

Establishment of Metal Die Fabrication Method with Short Production Work Hours by Implementing Technology of Liquid Metal Forging for Cast Iron

Takunori KITAMURA*

Hiroki NAGURA*

ABSTRACT

A technology has been sought for the metal mold fabrication that could be used for a trial manufacturing in the stage of a product development and/or the actual production stage for a small production volume to make the vehicle development flexible and conducted in timely manner. For the dies used for high pressure casting, surpassing mechanical properties are needed because of the severe requirements for durability in their operations. Therefore, hot forming die steel is usually used for the die steel material. However, this material is disadvantageous to machinability and takes longer period for its fabrication. With this background, the study on a technology of liquid metal forging for cast iron was conducted, in which ductile cast iron is cast in a mold and solidified under high pressure. By implementing the adjustments of the base material structure together with enhancements in surface properties, the production method was established to fulfill the requirements in dimensional accuracies, qualities of inner material and the life of mold.

1. Introduction

A large number of cast aluminum parts are used in a motorcycle. The prototype of such parts is usually produced by sand casting in the development stage of a new model to maintain flexibility for design changes while taking into account the production cost. The aluminum material such as JIS AC2B is used in the sand casting. Meanwhile in the mass production, the parts are produced by the high pressure die casting (HPDC) using the material like JIS ADC 12. It should be noted that there are differences in the mechanical properties between the two materials mentioned above. The product made by sand casting is less precise than the one made by HPDC. It is therefore necessary to verify durability of the part produced by HPDC in the final stage of product development. If a lack of strength or durability is found in that stage, a design change is required. A design change affects development schedule and development cost. Due to recent diversification of demands from the market, the needs for small-volume, multiple-model production are increasing. Under such circumstances, there is a requirement for a die manufacturing method applicable to the prototype manufacturing in the development stage as well as to the small-volume production in the mass-production stage.

The die for high pressure die casting is generally subjected to strong impacts from the molten metal charged into the die at a high speed under high-temperature and

high pressure conditions. Accordingly, the cavity section is generally made of a high strength material such as the hot die steel. Machining of such a high strength material, however, is difficult, requiring electro discharge machining (EDM) and hand polishing in the latter processes. Consequently, the total die manufacturing period becomes lengthy, which is an issue in the die manufacturing from the perspectives of cost and schedule.

To deal with this issue, studies have been conducted to produce dies by casting using the ductile cast iron (FCD)⁽¹⁾. In those studies, the die is produced by two manufacturing methods. For one, it is the semi-full-mold method using the ceramic shell mold requiring no machining of the cavity. In that die manufacturing method, the warpage of cast material, the rough surface and the metal structures on the surface were the concerns. The second one is the full mold method using foamed styrol and sand mold. The cavity section is machined. Though there is no quality-related problem in this method, there are issues in the production cost and the schedule.

With the aforementioned in the backgrounds, this project is targeted at realization of die manufacturing by the liquid metal forging using FCD as the die material. To allow use of FCD as a die material, it is necessary to take into account the inaccuracy of cavity shape due to the solidification contraction at the time of casting and the reduction of strength due to porosity. To deal with the said issues, the authors and others sought feasibility of liquid metal forging

* Motorcycle R&D Center

for cast iron. In this manufacturing method, retention of precise cavity shape and control of porosity are prospective by letting the molten FCD to solidify while being pressurized, thereby allowing reduction of total production time period by elimination of cavity machining, EDM and hand polishing from the die manufacturing processes. It is also considered that the control of porosity prevents lowering of strength, and allows application of the method to the die casting. Mentioned in this paper are the development process of HPDC dies by the liquid metal forging and the results of validation for practical applications.

2. Quick Die Production Method

2.1. Die Production Processes and Total Production Time Period

In the die manufacturing, the part that takes a long production time is the cavity because it is a reverse copy of the cast product having a complex 3D shape. The cavity production processes are shown in Fig. 1. Firstly, the cavity machining data is created from the 3D data of die using CAM. Then, the cavity is machined by the NC machine. At that time, the small section and/or the deep part shown red in the picture are left without being machined. Accordingly, the EDM is conducted after the machining. Although the EDM is an effective method to remove un-machined objects, it takes a long processing time because the metal is removed by electric erosion. As the metal property changes on the work surface in the EDM, the hand polishing is required in the final process. Consequently, the cavity production takes a long period of time.

Keeping in mind the aforementioned, the authors and others simulated the total production time for each part expended at the time of HPDC die production. The subject part is the crankcase of motorcycle engine. The size is; X: 300 mm Y: 195 mm Z: 60 mm. The high-pressure die cast machine having a die clamp force of 500 ton is applied. The material of the die bases is presumed as FCD 550, and the cavity material as SKD 61. It has been clarified upon the computer simulation that the total cavity production time shares approximately 58% of the entire die production period. We accordingly decided to work out a way that allows minimization of machining, EDM and hand polishing at the time of cavity production.

2.2. Quick Die Manufacturing Method

Roughly classified, there are two ways that can shorten cavity machining processes. One is such a method that applies finishing after producing a cast material having a shape that corresponds to the roughly-machined cavity. The other one is the liquid metal forging that fills molten metal in a mold and let it solidify while pressurizing. The liquid metal forging is a production method that ensures precise cavity shape while having less porosity inside. In the feasibility study, the preciseness of cavity shape was targeted at ± 0.1 mm, which was set taking into account the

cavity dimensions being X: 350 mm Y: 400 mm Z: 180 mm with the general tolerance of product at ± 0.4 mm. The die production time in those two methods were simulated. In the first method, the time saving is approximately 20% for the cavity made of SKD 61. Meanwhile in the second method, a saving as high as 50% is prospective. That's an end result of time saving from the machining, EDM and hand polishing. In view of the above, it was decided to start development of die production method based on the liquid metal forging.

