

Development of Aluminum Cylinder Block for Diesel Engine

Masakazu YAMAZAKI*
Mitsuhiko KAWABATA*

Atsushi TAKAI*
Osami ITO**

Osamu MURAKAMI*
Koichi KUROKI**

ABSTRACT

A high-strength aluminum cylinder block manufactured using a new production process, ASCT (Advanced Semisolid Casting Technology) has been adopted for the newly developed 2.2L 4-cylinder i-CTDi (Intelligent Common rail Turbo Diesel Injection) diesel engine fitted in the 2003 Accord marketed in Europe. In the production process, semi-solid aluminum is used during high pressure die-casting. In addition, newly developed pressure-proof sand cores are used to mold the closed deck, and heat treatment is conducted to ensure a high level of material strength.

To respond to the high load on the crankshaft journal, die-cast aluminum lower block and cast iron bearing caps are employed. Adopting the dummy head honing and offset cylinders to reduce bore deformation have enabled the achievement of a lightweight, compact cylinder block configuration matched to the high combustion pressure of the latest diesel engines, while maintaining a high level of quietness.

Thanks to these counter measures, a 30% weight reduction for the new cylinder block has been achieved compared to that of the conventional cast iron diesel engine of the same displacement.

1. Introduction

Diesel engine performance has recently increased dramatically with advances in fuel system technologies, in particular the common rail. Increased performance has led to consequent increases in combustion pressure, and greater durability is now required in the structural components of the engines, including cylinder blocks. On the other hand, the achievement of compactness and low weight is also a factor in the over-all reduction of CO₂ levels in automobiles, making it extremely important to achieve weight savings in the cylinder block, which represents the heaviest component

in the engine^{(1), (2)}. This has led to the increased use of aluminum alloy cylinder blocks in diesel engines⁽³⁾.

Aluminum alloy cylinder blocks are already widely used in gasoline engines, and the majority of these are produced by high-pressure die casting (HPDC) to ensure productivity. Undercut forms cannot be produced using HPDC. When the HPDC method is employed it is necessary to use an open structure in the deck section that forms the mating surface with the cylinder head. It is also difficult to increase the strength of the cylinder block with solution heat treatments because of difficulty in ensuring material quality. However, productivity declines noticeably if low-pressure die-casting

* Tochigi R&D Center

** Honda Engineering Co., Ltd.

(LPDC) is used to enable heat treatments to be applied and allow the formation of a closed deck. In this case, it becomes difficult to mold the thin sections of the block, the dimensions between the cylinder bores increase, and the overall weight of the block increases⁽⁴⁾.

The development of an aluminum alloy cylinder block for a high-performance diesel engine without sacrificing performance or productivity necessitated a detailed study of structure and the development of a new production technology. The challenges outlined above were overcome through the employment of semi-solid die casting and the development of pressure-proof sand cores, enabling weight reduction of the cylinder blocks while maintaining good machinability.

2. Concept Behind Development of a Cylinder Block for a High-performance Diesel Engine and Performance Requirements

The cylinder block is a key component of the engine, and since the development of the original Civic model, Honda has been producing these components from aluminum to make its engines both lightweight and compact. The cylinder block used in the newly developed i-CTDi diesel engine (Fig. 1) was required to use the same packaging and production equipment as the cylinder block employed in the 2.0 – 2.4L class intelligent variable valve timing and lift electronic control system (i-VTEC) series (K24A) gasoline engines. And, therefore, during its design the K24A cylinder block was employed as a base. The concept behind the development was the production of a high-performance cylinder block that matched the functions and performance of the cast blocks employed in competitors' high-power diesel engines with a minimum increase in weight over the base gasoline engine cylinder block. Table 1 shows a comparison of the basic specifications of the diesel and gasoline engine cylinder blocks, and Fig. 2 shows an exterior view of the diesel cylinder block.



Fig. 1 External view of i-CTDi engine

Table 1 Specifications of engines and cylinder blocks

	i-CTDi Diesel	i-VTEC Petrol
Total displacement (cc)	2204	2354
Bore (mm)	85	87
Stroke (mm)	97.1	99
Bore pitch (mm)	94	94
Compression ratio	16.7	10.5
Maximum output /engine speed	103kW (140PS)/ 4000rpm	147kW (200PS)/ 6800rpm
Maximum torque /engine speed	340Nm/2000rpm	225Nm/4500rpm
Configuration	Closed deck/ Lower block configuration	Open deck/ Lower block configuration
Block height (mm)	247.1	231.5
Cylinder offset (mm)	6.5	0
Upper block material	Aluminum alloy	Aluminum alloy
Liner material	FC (Centrifugal casting)	FC (Centrifugal casting)
Liner thickness (mm)	3	2
Lower block material	Aluminum alloy	Aluminum alloy
Lower block height (mm)	75	60
Bearing cap material	FCD450	FC250
Bearing cap bolt size	M11 × 102	M11 × 95
Weight (kg)	34.0	28.6

2.1. Changes, Issues and Solutions in Converting Cylinder Block from Gasoline to Diesel Engine Use

The major points of difference between a diesel engine and a gasoline engine taken into consideration when establishing the specifications of a cylinder block are as follows:

- (1) Increased combustion pressure
- (2) Increased engine heat at full load
- (3) Effect of increased soot concentration in lubricating oil and sulfur content in fuel

The following sections will discuss the issues generated by each of these topics and the counter measures employed as solutions.

