

Development of Aluminum Liner in Die-cast Cylinder Block for High-power and High-displacement V6 Engine

Takashi KOMATSUDA*
Junichi OHMURA*

Masayuki TAKAHASHI*
Noriyuki NAMBA**

Katsuhisa YASUKAWA*

ABSTRACT

A 3.7 L V6 engine has been developed for the 2007 model year MDX. The new engine was developed based on the framework of the 3.5 L V6 engine employed in the previous MDX, but the engine's displacement and power have been increased.

The use of an aluminum alloy cylinder liner is an effective method of simultaneously increasing engine displacement and power. In employing an aluminum alloy cylinder liner in the new engine, the development focused on the sliding characteristic between the liner and piston rings. The reliability of the sliding characteristic has been ensured by the application of two main new technologies to the sliding surface of the bore: Detailed specification of the exposure of the particles on the liner, and the achievement of increased adhesion between the liner and cylinder block to increase the resistance of the bore to thermal distortion. This paper discusses the development of the aluminum liner for use in a cast iron cylinder block in the new high-power, high-displacement V6 engine, and provides an overview of the main technologies employed.

1. Introduction

Today, there is a growing requirement to increase the power and displacement of automotive engines while also achieving compactness. As a major engine component, these requirements have an effect on the cylinder block in particular. Effectively cooling the combustion chambers and pistons to reduce temperatures and prevent abnormal combustion is an important factor in the achievement of increased engine power. To balance increased displacement with compactness, it is important to increase the diameter of the cylinder bores without increasing the dimensions of the engine. However, reducing the dimensions of the bore bridges by increasing the diameters of the bores increases the likelihood that higher temperatures will be generated in the block. Reducing the temperature of the cylinder bores to make certain that it does not exceed limits for strength is an important point to be considered in achieving increased displacement.

Making the transition from a die-cast cylinder block using cast iron liners, as currently employed in the

majority of automobiles, to an all-aluminum cylinder block with a high heat transfer coefficient would represent an effective means of enhancing the cooling performance of the engine⁽¹⁾⁻⁽⁴⁾.

A variety of aluminum alloy cylinder blocks have been developed to this end. An all-aluminum cylinder block using a hypereutectic Al-Si alloy ("A390 alloy" below) has been put into practical use. To ensure quality in the inner surfaces of the bores, low-pressure die casting or low-speed medium-pressure die casting are employed when manufacturing a cylinder block using A390 alloy. Compared to high-pressure die casting methods ("HPDC" below) in which injection is conducted at high speeds and under high pressure, these techniques result in a higher average wall thickness, making it a challenge to achieve weight savings in the cylinder block as a whole, and they also result in a longer production cycle.

In order to continue to benefit from the cooling performance of all-aluminum cylinder blocks, while achieving higher quality and increased productivity by sharing production facilities and processes with die cast

* Automobile R&D Center

** Honda Engineering Co., Ltd.

cylinder blocks using cast-iron liners, it was necessary to develop a technology enabling the use of die casting to manufacture a die cast cylinder block with aluminum liners^{(2), (4)}.

2. Establishment of Targets for Development of Cylinder Block with Aluminum Liners

Honda's V6 engines for both the domestic and overseas markets have increased in power (over 220 kW) and displacement, as can be observed in the LEGEND models. As a major engine component, the cylinder block should respond to these demands, but it is also necessary to ensure quality and productivity. To satisfy these requirements, the following targets were set for the development of aluminum liners for a high-power, high-displacement 3.7 L V6 engine.

- (1) To achieve high power and high displacement by increasing the diameter of the bores, without increasing the external dimensions of the cylinder block against the previous 3.5 L V6 engine.
- (2) To ensure quality and productivity by sharing production facilities and processes with the die cast cylinder block with cast iron liners used in the previous 3.5 L V6 engine.

The material for aluminum liners is produced by adding high concentrations of silicon, alumina, or other hard substances to the aluminum base material. The composition of the material therefore differs fundamentally from that of the material used for cast-iron liners.

The hard materials help make certain that no abnormal wear, seizure, or scoring of the inner surfaces of the bores occur due to the pressure of the sliding surfaces of the piston rings and pistons. It is important to use hard materials with appropriate properties and to specify an appropriate degree of exposure of particles in order to achieve functional surface properties on the inner surface of the bores, or it would be unlikely to ensure the sliding characteristic of the piston rings, pistons, and aluminum liners.

With regard to the cylindrical stiffness of the liners, bore stiffness may decline due to the fact that aluminum, the base material, has a lower Young's modulus than cast iron. The issues discussed above can be summarized as follows:

- (1) Ensuring the sliding characteristics between the aluminum liners and the piston rings and pistons, to increase reliability with respect to seizure and scoring.
- (2) Ensuring the stiffness of the area around the cylinder block bores in which the aluminum liners are fitted, to help prevent heat distortion and reduce oil consumption and degradation.

These two issues are related to the characteristics of the materials used in the aluminum liners and structure of the cylinder block employing the aluminum liners. Issue (1) necessitates a new way of thinking and new

criteria of evaluation with regard to the conventional die cast cylinder block with cast-iron liners, and issue (2) necessitates the same with regard to the A390 alloy cylinder block.

The following techniques were employed to respond to these issues:

- (1) Optimal materials were selected for the hard materials used for the aluminum liners and the materials used for the piston rings. In addition, hard particles were exposed on the inner surfaces of the bores of the aluminum liners to enhance the sliding characteristic.
- (2) Minute projections were employed on the outer surfaces of the cylinder liners to enhance adhesion, and stiffness has been increased by the integration of the liners and the bores. A method of evaluating liner adhesion was also developed.

3. Development of Cylinder Block with Aluminum Liners

A width of 3 mm was set for the die cast aluminum between the liners, the part in which the main change was made. In order to achieve increased displacement, the bore diameter was increased to $\phi 90$ mm from $\phi 89$, used in the previous 3.5L V6 engine, without changing the 98 mm bore pitch.