The die manufacturing processes by the liquid metal forging are shown in Fig. 2. Firstly the forging die is designed by reversing the cavity from the 3D data of the die. After preparing the machining pass by CAM, the forging die is fabricated by the machining center. Then, the forging die is set on the fixture and heated with the heater. After the forging die is heated to the prescribed temperature, the molten FCD is charged in the forging die, and pressurized. Then, the die is cooled down until completion of solidification while maintaining the pressure. The die is separated from the mold upon completion of solidification, thus completing the cavity manufacturing. In the liquid metal forging, a material having the following characteristics is required.

- Shall be able to maintain strength and shape preciseness under high temperature conditions
- Shall be inexpensive and easily available
- Shall have good machinability

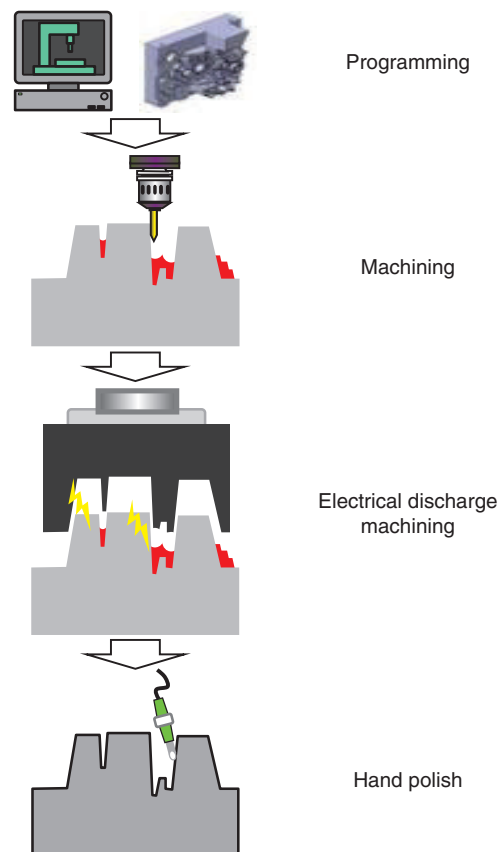


Fig. 1 Mold fabrication process

The authors and others therefore considered use of graphite for the die material. The graphite is commercially available and inexpensive. In addition to that, it resists heat as high as 3000°C in an inert gas while excelling in the shape preciseness. Moreover, its machinability is better than the hot forming die steel, thereby allowing forging die production in a short period of time. The graphite, however, has a thermal conductivity approximately three times higher than that of steel. Accordingly, as the molten metal is quickly cooled, faulty duplication of shape such as misrun tends to occur. To deal with this issue, die temperatures that ensure correct running of molten metal were analyzed.

2.3. Graphite Die Temperature Analysis

The charged FCD is cooled from the part that contacts the graphite, reducing flowability. As a result of reduced flowability, the material is missing in some areas, causing faults from misrun on the surface as shown in Fig. 3 in some cases. Accordingly, the relationship between the misrun and the die temperature was analyzed using the test piece created by the liquid metal forging. The shape of test piece was chosen from a part of the crankcase of motorcycle engine as shown by Fig. 4. Moreover, the part having a complex shape including ribs having a tip width of 2 mm and a depth of more than 80 mm was selected taking into account the

difficulty of high-pressure die-casting of parts having a large number of ribs. In the test piece preparations, the molten metal temperature was set at 1400°C. The graphite die temperature was increased from 400°C up to 1000°C with an increment of 50°C, having a total of 13 dies prepared. The die temperature was measured in the center of die and at a depth of 20 mm from surface of the deepest part of cavity. The test pieces were prepared under the abovementioned conditions and the number of misrun occurring on the surface was counted. At that time, a misrun was determined when the fault was as extensive as to require correction by welding.

The test results are shown in Fig. 5. When the die temperature is under 600°C, the number of the surface defects decreases rapidly along with an increase of temperature of the graphite die. As the die temperature is further increases, the number of the surface defects saturates and becomes close to zero. From the abovementioned findings, we concluded that it was necessary to set the die temperature at above 700°C in order to obtain acceptable surface quality.

2.4. Feasibility of Die Manufacturing by Liquid Metal Forging

The manner the FCD solidifies is a mushy solidification. In the mushy solidification, the molten metal becomes like mush as the cooling advances. It is such a manner of

