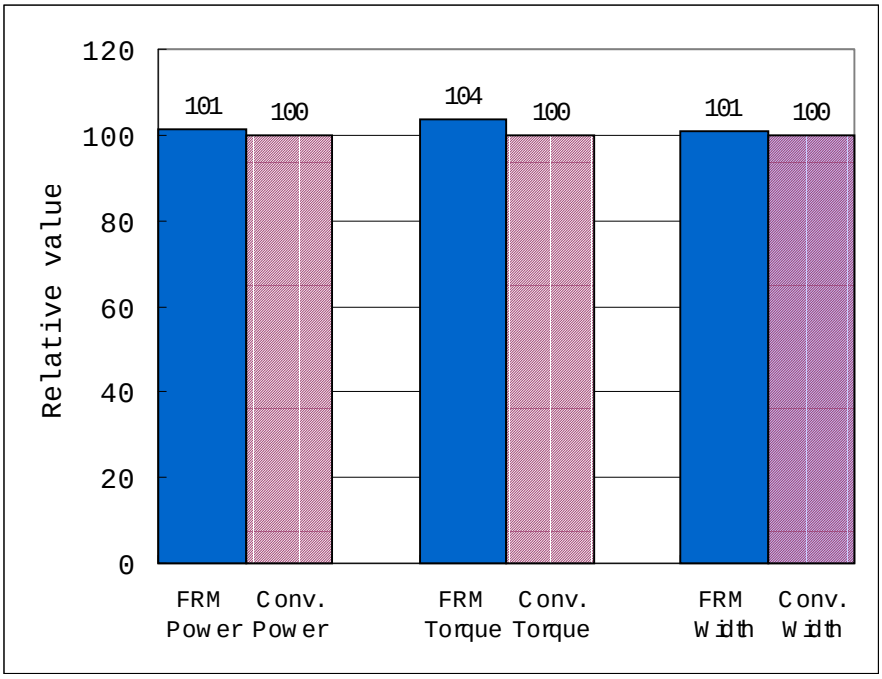


Fig. 11 : The comparisons of engine test results between the engines using the conventional and the FRM piston.

CONCLUSIONS

1. The tensile strength of the HTZ FRM was about the same regardless of the fiber volume fraction and the preform sintering temperature. However, the wear resistance of the HTZ FRM was improved significantly when the preforms were sintered above 1100 .

2. The HTZ FRM has a better wear resistance compared to other types of materials such as

Ni-resist iron, Saffil fiber or Kaowool fiber reinforced composites and particle reinforced composites.

3. Based on the full load engine tests for 50 and 500 hours, the piston reinforced by HTZ FRM can be applied to the high performance diesel engine.

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