The aluminum liner materials provided the advantage

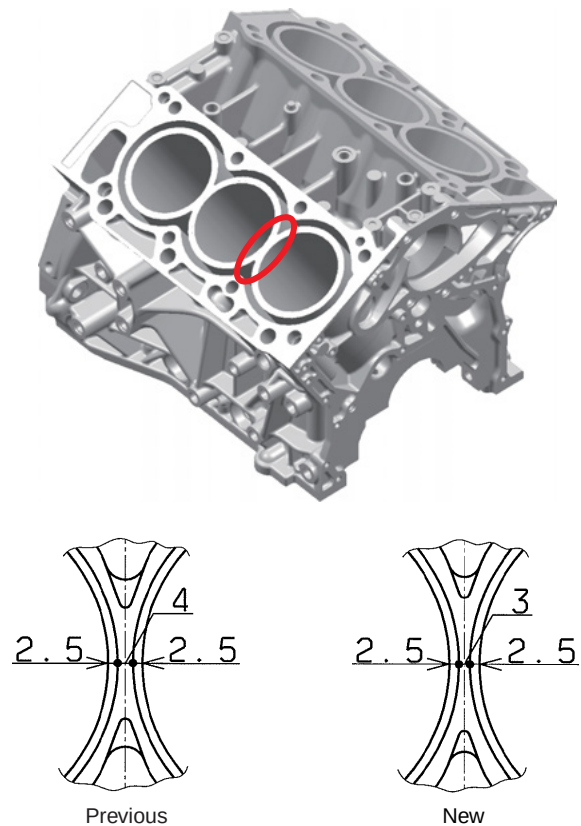


Fig. 1 Cylinder block and bore bridge section

Table 1 Specifications of cylinder blocks

	Previous	Developed
Total displacement (cm ³)	3471	3664
Bore (mm)	89	90
Stroke (mm)	93	96
Bore pitch (mm)	98	98
Block height (mm)	235	235
Block material	Aluminum alloy	Aluminum alloy
Liner material	Cast iron	AL (Spray compacted) High-Si aluminum alloy
Liner thickness (mm)	2.5	2.5
Weight (kg)	27.4	25.3

of increased castability, enabling the dimensions of the die cast aluminum between the liners to be reduced. The materials used in the aluminum liner and die cast aluminum have similar linear coefficients of expansion, thereby reducing the residual stress in the bore bridges caused by contraction as the material solidifies. This reduces the tendency for cracks to appear in the die cast aluminum used in the bore bridges, enabling the dimensions of the aluminum between the liners to be reduced from 4 to 3 mm.

Figure 1 shows an exterior view of the cylinder block and liners, and a magnified diagram of the bore bridge section.

By means of changing only the liners from cast iron to aluminum in a die cast cylinder block, the bore diameter was able to be expanded while maintaining compactness, with the external height and width of the cylinder block identical to those of the cylinder block employed in the previous model. In addition, the use of a shared exterior form for the block and shared die cast aluminum materials has enabled the existing HPDC facilities and exterior surface machining facilities to be shared. The use of the aluminum liners also enables the achievement of weight savings, reducing the weight of the cylinder block by approximately 2 kg against that of a die cast cylinder block using a cast-iron liner.

Table 1 shows the specifications of the cylinder blocks.

3.1. Selection of Aluminum Liner Material

The sliding surfaces of the liners are constantly exposed to high pressures from the pistons and piston rings. In addition, if impurities are present, scoring can occur. The base material for the aluminum liners has a low level of hardness, and hard materials are therefore added to ensure the hardness of the sliding surfaces. Alumina and silicon are currently the major hardening materials used in aluminum liners.

Table 2 shows the materials used in comparative tests.

As has already been indicated in a variety of reports, the amount of hardening material used, and the diameter and form of the particles in the materials, are important factors in ensuring the sliding characteristic^{(1), (2), (4)}.

However, the decision on whether to use alumina or

Table 2 Liner samples for engine tests

	Sample A	Sample B	Sample C
Particulate material	Al ₂ O ₃	Al ₂ O ₃	Si
Particle diameter (μm)	3	30	5
Liner manufacturing method	Powder metal	Melt-in	Spray forming

Table 3 Material property of aluminum liner

	Item	Unit	Sample A	Sample B	Sample C
Particle	Material	—	Al ₂ O ₃	Al ₂ O ₃	Si
	Hardness	Hv	2600	2600	1000
Liner	Tensile strength	(MPa)	250	240	250
	Young's modulus	(GPa)	100	95	90
	Thermal conductivity	(W/m·K)	120	115	120
	Thermal expansion coefficient	(×10 ⁻⁶ /K)	16	19	16

Table 4 Comparison of hardness

	Piston ring		
	Top	2nd	Oil
Average hardness (Hv)	1150	900	1050

silicon was a higher priority than the amount of hardening material to be used or the diameter and form of the particles, and it was therefore necessary to determine the areas in which these materials differed.

Table 3 shows a comparison of hardening material and aluminum liner properties.

Table 4 shows the hardness of the piston ring material that the liner material would be sliding against.

Alumina is harder than the nitrided stainless steel that is generally employed in the piston rings used in hypereutectic A390 alloy cylinder blocks, while the hardness of silicon is basically identical. Silicon is therefore the preferred hardening material.

Because these liner materials are compound materials of aluminum and hardening materials, the important factor is the retention capacity of both materials.

A microscope was used to study the dropping out of particles from the inner surface of the bores due to machining as a means of evaluating the retention capacity of the hardening material with respect to the aluminum base material.

Figures 2 and 3 show microscope photographs of the inner surface of a liner following machining.