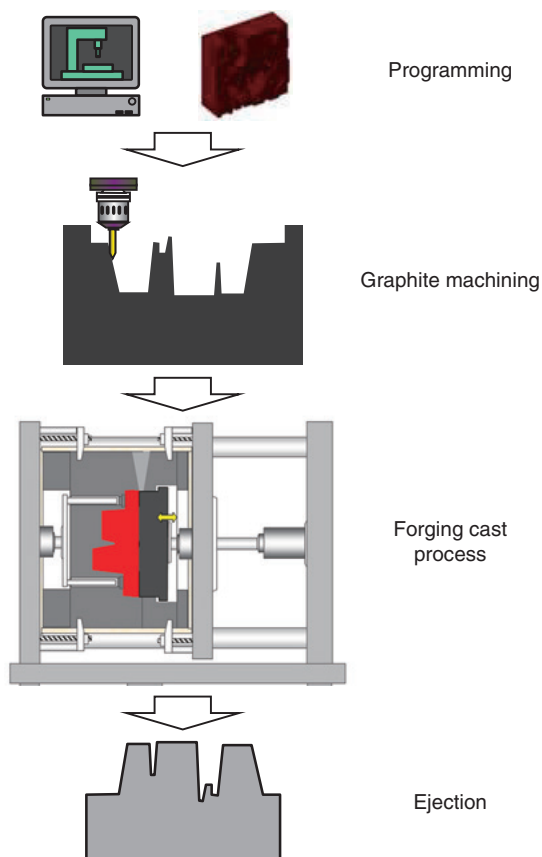


Fig. 2 Mold fabrication by forging cast process



Fig. 3 Appearance of surface defects



Fig. 4 Appearance of test piece

solidification in that the solidification completes all at once as soon as the cooling advances further and the temperature becomes lower than the solidus temperature. Due to the said characteristics, the pressurized molten metal stays closely in contact on the graphite die until completion of solidification. Additionally in the liquid metal forging, the molten metal is supplemented by the pressure at the time of contraction. Accordingly, an improvement of shape preciseness and internal quality is prospective from the liquid metal forging. The results of analysis on the shape preciseness and the internal quality are described hereafter.

2.4.1. Liquid metal forging process

How to inject molten metal into the liquid metal forging die is shown in Fig. 6. The “bottom gate” design in which the molten metal enters from the lower part of the cavity is selected to control occurrence of molten-metal balls and lowering of temperature due to spread of molten metal in

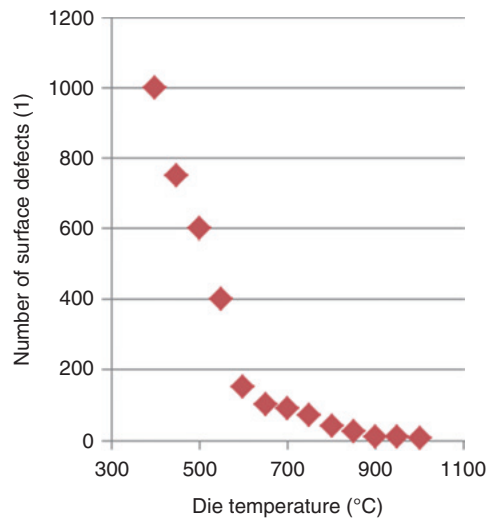


Fig. 5 Surface defects and die temperature

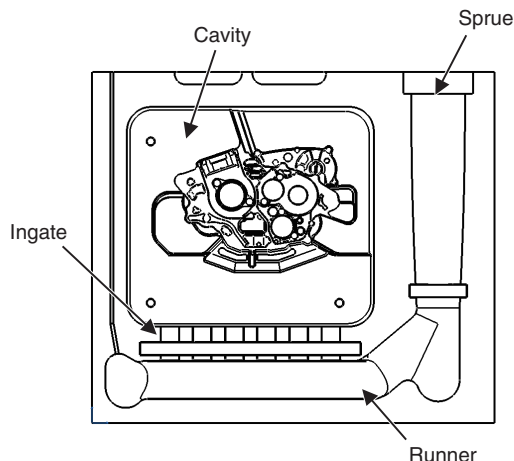


Fig. 6 Casting plan

its end. An overflow well is provided in the upper part to allow escape of excess molten metal and gas at the time of injection.

Next, the processes from the injection up to the ejection are shown in Fig. 7. The graphite die is composed of three parts. One is the fixed die having a reversed shape of the die cavity. The second one is the fore-and-aft sliding die for pressurizing of molten metal after completion of injection. In addition to that, the drawing system is incorporated for ejection. The third one is the retainer die which supports the sliding die. After securing the three dies in the fixture, the die is heated, and as soon as the graphite die reaches the prescribed temperature, injection of molten metal starts from the gate. After confirming that the molten metal is discharged from the overflow well, the slide die is moved