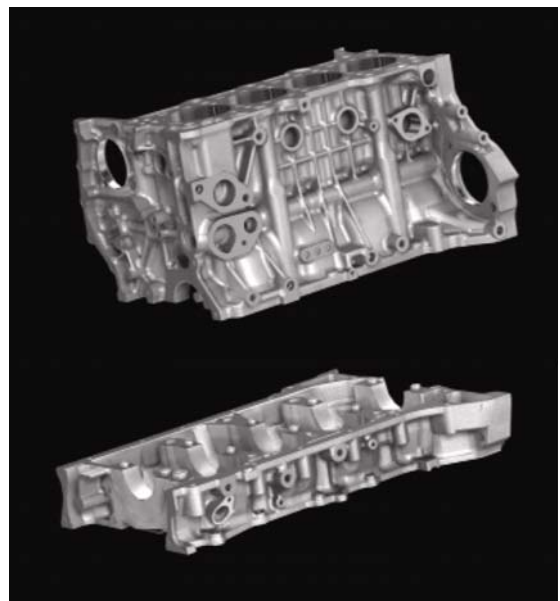


Fig. 2 External view of cylinder block

2.1.1. Dealing with increased combustion pressure

It was necessary to consider a figure of 16 MPa, including fluctuations, as the maximum combustion pressure in the i-CTDi engine, when compared to 8 - 10 MPa in a gasoline engine. Figure 3 shows a graph comparing combustion pressure in a gasoline and diesel engine. The counter measures employed to deal with this issue generated by increased combustion pressure are discussed below.

(1) Closed deck design A closed deck configuration was employed in the cylinder block to ensure sufficient rigidity in the cylinder bore section and toughness of the gas seal in the head gasket to resist high combustion pressure. Unit tests to measure stress produced by hydraulic pressurization, and FEM analysis, were carried out to enable optimization of the distribution of thickness in the liner and aluminum, the external shape of the liner, the thickness of the

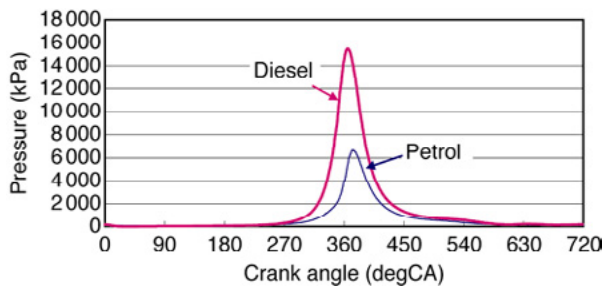


Fig. 3 Comparison of diesel and Petrol engine combustion pressure

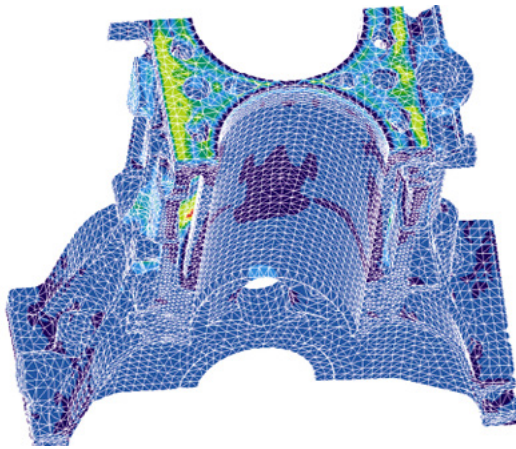


Fig. 4 FEM analysis of deck and surrounding sections

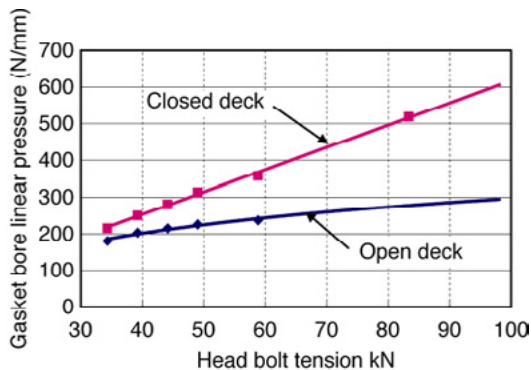


Fig. 5 Comparison of line pressure of head gasket bore

deck and the shape of the water jacket. An example of FEM analysis of the deck and surrounding areas is shown in Fig. 4. Figure 5 shows a comparison of line pressure in the head gasket bead with an open deck and the closed deck employed in the new cylinder block, demonstrating that a greater amount of line pressure is generated against the head bolt axial force in the closed deck configuration.

(2) High-quality aluminum materials and heat treatment

To enable the closed deck design to be employed and weight to be lowered, a new production process (Advanced Semi-solid Casting Technology as ASCT), was applied to the upper block. This enabled both the achievement of high quality while maintaining the same material thickness as in HPDC and the application of heat treatments to increase strength. FEM analysis was conducted to optimize thickness and structure in this production process. Figure 6 shows an FEM analysis of the cylinder head when connected and tightened as an example of strength analysis of the cylinder block.

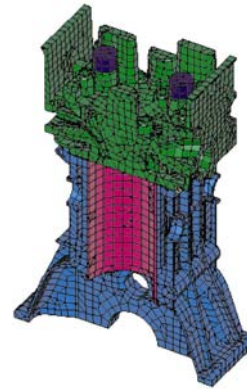


Fig. 6 FEM analysis of tightening cylinder head

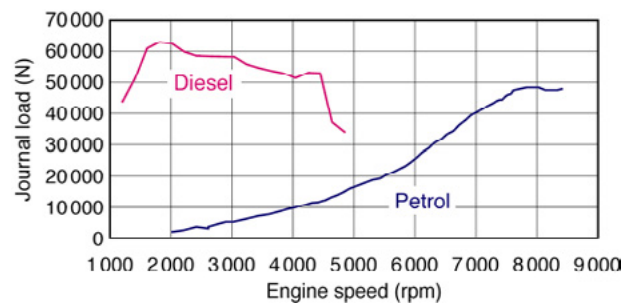


Fig. 7 Comparison of journal load

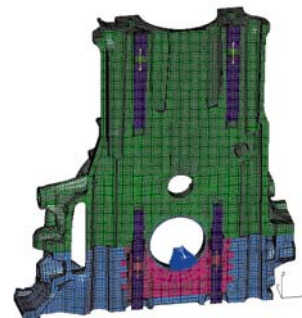


Fig. 8 Analysis of lower block load

(3) High-rigidity aluminum block In a gasoline engine, the maximum load is produced on the #3 crank journal. This load is produced from the inertial load at high