Resistance during honing made particles drop out of the surface of Sample A, using a material to which alumina particles had been added. Machining conditions were optimized and the sample was checked again, but the status of particle dropouts did not improve. This confirms the generally held belief that

ensuring retention between alumina and aluminum is challenging. Silicon particle dropouts were not observed in the case of Sample C.

Tests of seizure and scoring resistance were conducted in an actual engine to assure accurate reproduction of factors affecting lubrication and surface pressure.

The results of the durability tests are shown in Fig. 4.

Piston seizure occurred when Sample A was used, and the material did not satisfy the target durability time requirement. Given that aluminum particles dropped out at the machining stage, it is likely that additional dropouts occurred due to the sliding of the piston rings during actual operation, resulting in seizure of the pistons. Sample B was a material formed from chemical bonding between alumina and an aluminum base material, and no particle dropouts and consequent piston seizure was observed in this case.

When adding alumina to aluminum, it is necessary to modify the form of the alumina, for example by producing fibrous shapes, in order to ensure retention by the aluminum⁽¹⁾. In the case of Sample C, no abnormal dropouts of silicon particles were observed following the

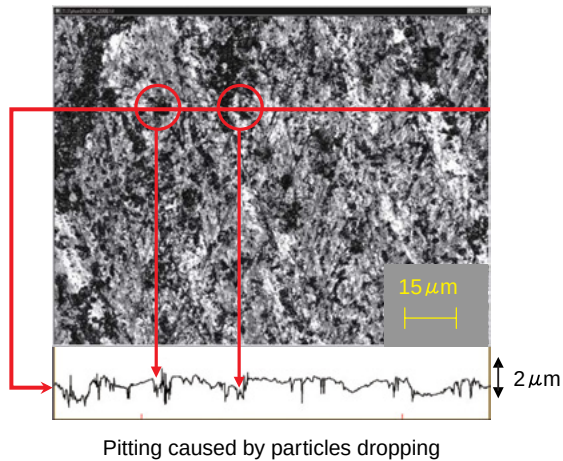


Fig. 2 Sample A

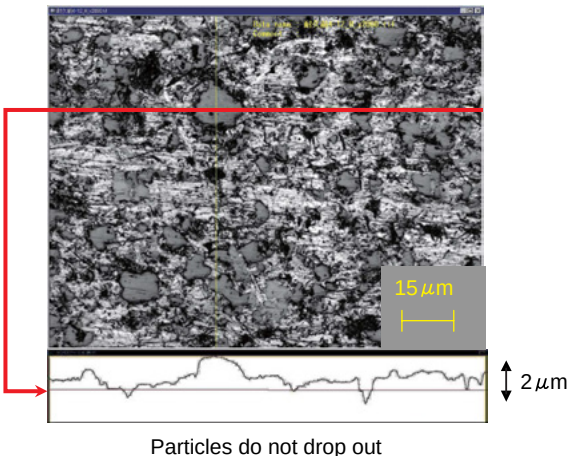


Fig. 3 Sample C

durability tests, highlighting the basic retention between aluminum and silicon.

Figure 5 shows a comparison of piston ring wear and blow-by gas deterioration rate between Samples B and C after the target durability time had elapsed.

Abnormal wear occurred in the case of Sample B, and blow-by gas increased during the durability tests. The high degree of hardness of alumina makes it important to select the amount to be added and the diameter of the particles to be employed. Sample B could not be modified due to the manufacturing method employed for the liners.

Based on these results, Sample C, in which silicon had been used as the hardening material, was selected as the material for the aluminum liners.

3.2. Form of Inner Surfaces of Bores

The initial form of the inner surfaces of the bores produced by machining, prior to break-in, is an important factor in ensuring the sliding characteristic of the aluminum liner. The achievement of an appropriate degree of exposure of the silicon particles on the bore surface is a key factor in preventing piston seizure and scoring during the initial operation of the cylinders. Figure 6 shows a diagram of the sliding of the piston rings and pistons over the inner surface of a bore. The exposed silicon particles form a sliding surface that prevents seizure and scoring by the piston rings⁽⁴⁾.

A three-stage honing process was developed as a new

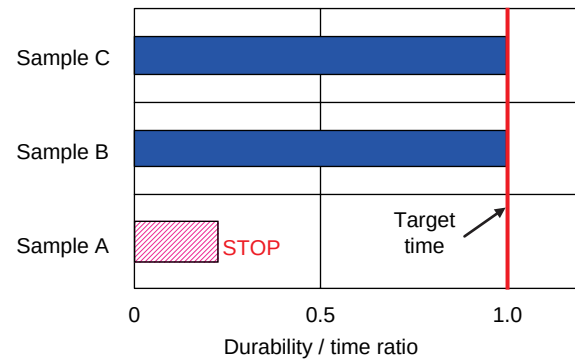


Fig. 4 Durability test results

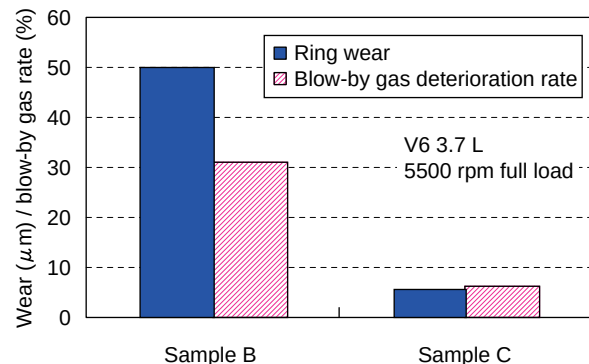


Fig. 5 Wear result

machining method for exposure of the silicon particles. A diagram of this process is shown in Fig. 7.

In the first stage of the process, the inner surface and inner diameter are machined. In the second stage, a smooth surface with a roughness of $0.9\text{--}1.8\ \mu\text{m}$ is achieved. The third stage of the process, the finishing stage, removes the small amount of remaining aluminum from around the silicon.