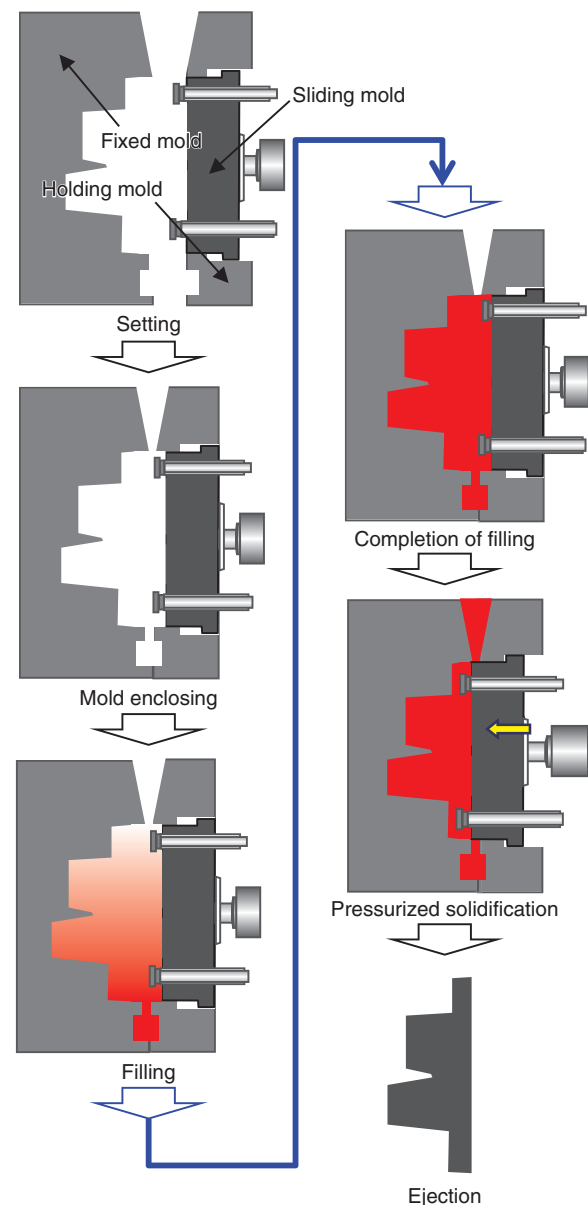


Fig. 7 Forging cast process

forward. The pressurizing starts as soon as the sliding die passes the gate and the overflow well, and continues until the pressure reaches the prescribed level. When the pressure reaches the prescribed level, cooling of the graphite die starts. As soon as the graphite die temperature has lowered to the prescribed level, the slide die is reversed. Thus, the die is separated from the graphite die.

2.4.2. Preciseness of shape transfer

How the solidification under the pressure affected the shape transfer preciseness was analyzed using the test piece shown in Fig. 4. The shapes of two kinds of test pieces prepared by the gravity casting and the liquid metal forging were measured, and the preciseness was compared. The non-contact laser contour measurement system was used for the measurement. The 3D shape data and the errors were calculated. The results of measurement are shown in Fig. 8. The negative side of color scale indicates the direction the shape shrinks and the positive side means the direction the shape expands. The left picture refers to the test piece prepared by the gravity casting. There is a maximum shape error of approximately 0.5 mm. Meanwhile, the right picture concerns the test piece prepared by the liquid metal forging. It is evident that the shape error is within ± 0.1 mm in all measurement points. Note that the blue-dotted part appearing on the upper left part of test piece is a deformation from the ejector pin, rather than an incorrect transfer of shape.

From the aforementioned findings, it has been confirmed that the solidification under the high pressure allows control of solidification contraction and strain as well as ensuring highly precise shape transfer.

2.4.3. Internal quality analysis

How the solidification under pressure affected the internal quality was analyzed using the test piece shown in Fig. 4. The test piece was sliced at an interval of 10 mm, and the dye penetrant inspection (JIS-Z2343) was conducted on all cross sections. Typical example of inspection data is shown in Fig. 9. The left picture refers to the test piece prepared by the gravity casting. Presence of porosity is seen. Meanwhile, the right picture concerns the test piece prepared by the liquid metal forging. No porosity is seen. It has been confirmed from these findings that the solidification under pressure prevents porosity.

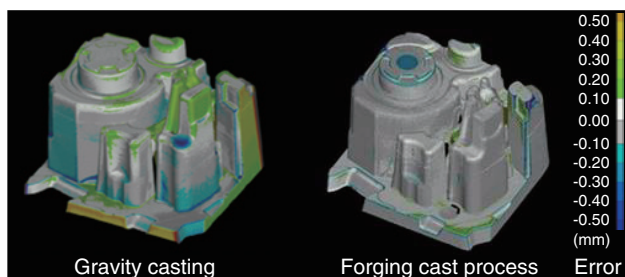


Fig. 8 Comparison of duplication accuracies

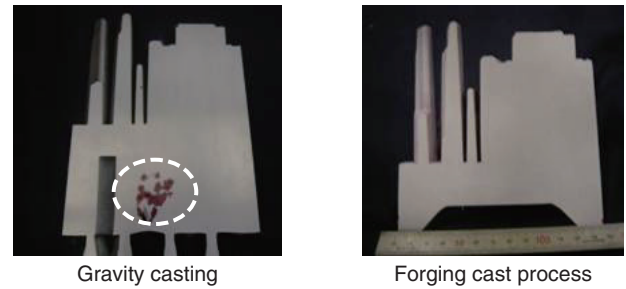


Fig. 9 Comparison of internal defects test results

3. Improvement of Durability of FCD Die

As this project is aimed at dies suitable for small-volume production, the following goals have been set for the durability.

- No damage after 10000 shots
- Heat checks within tolerance of appearance

Compared to other casting methods, the injection pressure is high in the HPDC, and the molten aluminum contacts on the die surface at a high speed. In addition to that, the water-soluble de-molding agent is sprayed on the die after ejection of the casting. Accordingly, thermal stresses from heating and cooling occur in the die. The tensile strength of FCD is lower than that of a hot forming die steel. Accordingly, heat checks occur earlier in the die made of FCD than the die made of SKD 61. The heat checks are transferred to the casting, negatively affecting the product appearance. Growth of heat checks eventually causes breaking of the die. To deal with this issue, the basic metal structure of FCD was analyzed and the material composition was adjusted to make the material suitable for HPDC. The following two test methods were employed. One is the “heat check test” by approximately inducing cool/heat cycle. The second one is the “die cast test”, in which the durability is assessed by actual casting.

3.1. Basic Metal Structures of HPDC Die and Adjustment of Material Composition

3.1.1. Life estimation by heat check test

The heat check test shown in Fig. 10 is one of the methods to test durability of the basic metal structures of die material. The heat check test is generally conducted using an induction hardening equipment. After induction-heating the test piece to the prescribed temperature, water cooling and air cooling are conducted. It is a test to assess heat check resistance by approximately duplicating the cool/heat cycle occurring on the die surface at the time of casting.