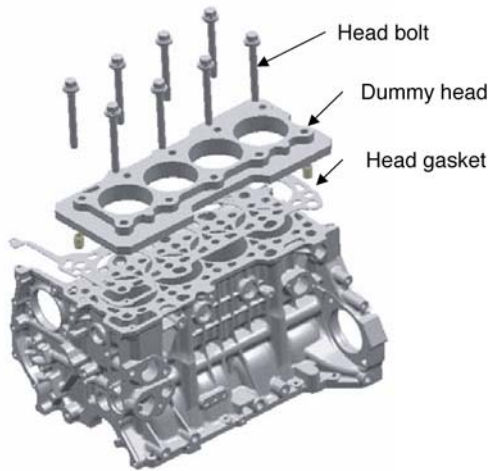


Fig. 9 Dummy head honing method

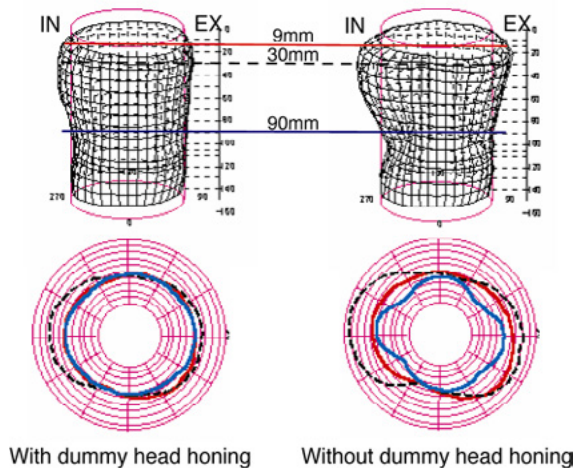


Fig. 10 Effects of dummy head honing

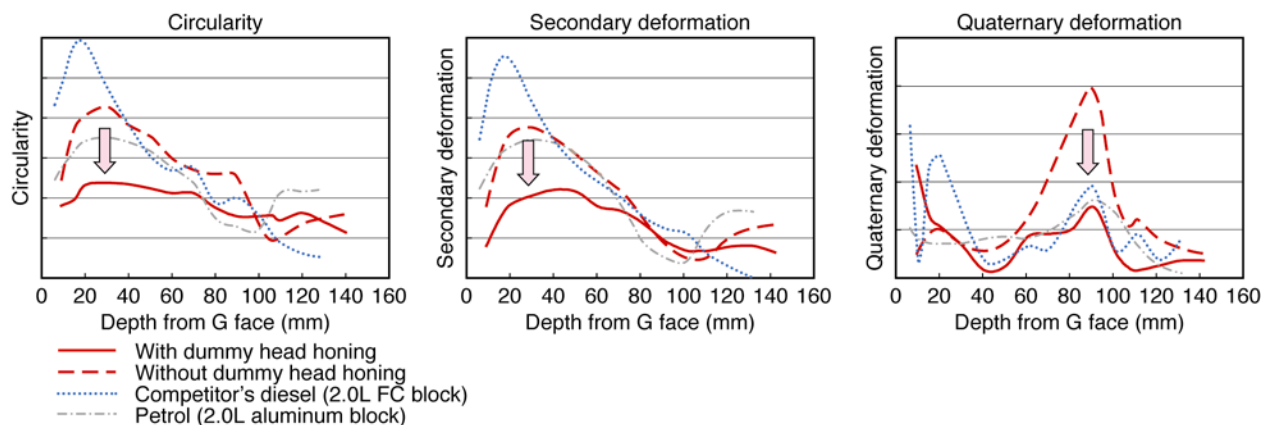


Fig. 11 Effects of dummy head honing

engine speed and the behavior determined by rigidity of the crankshaft and supporting cylinder block rather than combustion pressure. In a diesel engine, by contrast, explosive loads are dominant, and downward loads in journals #2 and #4 will be the maximum loads. Figure 7 shows a comparison of load on the crank journals in a gasoline and diesel engine. As per the example shown in Fig. 8, FEM analysis was employed to design the entire structure of the cylinder block, enabling the optimization of the basic dimensions for the bearing cap, material selection, and the establishment of specifications for the bearing cap bolt and the peripheral structure. FEM analysis was also used to optimize the height of the lower block, the cast form of the bearing cap and the connecting structure with the outer wall in order to increase the bending and torsional rigidity of the entire block.

(4) Dummy head honing A large M13 $\times$ 1.25 plastic region bolt, of a type not previously employed in a gasoline engine, was utilized for the head bolt in order to produce sufficient head gasket surface pressure. The rigidity of the cylinder head, the positioning of the head bolt, the depth of the female screw section and the peripheral structure were all optimized in the design process. There were concerns over deformation of the cylinder bore caused by the high-axial force head bolt. To ensuring rigidity in the bore and surrounding sections, dummy head honing, which honing is conducted with a dummy head tightened to the cylinder block, was used to minimize bore deformation when assembled. Figures 9 to 11 show the dummy head honing method and the results in reduction of bore deformation. The use of this technique has controlled oil consumption and suppressed piston slap noise, and reduced sliding wear on the pistons by stabilizing piston behavior.

(5) Offset cylinders High combustion pressure and variation in combustion pressure cause an increase in piston slapping sound. An increase in side pressure causes friction to increase. An offset cylinder configuration, in which the cylinders are offset from the crank center in the direction of anti-thrust, was employed to counter the increases in piston slap and friction. The degree of offset was optimized by estimating the piston behavior and the friction caused by side pressure using simulations. Figure 12 shows the reduction in side pressure on the piston achieved by using the offset configuration.

2.1.2. Increased engine heat at full load

Diesel engines require a higher degree of cooling at all levels of output than gasoline engines.