Figure 8 shows the results of laser micrography of the surface of the bore following the second and third stages of the process.

These images show that from the second through the third stages, the aluminum covering the silicon particles is removed, and the surface made smoother.

Figure 9 shows the results of scoring tests in an actual engine, conducted prior to break-in under dry lubrication conditions with different heights of exposure of the silicon particles.

The results indicate that while there is no impairment to function (engine shutdown, abnormal noise, etc.) even at a particle height of below around $0.1\ \mu\text{m}$, some scoring of the inner surface of the bore did occur. No scoring occurred at particle heights of $0.15\ \mu\text{m}$ or higher, and a figure of at least $0.15\ \mu\text{m}$ was therefore selected as appropriate for the initial height of the particles from considerations of function⁽³⁾.

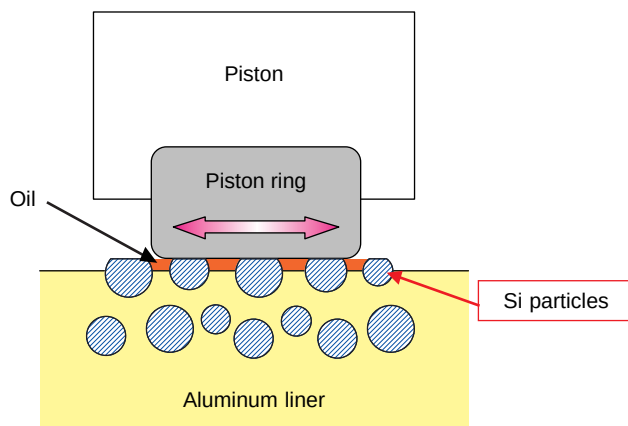


Fig. 6 Function of bore surface

1st process Rough boring	Si particles
2nd process Flat surface	Roughness: RzJIS $0.9\text{--}1.8\ \mu\text{m}$
3rd process Si exposure	Roughness: RzJIS $0.7\text{--}1.6\ \mu\text{m}$

Fig. 7 Bore honing process

Figure 10 shows changes in the roughness of the bore surface, from the initial state to completion, of a 1 800-hour bench durability test (simulation of 240 000 km of high-speed driving for EU standards). There is virtually no change in the figures, from initial figures of $0.9\text{--}1.4\ \mu\text{m}$ after machining, to $0.9\text{--}1.15\ \mu\text{m}$ following the completion of the durability tests.

The wear characteristic in an actual engine resembles the grinding characteristic of the third stage of the honing process. Honing proceeds by wearing away a greater amount of the soft aluminum than the hard silicon. At the same time, microscopic silicon particles drop out, and the

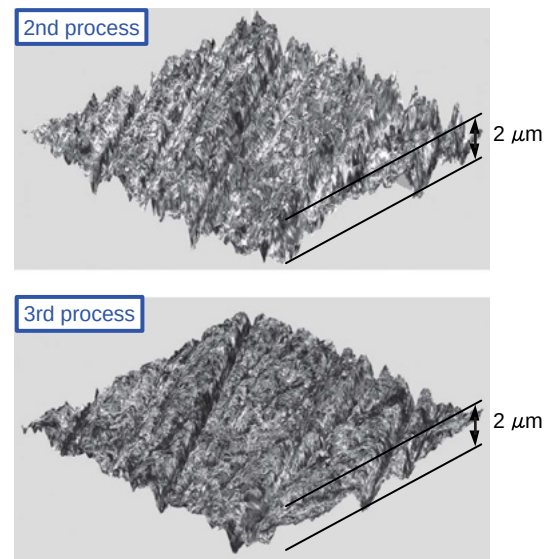


Fig. 8 Bore honing process surface measurement result

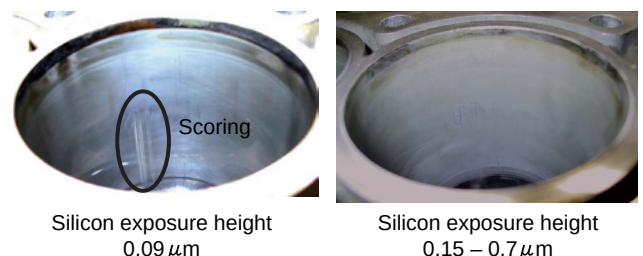
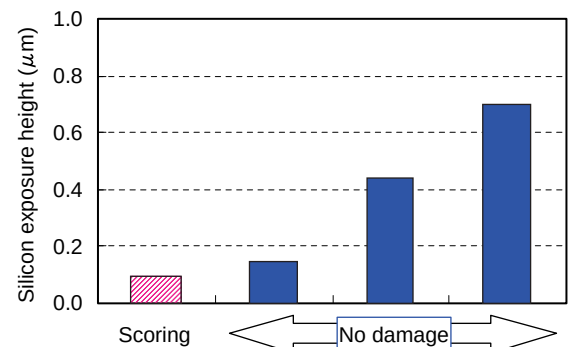


Fig. 9 Engine scoring test result

Table 5 Comparison of piston ring materials

Base metal	17Cr 0.8C	13Cr 0.6C	10Cr 0.5C
Cr nitride/carbonization particle size (μm)	5 – 8 μm	Under 2 μm	Under 2 μm
Average hardness of nitrided case (Hmv)	1150	1050	1050

repetition of this produces a uniform surface, ensuring that a particle exposure height of 0.15 μm or more is maintained until the liner reaches the end of its durable life. This three-stage honing process enabled an equivalent sliding surface to that produced following initial break-in in an actual engine by means of machining to be achieved.

3.3. Selection of Piston Ring Material for Use with Aluminum Liners

The nitrided stainless steel generally used in hypereutectic A390 alloy cylinder blocks was used as a base material, and the optimum amount of Cr for addition was determined.

