

Development of Metal Matrix Composite Piston

Kazuhisa ISHIZUKA*

Katsuhito KUSAKAI*

Nobuyuki IMAI*

ABSTRACT

A metal matrix composite that can be expected to have outstanding strength at elevated temperatures was applied to reduce the piston weight. In composites, it is generally difficult to cope with both strength and toughness. To solve this issue, a powder alloy was applied using the mechanical alloying process, and the manufacturing process and surface treatment were optimized. This achieved a 16% weight reduction compared to the conventional material, AA2618. In addition, this enabled the Formula One engine speed to be increased by 400 rpm.

1. Introduction

Reducing the inertial weight of reciprocating systems is the most important subject to increase engine speeds, and it was necessary to develop new materials to realize lightweight and high strength parts for Formula One pistons.

Aluminum alloy metal matrix composites (MMC) strengthened by ceramic dispersion can be expected to have high specific strength, high stiffness, and better characteristics at elevated temperatures. However, it was necessary to overcome the issues that toughness and ductility are generally low, and strength anisotropy which comes from the restrictions on the forging process. To solve these issues, a powder alloy was applied using the mechanical alloying process, and the characteristics were enhanced by modifying the forging and heat treatment processes.

2. Developed Technologies

2.1. MMC Materials (AMC225XE) for Pistons

Table 1 compares the physical properties of MMC and the conventional material, AA2618⁽¹⁾. MMC uses AA2124 as the base alloy, and adds SiC with a particle size of 3 μm in a 25% ratio by volume as the dispersed ceramics. The SiC is dispersed and alloyed with the base alloy powder for the prescribed time using a high energy mill. Figure 1 shows a metallographic image of the MMC, and a mapped image of the carbon from the SiC obtained using EPMA. Here, a countless number of submicron size particles can be observed, dispersed uniformly between large particles with several μm . These submicron particles are thought to be the SiC crushed by the mechanical alloying process and dispersed within

Table 1 Properties of piston material

Material	Modulus	Density	CTE	CTC
	GPa	g/cm ³	ppm/K	W/mK
AA2618	74.6	2.76	22.6	165
MMC	113.0	2.89	15.5	129

the matrix. This material realizes high fatigue strength at elevated temperatures and better toughness and ductility by not only precipitation of the base alloy and the law of mixture, but also dispersion strengthening mechanism of the nanosize particles.

2.2. Forging and Heat Treatment Technologies

In general, powder metal materials are worked after sintering to achieve good mechanical properties. In early days, pistons were forged using previously extruded bars, but there was the issue that anisotropy in the piston roof was serious, and the expected characteristics could not be obtained. The issue of anisotropy was successfully resolved by forging pistons directly from HIP (Hot

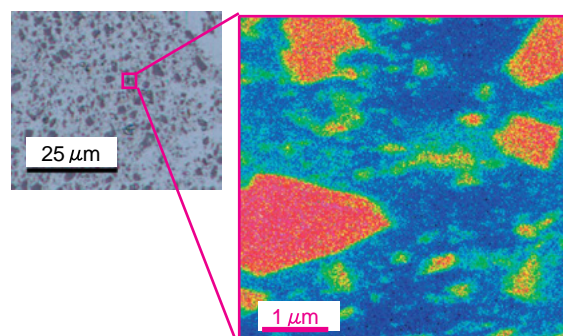


Fig. 1 Metallograph of MMC and distribution of carbon

* Automobile R&D Center

Isostatic Pressing) materials for which 3-dimensional isotropy can be expected.

The required forgeability was achieved by the low-speed hydraulic forging press. High cooling rate during quenching was ensured by using thin materials with a near-net shape, which realized good mechanical characteristics. Application of near-net materials also helped reduce machining of MMC, which is a difficult-to-cut material.

2.3. Surface Treatment

The lower coefficient of thermal expansion due to SiC dispersion leads to an increase in the clearance between the piston and the cylinder. This causes an issue in securing reliability of these sliding parts. This issue was overcome by applying an electroplated hard film and a resin coating containing dispersed hard particles to the skirt and top land, which secured the required durability and reliability.

3. Effects on Performance

Figures 2 and 3 show the mechanical characteristics of a test sample taken from the roof section of the piston material. Both high fatigue strength and ductility were achieved in the piston operating temperature range of 200 to 300 °C.

Use of this material realized lightweight and high strength pistons that were applied to races from the first GP of 2004.

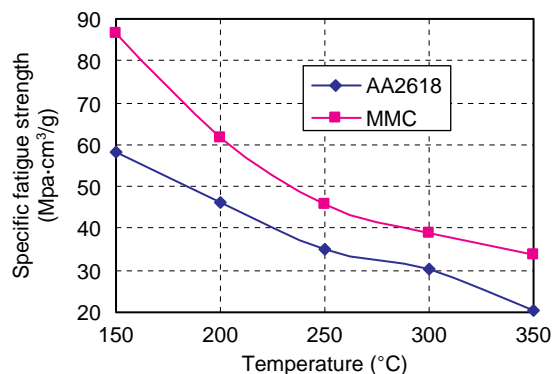


Fig. 2 Specific fatigue strength of developed material

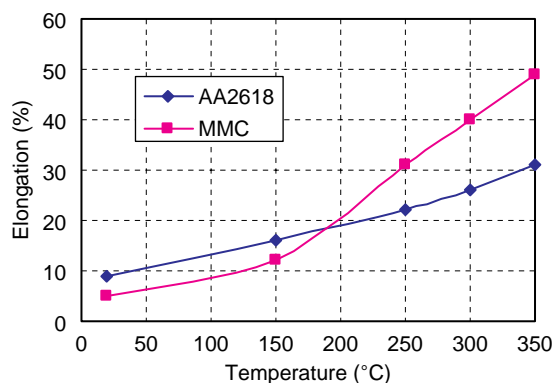


Fig. 3 Elongation of developed material

4. Conclusion

A high strength piston material was successfully developed by optimizing the composition and manufacturing method of MMC manufactured using the mechanical alloying method. Application of this material reduced the piston weight by 16% compared to the conventional material AA2618, and achieved an increase in the engine speed of 400 rpm.

Reference

- (1) <http://www.amc-mmc.co.uk/>

■ Author ■



Kazuhisa ISHIZUKA



Katsuhito KUSAKAI



Nobuyuki IMAI