Figure 13 shows a comparison of the required cooling performance in gasoline and diesel engines.

There were concerns with cylinder blocks that increased temperature of the aluminum sections between the cylinder bores would reduce strength, causing the seal of the head gasket to deteriorate and the cylinder bore deck section to deform. To prevent this, a simulation of the water flow through the entire water jacket, including the cylinder head, was conducted, and measurements of temperature were taken. The results were utilized to tune the flow to ensure that the cooling water did not back up at any point.

This enabled the temperature to be controlled to under 190°C , the temperature which aluminum strength begins to drop, without any loss of cooling performance in the cylinder head.

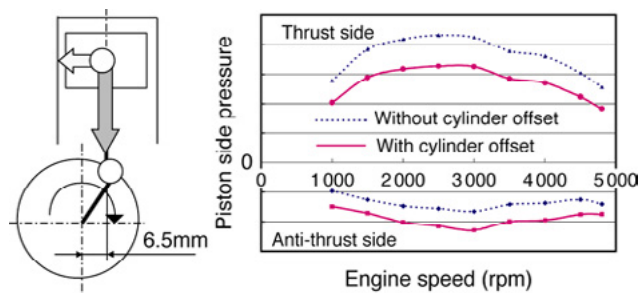


Fig. 12 Reduction of piston impact load due to offset cylinders

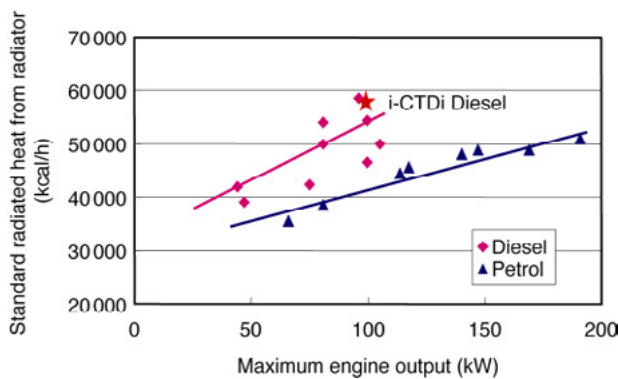


Fig. 13 Comparison of required cooling performance by output

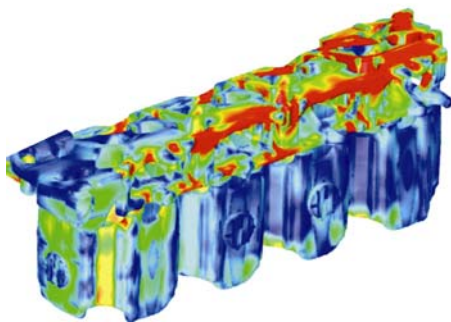


Fig. 14 Example of simulation of flow of water through water jacket

Figure 14 shows the simulation of the water flow through the water jacket, and Fig. 15 shows the temperature characteristics between the deck bores.

2.1.3. Effect of increased soot concentration in lubricating oil and sulfur content in fuel

The liner of the new cylinder block is produced by centrifugal casting. The optimal addition of P, Cu and Mo, not used in materials for liners employed in standard gasoline engines, enabled the new cylinder liner to display the same level of workability as the conventional liners, while resisting corrosion caused by the sulfur components in the fuel, and wear caused by high loads and soot in the engine oil. A large liner with a spiny outer (columnar projection) surface and a standard thickness of 3 mm formed by centrifugal casting has been employed. In addition to distributing residual stress in the aluminum section of the outer circumference, mechanical coupling to the circumference provides increased reliability against potential breakdown at the cylinder bore and surrounding sections. Figure 16 shows the spiny appearance of the outer circumference of the liner.

3. Overview and Characteristics of New Production Process

3.1. Aims of Development of New Production Process

The production process was examined to enable the following four concepts for the upper block to be realized.

- (1) Closed deck configuration to provide high rigidity
- (2) Thickness of 3 mm between shafts and a standard thickness of 4 mm, to achieve weight savings and compactness
- (3) Use of high-quality materials and heat treatment to achieve high strength
- (4) Achievement of high level of manufacturability

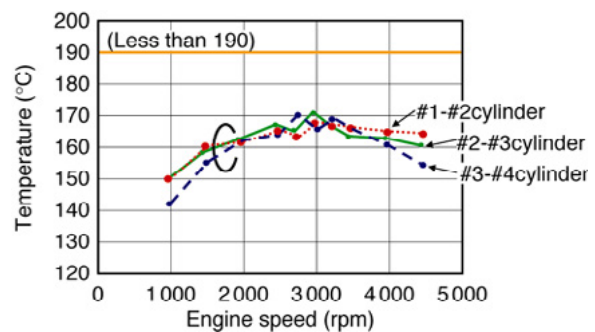


Fig. 15 Aluminum temperature characteristics between deck bores

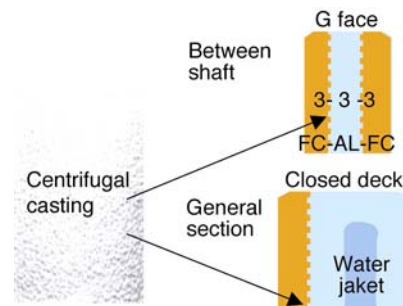


Fig. 16 Spiny exterior of liner

Table 2 Production targets and production methods

	Flexibility of shape		Function			Cost	
	Closed deck	Reduction of thickness	Reduction of machining	Heat treatments T6 and T7	Strength	Cycle time	Investment
LPDC	Good	Poor	No good	Possible	Excellent	No good	Large
HPDC	No good	Excellent	Good	Impossible	Poor	Excellent	Small
NDC	Good	Good	Good	Poor	Poor	Good	Large
ASCT	Good	Good	Good	Possible	Excellent	Good	Small

As Table 2 indicates, LPDC is a production method well suited to the demands of forming the closed deck structure and the application of heat treatment. However, a new method of production was required which would enable thin materials and a high level of productivity (usually achieved with HPDC) to be balanced.