Table 5 shows the piston ring materials examined in this process.

It is not necessarily the case that the harder material is an appropriate choice. The degree of wear of the piston rings and the liners when the piston rings are used in combination with aluminum liners containing silicon should also be considered.

The wear resistance of the ring material and the liner material was tested for each amount of Cr added. The change in the amount of Cr added had virtually no effect on surface hardness, but the diameter of the Cr carbonitride particles varied from 5-8 μm at 17Cr to 2 μm or less at 13Cr. Figure 11 shows the microstructure of the piston ring.

The degree of wear of the aluminum liner material was measured in component sliding tests. Figure 12 shows the results of these tests. The low-Cr material in which the diameter of the nitrocarbide particles was lower displayed reliable results, leading to the conclusion that Cr nitrocarbide particles of lower diameter caused less impact with the aluminum liner.

Durability tests were conducted for 100 hours in an actual engine to determine the level of wear of the piston

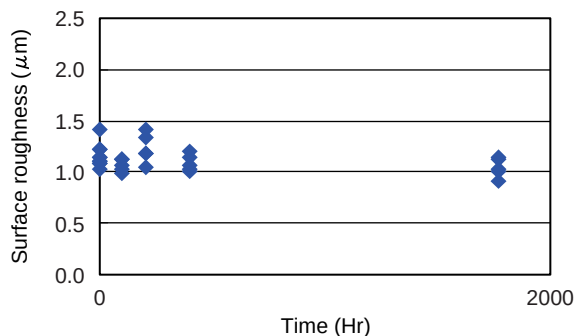


Fig. 10 Variations in bore surface roughness

rings themselves and of the cylinder liner. Figure 13 shows the results of these tests.

Lower wear was displayed by the piston rings using the 13Cr material, while wear in the aluminum liner was identical, and sufficiently low, for both the 10Cr and the 13Cr materials. The 13Cr material was selected as the piston ring material based on these results.

3.4. Bore Stiffness of Cylinder Block with Aluminum Liners

Table 6 shows a comparison of the material properties of the materials making up the cylinder block.

The linear coefficient of expansion of the aluminum liner material is similar to that of the aluminum material

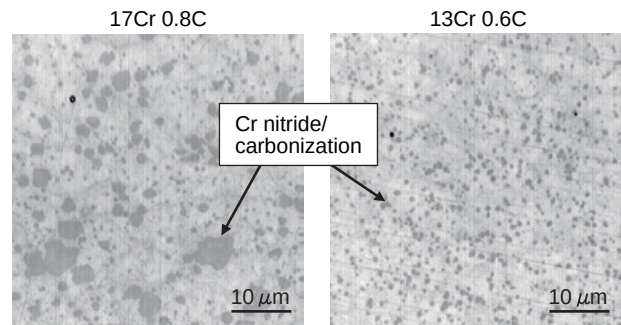


Fig. 11 Piston ring microstructure

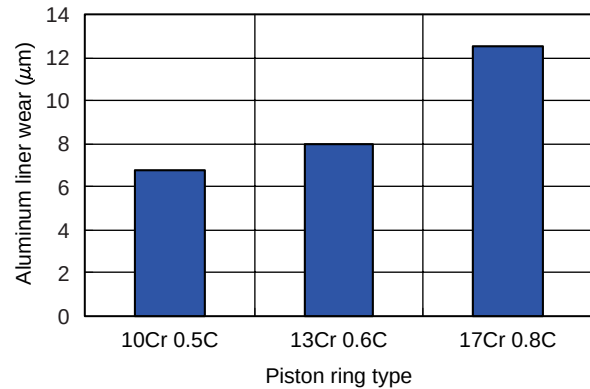


Fig. 12 Aluminum liner wear in Component jig test

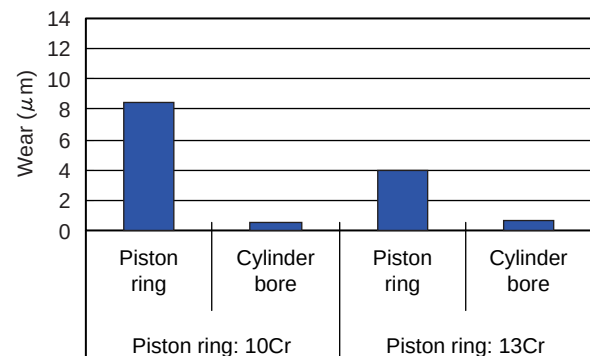


Fig. 13 Aluminum liner wear in actual engine

Table 6 Comparison of material properties

Item	Unit	Cylinder block ADC12	Cast iron liner	Aluminum liner
Young's modulus	(GPa)	72	110	90
Thermal expansion coefficient	($\times 10^{-6}/K$)	23	11.5	16

used in the cylinder block. The change in the dimensions of the materials under heating therefore matches well, enabling the cylindrical shape of the bore to be maintained. Because of this, the aluminum liners display greater resistance than the cast-iron liners to bore distortion caused by combustion temperature.

The level of bore stiffness is also lower in the aluminum liners because the Young's modulus of these liners is lower than that of the cast-iron liners.

Figure 14 shows a cross-section of the cylinder block with aluminum liners.

In order to prevent distortion of the bore from being exacerbated by the tightening of the cylinder head, the total bore thickness (a basic dimension of the aluminum liner) is increased by 1 mm in the 3.7 L V6 engine against that in the 3.5 L V6 engine.

3.5. Adhesion of Aluminum Liner

Another key factor in ensuring bore stiffness is the integration of the liners and the bores, achieved by increasing the adhesion between the two. Because the linear coefficient of expansion of the liner material is similar to that of the aluminum material used in the cylinder block, less residual tension is generated by contraction as the material cools following casting, and ensuring sufficient retaining force for the liner therefore represents a challenge.