The conditions under which the heat check test is conducted are described hereafter. The test piece diameter is 42 mm and its length is 80 mm. The outer circumference and the end surfaces are machined. The surface temperature is increased to 620°C by heating for 10 sec, and after that, the surface temperature is lowered to 50°C by the 15 sec

water cooling and 5 sec air cooling. The said procedures complete a cycle. Also in the tests at this occasion, SKD 61 was selected as the durability reference material. The number of cracks in SKD 61 occurring after conducting 1000 cycles of the aforementioned test was used as the reference. In this project, the durability of SKD 61 die was presumed at 50000 shots. As the durability of FCD die is targeted at 10000 shots, the target number of cycles at which the number of cracks and its length become equal to the reference corresponds to 200 cycles.

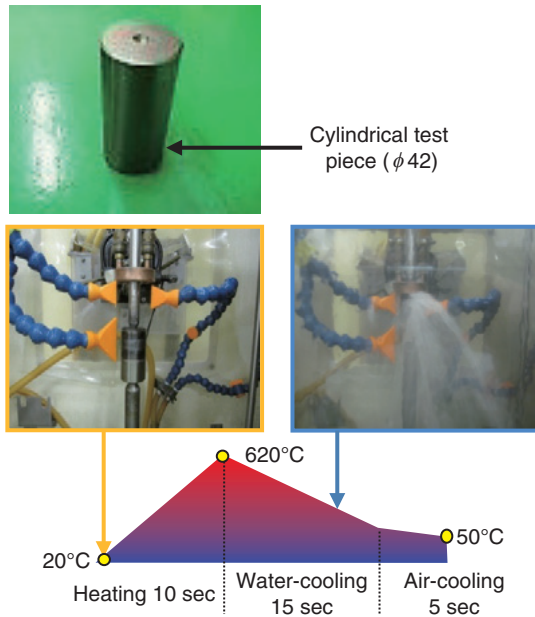


Fig. 10 Test conditions for heat check

Table 1 Specification of test piece

TP	Structure	Ferrite (%)	Pearlite (%)	Hardness (HRC)
(1)	Ferrite	100	0	<0
(2)	Ferrite-rich	95	5	10
(3)	Ferrite-Pearlite	40	60	22
(4)	Pearlite-rich	5	95	25
(5)	Martensite			37
(6)	Bainite			42
(7)	Cementite			51

3.1.2. Relationship between basic metal structure and occurrence of heat checks

The following seven types of metal structure were designated for the test piece to conduct heat check tests. Major specifications are shown in Table 1. The rate of ferrite and pearlite in the chart is by the rate of respective area with the graphite excluded. The hardness is shown in HRC scale converted from the Brinell hardness.

Test piece (1) All ferrite

Test piece (2) Ferrite-pearlite (ferrite-rich)

Test piece (3) Ferrite-pearlite

Test piece (4) Ferrite-pearlite (pearlite-rich)

Test piece (5) Martensite

Test piece (6) Bainite

Test piece (7) Cementite

The test results are shown in Fig. 11. The following characteristics are seen in the diagram. The trend is such that the higher the hardness, the number of cycles decreases until

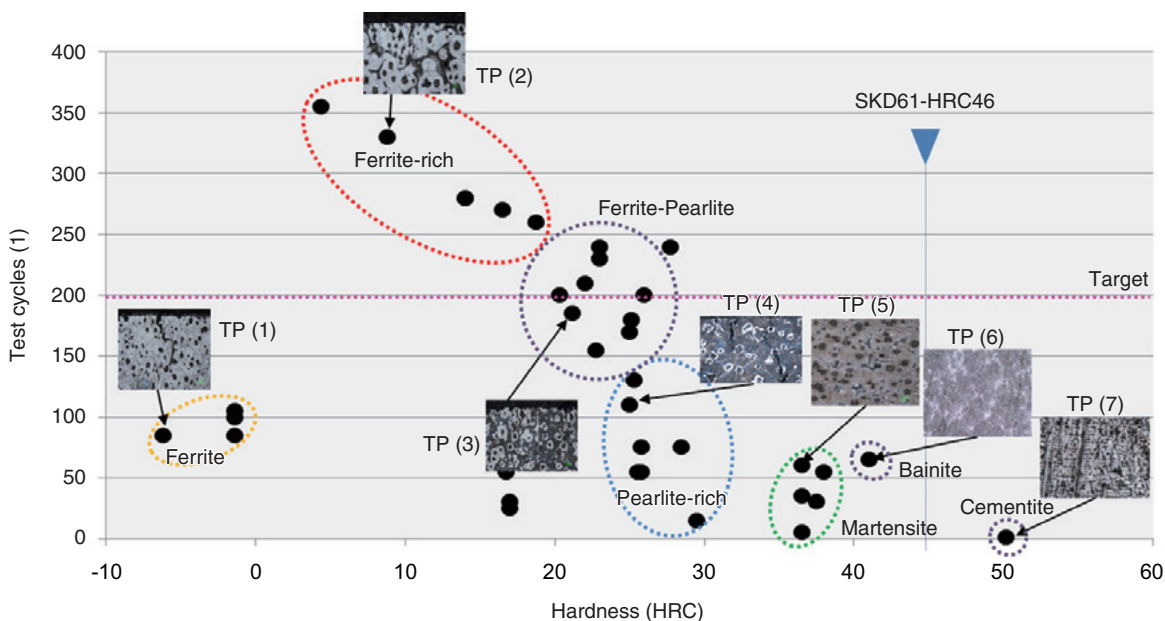


Fig. 11 Results of heat check classified by metallographic structure

reaching the aforementioned reference level. Also, in the test piece having two kinds of metal structures such as the ferrite-pearlite structure, the number of cycles is large until entirely reaching the reference level. Especially in the test piece rich with ferrite, the durability exceeds the target. Meanwhile, none having a single metal structure satisfies the target.