From the mid-1980s through the 1990s, Honda employed the low-speed, medium-pressure casting (New die cast as NDC) method to produce the closed deck configuration, but this method necessitated higher material quality to cope with heat treatment and the use of different casting equipment to HPDC. For these reasons, the rationalization of production facilities required a new method capable of producing higher quality components and ensuring greater productivity to be found.

3.2. Overview and Characteristics of ASCT

In a cylinder block, there are thick sections such as the journals and thin sections such as the cylinder bore and surrounding sections and regular sections. To control internal imperfections such as shrinkage (imperfections caused by solidification and shrinkage), gas inclusions during production process, etc., which are difficult to avoid using the standard casting method, a die cast technique has been employed in which aluminum is injection formed in a semi-solid state, which enables stable and highly efficient production of strong, high-quality components to which heat

treatment can be applied. With the semi-solid casting method as a base, Honda has independently developed ASCT as a packaging system which has further evolved and integrated the conventionally employed element technologies, in order to enable the various requirements for the finished cylinder block described previously to be met.

ASCT is made up of the following element technologies:

- (1) Casting Aluminum in a semi-solid state is injected into a metal mold in a laminar flow at low speed and high pressure
- (2) Slurry production Production process for semi-solid slurry using mechanical stirring
- (3) Sand cores Uses pressure-proof cores formed by coating the surfaces of shell cores

3.3. Element Technologies

3.3.1. Casting

Techniques of injection forming aluminum in a semi-solid state can be classified into thixocast, in which aluminum is used in a semi-molten form, and rheocast, in which aluminum is used in a semi-solid form^{(5), (6)}. Both these methods use agitation and pulverization to convert the dendrite, which is produced when the normal aluminum alloy is gradually cooled, to granular crystal, and apply shearing force to reduce viscosity and increase the flowability of the metal (thixotropy) (Fig. 17).

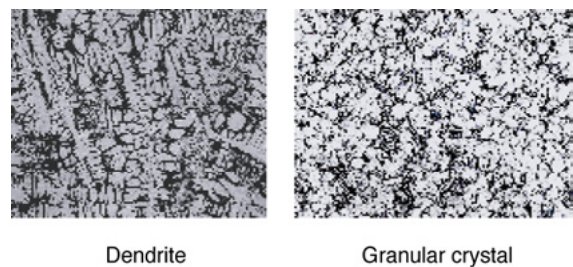


Fig. 17 Comparison of microstructure

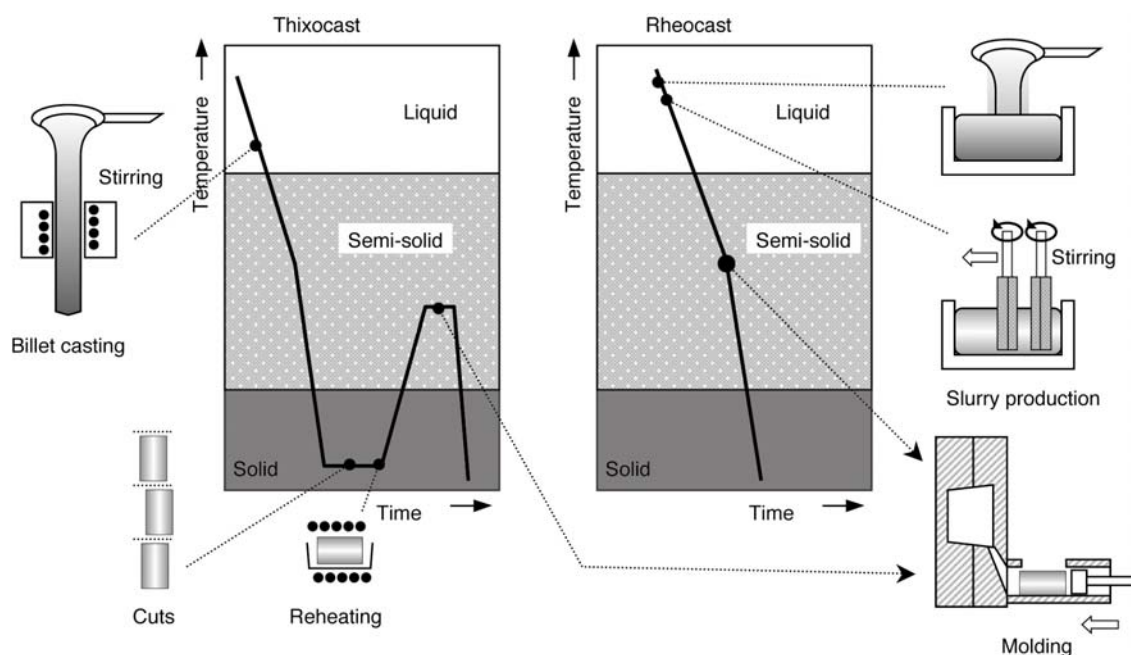


Fig. 18 Production efficiency of thixocast and rheocast methods

Rheocast was utilized in the production of the new cylinder block, to enable the production process to be simplified and increase energy efficiency⁽⁷⁾. Figure 18 shows a comparison of the energy efficiency of thixocast and rheocast.

3.3.2. Semi-solid slurry production

The most important element in the rheocast process is the production of the semi-solid aluminum slurry. In this process the molten metal is maintained at a set temperature in a furnace, after which a specified amount is poured into a crucible (an insulated container used to transport the molten metal to the die) preheated using a heater. Chillers and stirrers are then immersed in the molten metal. These rotate while sliding through the metal in a set trajectory, enabling the achievement of uniform semi-solid state. Figure 19 shows an overview of the process.