The roughness of the outer surface of the liner, prior to casting, is an important factor in the achievement of increased adhesion.

Figure 15 shows an external view of the aluminum liner and the roughness of the outer surface of the liner.

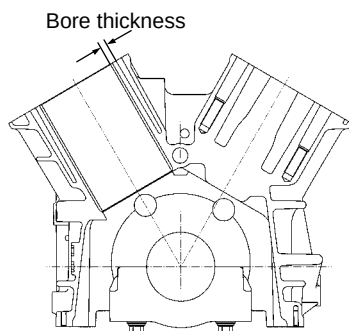


Fig. 14 Cylinder block section view

The minute projections on the surfaces of the liners are designed to increase the area of concavities and convexities on the surface, thus increasing the mechanical retaining force and the adhesion of the liners.

In the initial stage of development, the roughness of the liner surfaces was approximately 30 μm . However, following the casting of the cylinder block, it was determined that good adhesion was not achieved at this level of roughness.

Balancing the maintenance of equivalent productivity (mainly in terms of the casting tact time) in the HPDC process to that achieved when manufacturing cast iron liners with increased liner adhesion represented a challenging issue. The optimization of the roughness of the outer surface of the liners enabled an equivalent level of productivity to be maintained while increasing the adhesion of the liners.

3.6. Evaluation Method for Adhesion of Aluminum Liners

In the die cast cylinder blocks with cast iron liners that are in general production today, the stiffness of the liners themselves is the basis of the stiffness of the area around the bores. In the case of the aluminum liners, as it was necessary to integrate the liners and the bores to ensure stiffness, non-destructive ultrasonic measurement⁽⁴⁾ was employed as a new method of evaluating gaps in the outer surfaces of the liners.

Eliminating gaps at the boundary between the outer surface of the liner and the bore aluminum is a key element in the achievement of adhesion. Microscopic observation of the boundary between the liner and the bore aluminum following casting showed complete adhesion, other than localized gaps of 5 μm or less.

Figure 16 shows an enlarged photograph of the boundary between the liner and the bore.

If the area of the outer surface of the liner in which there are no gap increases, the retaining force of the liner then also increases. An ultrasonic tester was employed for

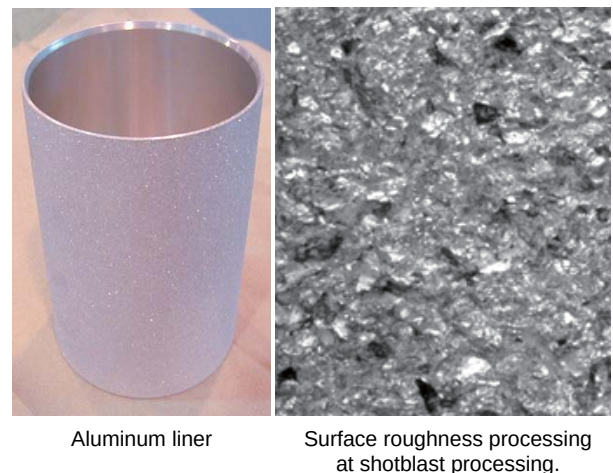


Fig. 15 Exterior view of liner / liner outer surface

measurements. The dimensions of the gaps in the liner boundary surface (as determined by the rate of reflection of the ultrasonic waves) were color-coded, with acceptable gaps of $5\ \mu\text{m}$ or less shown as yellow, and gaps of more than $5\ \mu\text{m}$ shown as red. The rate of adhesion was defined as the specific area ratio of the acceptable areas shown as yellow, where there were no gaps, to the area of the outer surface of the liner.

Figure 17 shows measurement data.

3.7. Method of Increasing Adhesion of Aluminum Liners

As discussed in Section 3.6., the roughness of the surfaces of the liners was varied, liners were cast in cylinder blocks, and their adhesion was evaluated. Differences in the level of adhesion of the liners affect the distortion of the bore caused by exposure to combustion heat. It is therefore necessary to ensure stiffness by taking into consideration both heat distortion and the distortion caused by the initial tightening of the

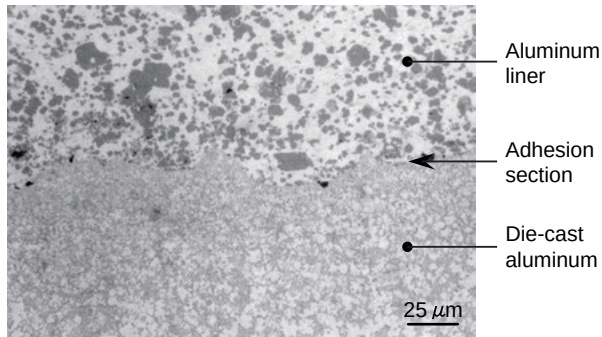


Fig. 16 Cross-section of adhesion section

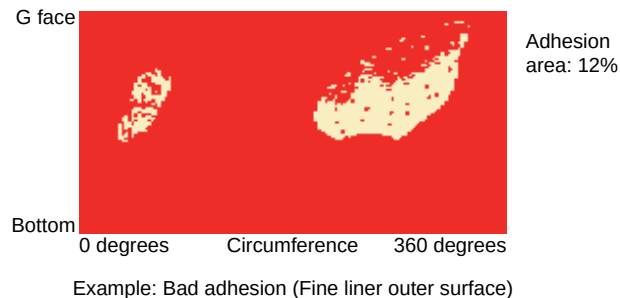
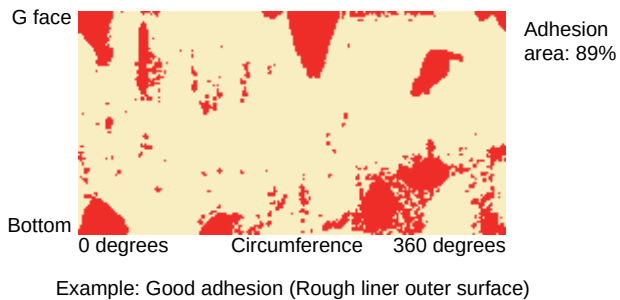


Fig. 17 Ultrasonic test results (C scope image)

cylinder heads.