Next, the details of heat check were observed with the metallurgical microscope. Taken for the observation were four kinds of the test pieces, i.e., the test piece (1) and (4) in which the number of test cycles was small, and the test piece (2) and (3) in which the number of test cycles was large. The results of observation are shown in Fig. 12. In the test piece (1), the heat check grows along the graphite in the ferrite structure. The same applies to the test piece (4) featuring pearlite. On the other hand, in the test piece (2) and (3), while the heat check grows along the graphite, in some areas, the heat check occurring in the ferrite stops growing at the ferrite-pearlite interface. It is also known that the FCD having ferrite-pearlite two-phase mixed structure is highly ductile⁽²⁾. In view of the above, the authors and others have considered that the growth of heat check can be controlled by making the basic metal structure composed of two kinds, i.e., ferrite and pearlite.

3.1.3. Influence of material composition to heat check

With respect to the material composition, our attention was focused on manganese (hereafter Mn). The FCD contains Mn by approximately 0.2-1.0 wt%. The Mn is added to remove sulfur in the molten metal by forming its chemical compound (manganese sulfide). The residual Mn unrelated to the forming of manganese sulfide becomes carbide⁽³⁾. The carbide is brittle, hard and easy to crack.

Table 2 Enhanced toughness against heat check by decreased Mn content

TP	Structure	Mn (wt%)	Hardness (HRC)
A	Ferrite-rich	0.39	17
B	Ferrite-rich	0.13	15
C	Ferrite-Pearlite	0.36	22
D	Ferrite-Pearlite	0.11	20
E	Pearlite-rich	0.37	28
F	Pearlite-rich	0.12	24

Accordingly, in an attempt to clarify how the Mn content affects the growth of heat check, 6 kinds of test pieces with various Mn contents were prepared and heat check tests were conducted. The test piece A and B were prepared with a target hardness of HRC 15, C and D at HRC 20, E and F at HRC 25 (Table 2). The difference of hardness was created by changing the ferrite/pearlite ratio. The test results are shown in Fig. 13. The test piece with the Mn content reduced to 0.1 wt% achieved the targeted 200 cycles.

On the basis of the above findings, the sample B, which is the best from the strength standpoint, has been employed.

3.1.4. Die cast test

To verify durability of the FCD die in actual casting operations, 3000-shot die cast test was conducted using the HPDC machine having a clamp force of 350 ton. The overview of the die and the test piece are shown in Fig. 14. Three criteria were defined for the judgment to meet the requirements for die durability. Those are the dimensional

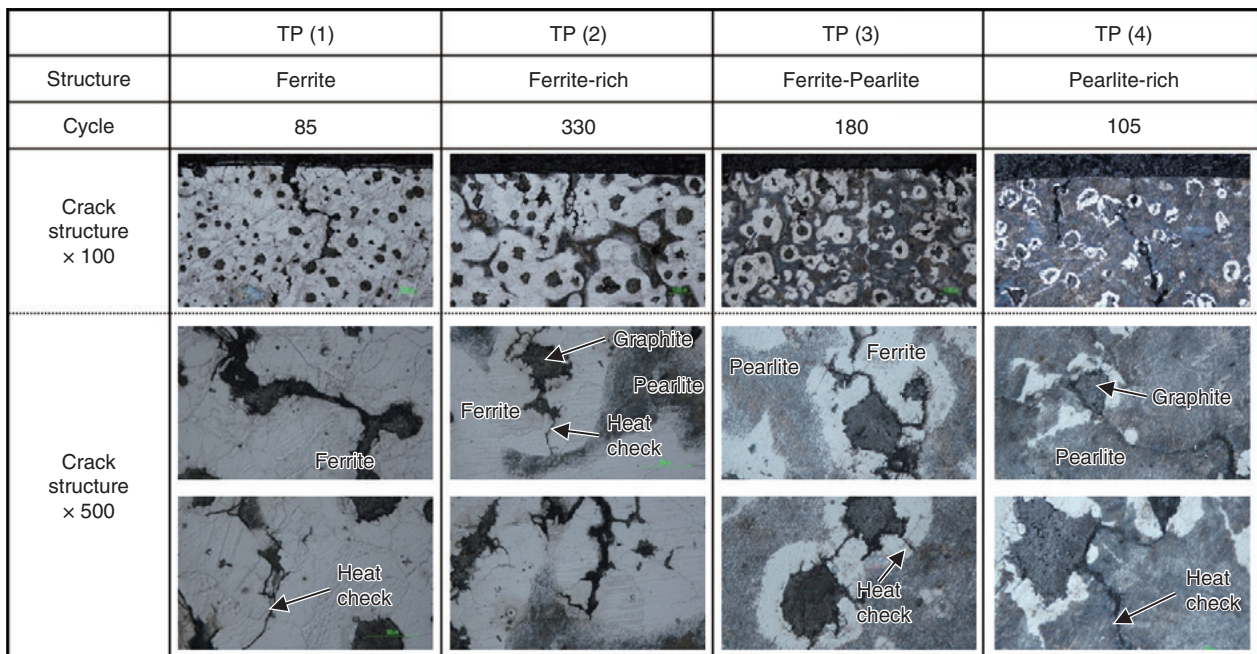


Fig. 12 Cross sections showing heat checks in micro structures

accuracies and the quality of appearance of the casted products together with the existence of breakages on the dies.