The issue the project faced here was how to create a semi-solid slurry with a higher degree of applicability to forming. In the conventional production process, it is usual to control the temperature of the molten metal directly before forming, but the presence in the aluminum alloy of alloy ingredients such as Mg, Cu, and Si with different contents means that at the same temperature some components are more solid than others. Figure 20 shows the differences in solidity for different components at the same temperature. The different solidities of these components make it difficult to produce a semi-solid slurry with a stable formability by controlling only the temperature of the molten metal.

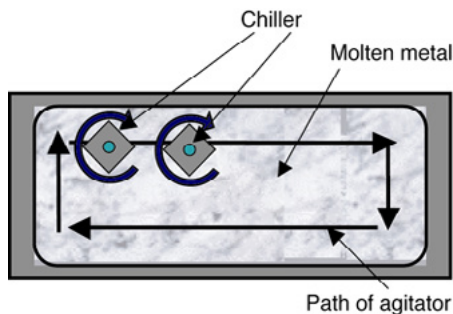


Fig. 19 Diagram of mechanical stirring

To produce a stable semi-solid slurry that was not affected by variations in alloy ingredients, crucible temperature, temperature of the molten metal in the mold, etc., this project focused on controlling the kinetic viscosity of the slurry.

Control of the kinetic viscosity of the slurry is applied during the stirring process in the crucible discussed above, and employs the kinetic viscosity measurement device shown in Fig. 21.

Conducting the kinetic viscosity measurements during the process of stirring and cooling the semi-solid slurry means that the process can be stopped when the slurry reaches the necessary kinetic viscosity, enabling a semi-solid slurry of uniform viscosity to be formed. Compared to the conventionally employed control of temperature, this measurement method enables more accurate control of the consistency of the semi-solid slurry at a predetermined temperature.

The application of these methods produces a stable slurry that has excellent formability, and has enabled significant improvements in the interior and external quality of the molded component.

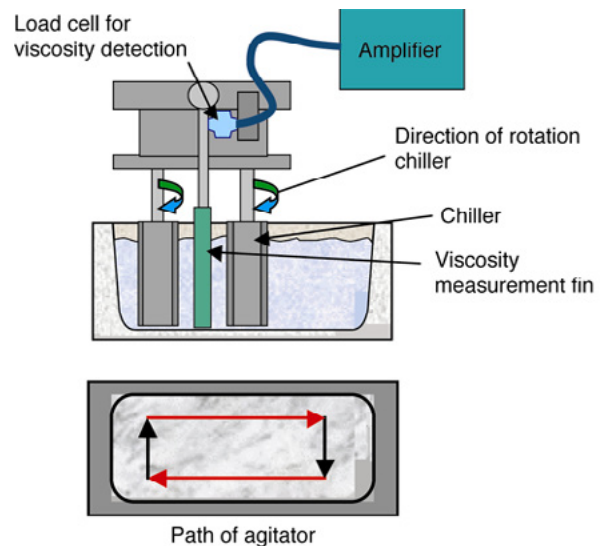


Fig. 21 Diagram of mechanical stirring and viscosity measurement unit

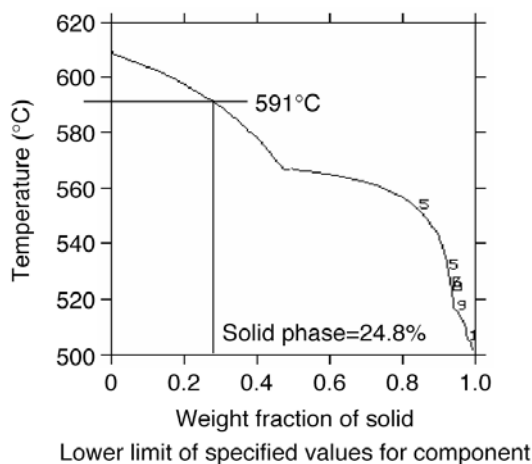
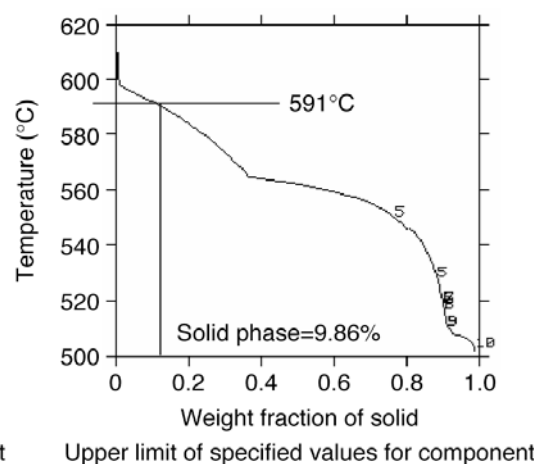


Fig. 20 Thermo calculation graphs: Change in solid phase due to change in components at identical temperature



3.3.3. Sand cores

Sand cores are used to mold the water jacket section, which is undercut during forming (Fig. 22). Because these sand cores are used with semi-solid aluminum, large-scale improvements over the sand cores used in conventional molten molding were required, in particular improvements in strength. The requirements for the sand cores employed in ASCT casting are as follows:

- (1) Strength to resist molding pressure (≈ 100 MPa).
- (2) Sufficient dimensional accuracy to satisfy design values.
- (3) Clean removal from mold for post-processing after molding.

To achieve pressure resistance, the filling density of the sand was increased and a coating was applied, enabling the production of sand cores with a deflecting strength of 11 - 12 MPa, resistant to failure or penetration of the molten metal when subjected to high casting pressures. Artificial ceramic casting sand (ceramic beads) was selected as the framework due to the uniform diameter of the grains and the ability of the material to expand at low temperatures. A high-strength resin capable of expanding at low temperatures was employed as the binder. A two-layer coating was employed to balance pressure resistance in the core with separability (sand removability). The first coating functions as an ultra-fine skin, increasing pressure resistance, while the second coating promotes peeling of the aluminum from the mold. This has resulted in the production of a high-strength sand core, with a 15% higher filling density and a 20% higher deflecting strength than a normal silica core. Figure 23 shows a comparison of cross-sections of a conventional core and the newly developed core.