The relationship between the roughness of the outer surfaces of the cylinder liners and adhesion is shown in Fig. 18.

Figure 19 shows the relationship between liner adhesion and bore distortion following a durability test in an actual engine. The degree of bore distortion following the durability test is reduced as the adhesion rate of the liner increases.

Having measured the rate of adhesion of liners that satisfied the target for bore distortion following durability tests, a standard was set for the roughness of the outer surfaces of the liners. Figure 20 shows a comparison of the bore distortion, with the cylinder head tightened, of an aluminum liner and a cast iron liner in cylinder blocks that satisfied this standard for liner adhesion.

The increased thickness of the bores and enhanced adhesion of the liners have ensured the achievement of a level of bore distortion equivalent to that of a cast iron liner.

Figure 21 shows the bore distortion at a high temperature ($150\ ^\circ\text{C}$). Because the linear coefficient of expansion of the aluminum liner material is similar to that of the aluminum material used in the cylinder block, the change in their dimensions matches well, even at high

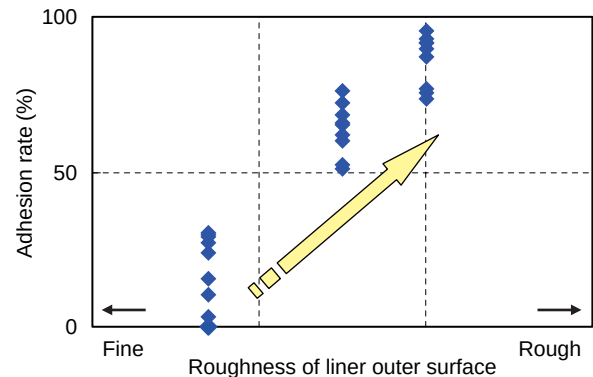


Fig. 18 Correlation between roughness of liner outer surface and adhesion

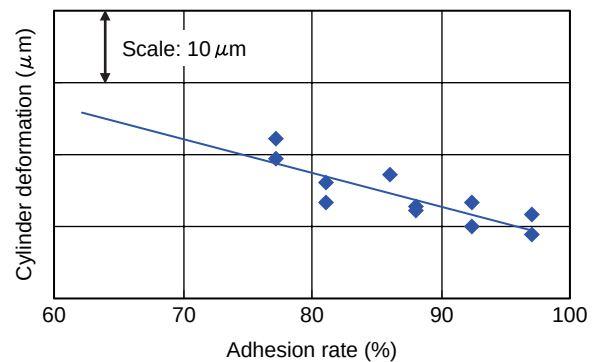


Fig. 19 Correlation between roughness of liner outer surface and bore distortion after durability test

temperatures, and the shape of the bore remains acceptable, even at the bottom of the water jacket, where the level of change is greatest.

3.8. Performance Enhancements due to Use of Cylinder Block with Aluminum Liners

The heat transfer characteristic of the aluminum liner material helps make certain that the temperature of the hottest area of the cylinder block remains cooler than in a cast iron liner cylinder block at the same water temperature.

Figure 22 shows the effect of the aluminum liners in reducing the temperature of the bore bridges, the areas of the cylinder block in which the temperature is highest.

From 190 °C, the strength of aluminum begins to decline, and this therefore represents the durability limit for the bore bridge temperature⁽¹⁾. However, increased engine power may lead to increased temperatures due to heat production. The use of the aluminum liners reduces the temperature of the bore bridges by 12 °C against that of the cast iron liners. Compared to the cast iron liners, engine output can be increased by approximately 51 kW before the aluminum liner temperature reaches 190 °C, indicating that the use of the aluminum liners is

compatible with the achievement of increased power.

The enhanced cooling of the cylinder block has also increased the cooling of the combustion chamber, resulting in an enhanced compression ratio and enhanced performance.

Figure 23 shows the effect of the aluminum liners on reducing the temperature of the pistons.

The temperature of the piston ceilings has been reduced by approximately 20 °C. This cooling effect increases the knocking limit, making it possible to advance ignition timing by 2 to 5 degrees.

Figure 24 shows spark advance data.

The cooling effect of the aluminum liners has resulted in a 1.5 kW increase in power and 9.8 Nm increase in torque.