The shape preciseness test method is described hereafter. The shape of product produced by HPDC at the 10th shot and 3000th shot was measured with the industrial CT scanner. The dimension variance between the measured data of 10th shot and the 3D data is shown in the left picture of Fig. 15. The dimension variance is within ± 0.1 mm. The right picture shows the dimension variance between the measured data of 3000th shot and that of 10th shot. The dimension variance is within ± 0.1 mm with an exception in a part. The cause of the shape deviation more than -0.2 mm in that part is due to the seizure of aluminum on the die, rather than a die deformation. No part of the die was broken either.

The overview of the product at 3000th shot is shown in Fig. 16. It can be seen that the large number of heat checks occurring in net-like patterns on the die surface is transferred on the product. The fault was beyond the tolerance of cosmetic quality of the product. The enlarged picture of heat checks on the die surface is in Fig. 17, and its cross-section in Fig. 18. The whitish aluminum

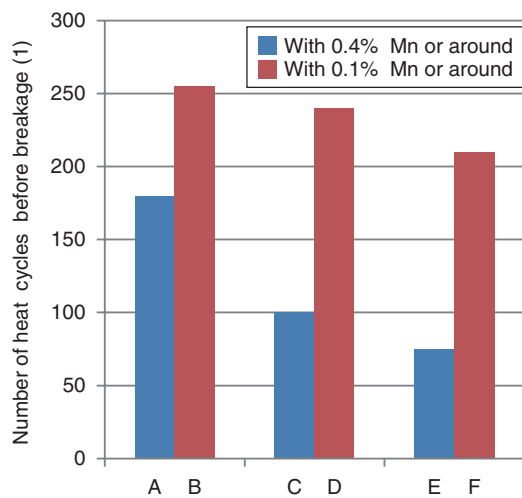


Fig. 13 Enhanced toughness against heat check by decreased Mn content

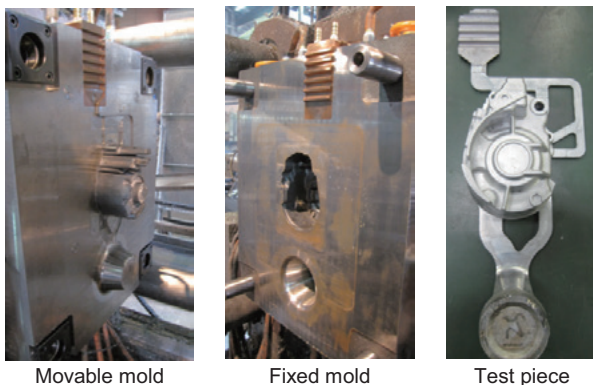


Fig. 14 Dies and test piece

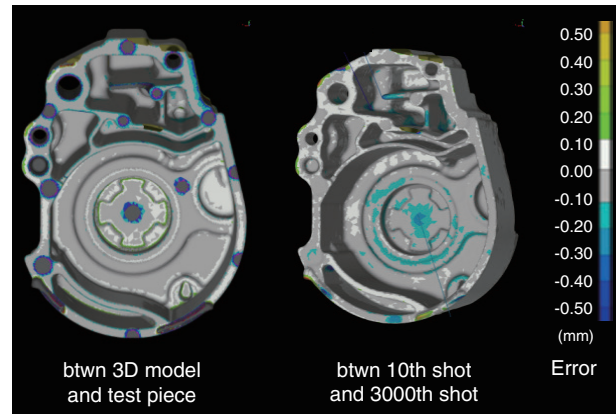


Fig. 15 Results of shape disparities checking



Fig. 16 Transferred heat checks



Fig. 17 Heat checks occurred on die surface

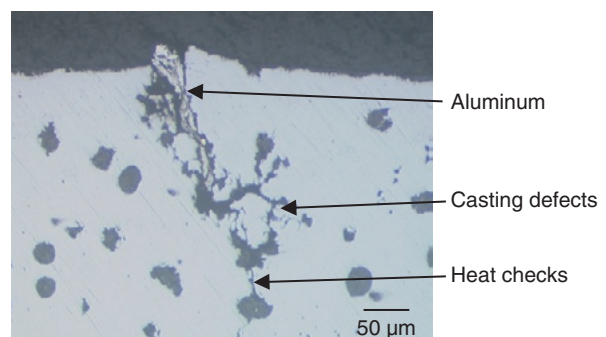


Fig. 18 Cross section at surface corrugation

penetrating in the heat check forms ridges on the die surface. With the ridges transferred, depressions occur on the product, causing lowering of cosmetic quality. The aforementioned findings mean that while the requirements on the retention of shape preciseness and the absence of die damage are satisfied, the cosmetic quality requirement is not satisfied due to the transfer of heat checks on the die to the product. Accordingly we decided to prevent formation of ridges in the opening of heat check.

3.2. Prevention of Ridges by Surface Modification

In the die cast tests, the cosmetic quality lowered to beyond the tolerable level due to the transfer of ridges on the product. It has therefore been decided to improve cosmetic quality by preventing formation of ridges on the die surface. As a means to prevent formation of ridges, the surface modification reformation was considered.