3.3.4. Quality

To meet the high performance requirements demanded of the new cylinder block, the block combines thin sections of 3 mm between the cylinder bores, and thick sections of 20 mm in the journals, etc. Preheating of the cylinder liner and the bore pin was employed to ensure the flow of the semi-solid slurry to mold the thin sections. Laminar flow was used to prevent inclusions during filling. The semi-solid

slurry was used to reduce the shrinkage in the molding of the thick sections. Together, these methods enable the achievement of a stable quality in the cast block with no imperfections (blowholes, etc.).

3.3.5. Heat treatment

To achieve the required strength, T7 heat treat (a treatment applied when the metal is in the molten state to prevent overageing) was chosen for application to the new cylinder block. Balance between strength and dimensional stability was considered. In conventional die casting, inclusions when the mold is being filled trap gas in the component being formed, causing blisters (surface swelling caused by gas) to form when the gas pressure increases with heat. This makes T6 and T7 solution heat treatments impossible. In the new production process, the semi-solid slurry fills the mold in a laminar flow, significantly reducing the amount of gas and enabling heat solution treatments without creating blisters. Figure 24 shows a comparison of proof stress and tensile strength.

3.3.6. Productivity

Figure 25 shows a comparison of productivity of various processes, as judged from cycle time. The newly developed ASCT improves cycle time by approximately 20% against NDC, and has an almost equivalent cycle time to HPDC. Productivity with the new process is approximately 4 times that of low-pressure casting, another process which enables sand cores to be used. In addition, because the new process uses a relatively low temperature semi-solid slurry, it reduces heat fatigue in the mold and significantly increases the life of the mold over the HPDC method.

4. Results and Performance

The discussion above has provided details of the development of a high-performance diesel engine cylinder block molded from aluminum. The following discussion will focus on the noise reduction and vibration characteristics of the new cylinder block and the weight savings it enabled.



Fig. 22 External view of pressure-resistant sand cores

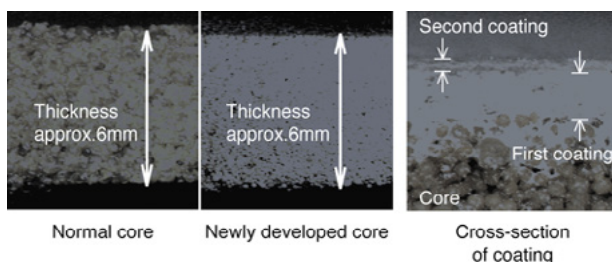


Fig. 23 Comparison of cross-sections of sand cores

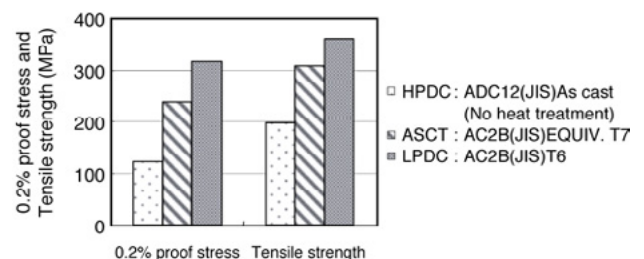


Fig. 24 Comparison of materials strength

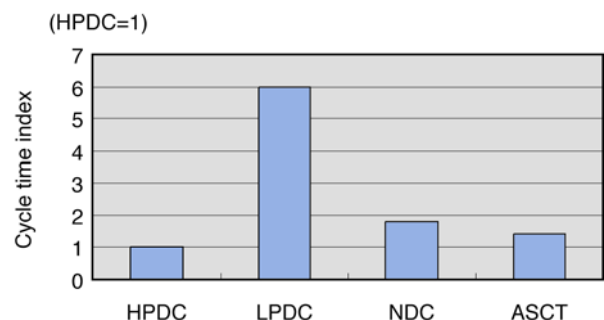


Fig. 25 Cycle time by production process

4.1. Noise Reduction and Vibration Characteristics

The use of the closed deck and new lower block structures, in combination with increased rigidity achieved by optimization of overall thickness and rib positioning has resulted in a reduction of engine noise. Figure 26 shows a comparison of structural attenuation using an index expressing the level of noise from the engine.

The aluminum cylinder block equaled the performance of cast cylinder blocks displaying ideal attenuation characteristics produced by competitors for vehicles of the same displacement.

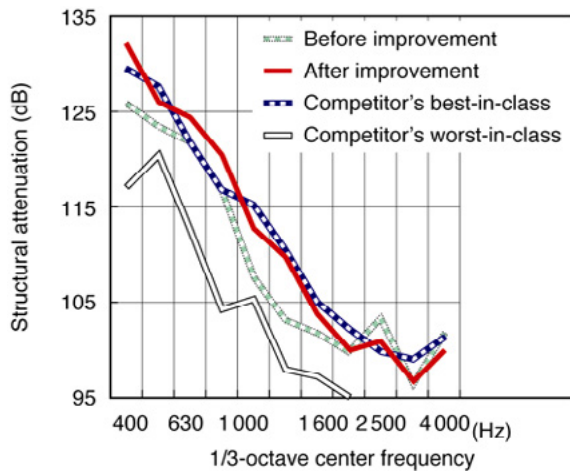


Fig. 26 Structural attenuation

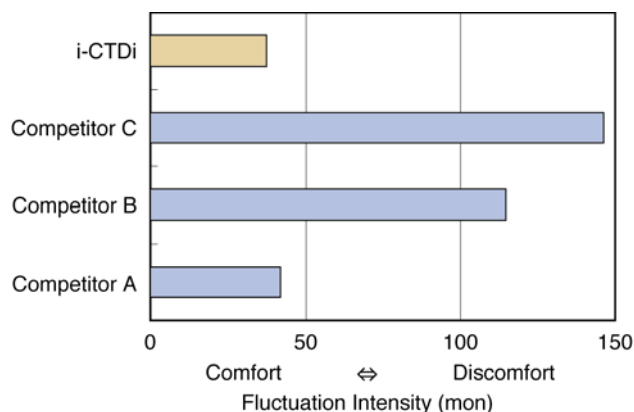


Fig. 27 Quietness at idling (1 m, diagonal and upwards)