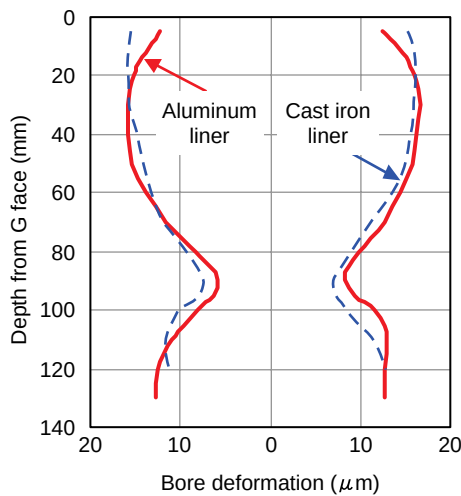


Fig. 20 Bore distortion with cylinder head tightening

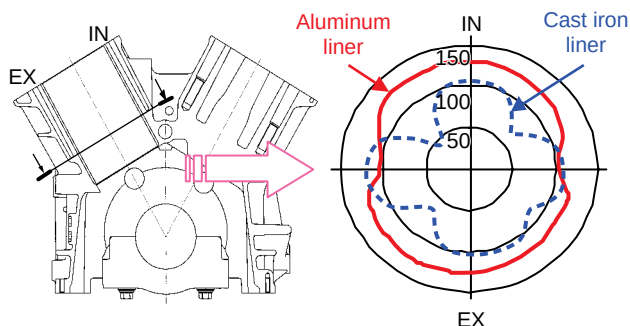


Fig. 21 Bore distortion at high temperature

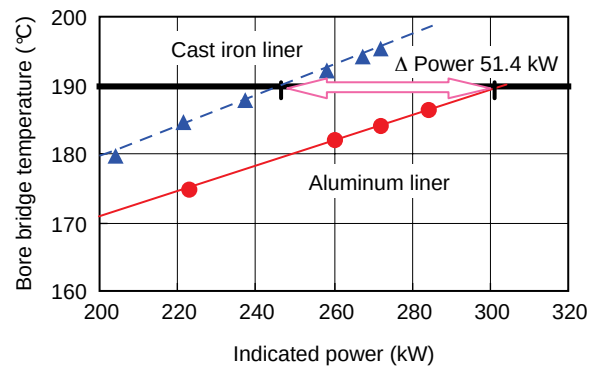


Fig. 22 Cooling effect for bore bridge

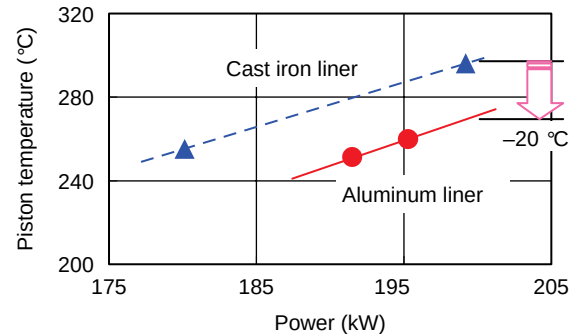


Fig. 23 Piston temperature reduction effect

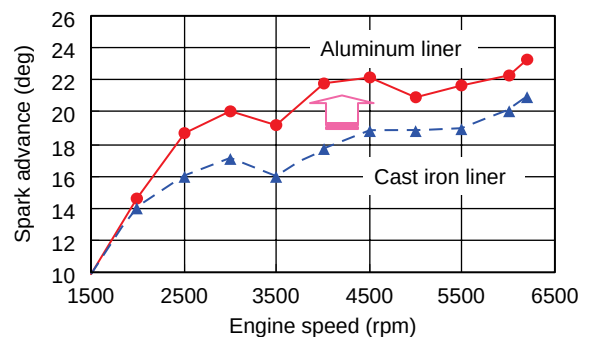


Fig. 24 Cooling effect for bore bridge

3.9. Durability and Reliability

Durability tests were conducted in an actual vehicle.

Figure 25 shows liner wear, wear of the outer surface of the piston rings, and bore distortion at the completion of the durability tests.

Figures are low for all three parameters, and satisfy engine function requirements.

Figure 26 shows oil consumption in the durability tests.

This is also a reliable result, with no significant change in oil consumption from initial figures. This demonstrates the reliability of the engine employing the die cast cylinder block with aluminum liners.

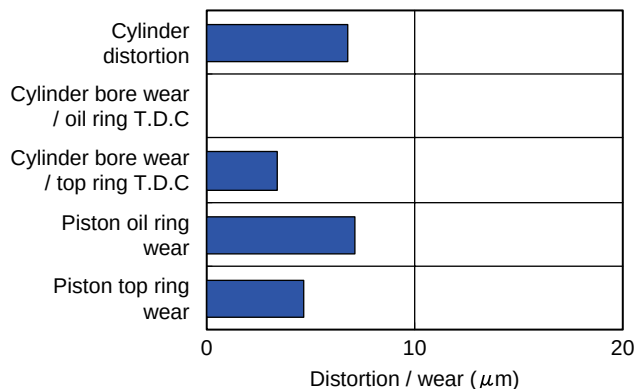


Fig. 25 Wear and distortion in durability test

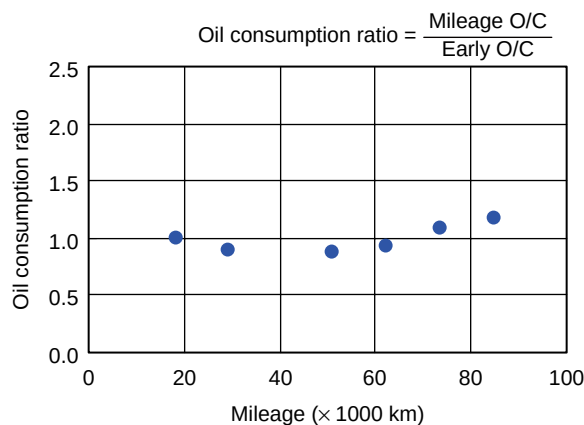


Fig. 26 Oil consumption in vehicle durability test

4. Conclusion

As demonstrated by points (1) to (3) below, the development of a die cast cylinder block with aluminum liners for a high-power, high-displacement V6 engine has enabled the achievement of increased power and displacement.

- (1) A high-Si content material was selected for the aluminum liners, and 13Cr stainless steel was selected as the

material for the piston rings. The combination of the two materials has ensured the achievement of higher wear and seizure resistance.

- (2) The exposure of hard silicon particles on the sliding surface of the aluminum liners prevents scoring.
- (3) The employment of minute projections on the outer surface of the liners has increased adhesion, ensuring adequate bore stiffness.

The use of these technologies has enabled a 3.5 L, 193 kW V6 base engine to be increased in power and displacement to produce a 3.7 L, 224 kW V6 engine. The technologies have been applied in the 3.7 L engine employed in the 2007 year model MDX.

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Author



Takashi KOMATSUDA



Masayuki TAKAHASHI



Katsuhisa YASUKAWA



Junichi OHMURA



Noriyuki NAMBA