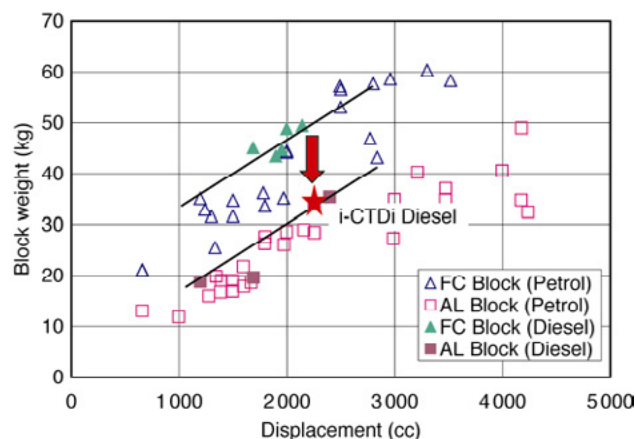


Fig. 28 Comparison of weight of cylinder blocks

In addition, the employment of offset cylinders and dummy head honing has made a significant contribution to reduce piston slapping noise. This, together with the reduction in excitation force due to optimization of combustion, enabled the achievement of class leading engine quietness. Figure 27 shows the extent of change in engine noise using an index representing the level of discomfort caused by slapping noise^{(8),(9)}.

4.2. Weight Savings

Figure 28 shows the relationship between displacement and the weight of the cylinder block. As discussed above, the cylinder block employed in the i-CTDi engine possesses a high level of functions and performance for use in a high-performance diesel engine, while being approximately 30% or 15 kg lighter than the cast cylinder blocks used in diesel engines of the same displacement. This is close to 10% of the unit weight of the engine.

If this reduction in cylinder block weight had not been achieved, the necessity for structural reinforcement when it was installed in a vehicle would have resulted in an overall increase in the vehicle weight, which would have led to a decline in vehicle performance, such as running characteristics and fuel consumption. This consideration indicates the significance of this development of a lightweight diesel engine cylinder block from the perspective of the performance of the vehicle as a whole.

5. Conclusion

- (1) A new production process has been developed which displays equivalent productivity to HPDC and enables the employment of a closed deck configuration and heat treatment through the development of a semi-solid die casting technique and coated pressure-proof shell cores.
- (2) The closed deck configuration, a new lower block structure, and high-strength materials were employed to produce a lightweight aluminum cylinder block that can resist the high combustion pressures of the latest diesel engines, and has a low level of structural response, giving it noise reduction and vibration characteristics equivalent to the best of class cast cylinder blocks.
- (3) The use of offset cylinders and dummy head honing have reduced piston slapping noise and sliding friction caused by combustion.
- (4) The new cylinder block is approximately 30%, or 15 kg, lighter than the cast cylinder blocks used by competitors in vehicles of equivalent displacement.

This paper discussed the element technologies employed in the high-strength aluminum cylinder block used in the i-CTDi, the first diesel engine independently developed by Honda, and the advantages the cylinder block possess. The authors hope that the research described in this paper will contribute to future reductions in the weight of diesel engines, which will in turn contribute to the reduction of CO₂ emissions in automobiles.

References

- (1) Miyahara, F., Ohshima, H., Ohtsuka, M.: Development of Cosworth process, Mazda Technical Review, No. 20, p. 97-102 (2002)
- (2) Hayashi, T., Ushio, H., Ebisawa, M.: The Properties of

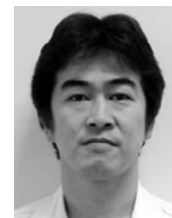
Hybrid Fiber Reinforced Metal and It's Application for Engine Block, SAE-Paper 890557

- (3) Hashimoto, H., Kibe, K., Nouno, Y., Sasaki, T.: Development of New 1.4DI Diesel Engine with Aluminum Die-cast Cylinder Block, TOYOTA Technical Review, Vol. 52, No. 1 (2002)
- (4) Uebayashi, H., Kadono, H.: Production Engineering for Aluminum Cylinder Block made by High-Pressure Die Casting, JSAE journal, Vol. 57, No. 6 (2003)
- (5) Saito, N., Nakamura, T., Ohtani, T., Kuroki, M., Masuda, E., Idegomi, T.: The development of joint parts for automobile body by thixocasting, JSAE20014005 (2000)
- (6) Idegomi, T., Hirono, H., Ito, O., Kimijima, S.: Application of SSC method to automobile components, Journal of JSTP, Vol. 41, No. 479, p. 1201-1205 (2000-12)
- (7) Adachi, M., Sato, S.: New Rheocasting process without stirring, Journal of JSTP, Vol. 41, No. 479, p. 1191-1197 (2000-12)
- (8) Noumura, K., Okada, Y.: Sound Quality Evaluation Technique of Vehicle in Consideration of Auditory Characteristic, HONDA R&D Technical Review, Vol. 9, p. 131-139 (1997)
- (9) Noumura, K., Yoshida, J.: Quantification of Luxury and Sporty Car Interior Sounds Perceived by the General Public in Different Markets, Honda R&D Technical Review, Vol. 14, No. 1, p. 237-246 (2002)

■ Authors ■



Masakazu YAMAZAKI



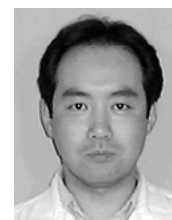
Atsushi TAKAI



Osamu MURAKAMI



Mitsuhiko KAWABATA



Osami ITO



Koichi KUROKI