3.2.1. How heat checks that form ridges on the surface occur

How the ridges are formed in the opening of heat check is explained using the image picture shown in Fig. 19. Firstly in the early stage of the casting cycle, small heat checks occur from the surface toward the graphite. However, as the gap is small, no aluminum penetrates. After that, along with repetition of casting cycles, the heat checks in the

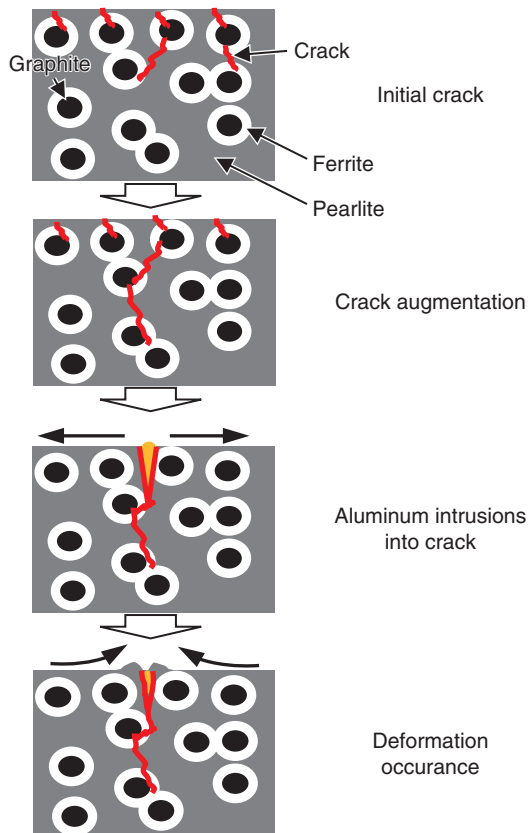


Fig. 19 Heat check generating mechanism in material structure

stress-concentrated area grow deep along the graphite. When the depth of heat checks becomes larger than a certain level, the oxide matter falls from the surface, causing an opening. The molten aluminum is charged in the opening at a high pressure at the time of injection. It can be presumed that a plastic deformation occurs around the opening in the process the die surface shrinks after solidification of the charged aluminum, causing formation of ridges. To deal with this issue, it was considered that the plastic deformation could be prevented by providing a hard layer on the die surface.

3.2.2. Validation of surface modification

Nitriding is generally applied to a die made of a hot forming die steel, etc. to improve heat check resistance⁽⁴⁾. It is mainly aimed at prevention of heat checks. In this project, the authors and others considered that the nitriding would be effective for prevention of ridges on the opening of heat checks occurring in the dies made of FCD. Then, the salt bath soft nitriding was selected, and die cast tests were conducted. The cosmetic appearance was compared by the product made at the 3000th shot for validation of effectiveness of the soft nitriding treatment. The overview is shown in Fig. 20. Compared to the earlier-mentioned product, the ridge is controlled and the transferred depression on the product is less. The measurement points of depression transferred on the product are shown in Fig. 21, and the

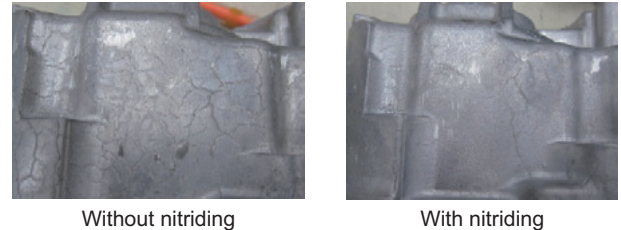


Fig. 20 Crack control effect by surface modification

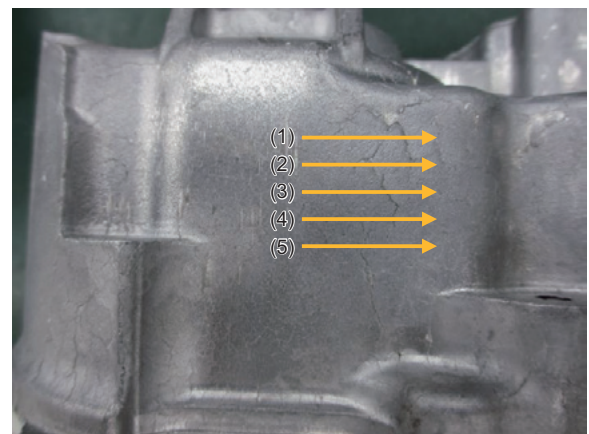


Fig. 21 Trace lines of depths measurement of transferred ditches on molded parts at corresponding locations of heat checks

measured data in Fig. 22. The depth of depression was measured using the surface roughness tester. The maximum depth of depression transferred on the product made with the die without the soft nitriding is 0.13 mm. Compared to that, the maximum depth is 0.07 mm in the product made with the die having the soft nitriding applied. From these findings, it can be presumed that the hard layer created on the die by the soft nitriding reduces formation of ridges. The first goal, i.e., improvement of cosmetic quality, has thus been achieved.

3.3. Durability after 10000 Shots

To verify the durability of FCD die at the targeted 10000 shots, durability tests were conducted by actually casting the product. The crankcase of a single-cylinder engine was selected for the tests. The shape of cavity is shown in Fig. 23. Using the HPDC machine having a clamp force of 500 ton, 10000 shots of actual casting was conducted. Three criteria were defined for the judgment to meet the requirements for die durability. Those are the dimensional accuracies and the quality of appearance of the casted products together with the existence of breakages on the dies.

The tests were conducted by the method mentioned in 3.1.4. Note that the measurement was taken from the

products at 3000th shot, 5000th shot and 10000th shot. The shape preciseness data are shown in Fig. 24. The shape deviation up to the 5000th shot was within ± 0.1 mm. The dimension variance at the 10000th shot was within ± 0.1 mm with an exception of a part. The variance more than ± 0.2 mm seen in a part results from a deformation of product due to an increase of ejection resistance attributable to heat checks rather than a deformation of the die. Also, the variance is larger than 0.2 mm in the parts colored orange or red in the picture because the shape to be removed by machining is indicated in the 3D data.

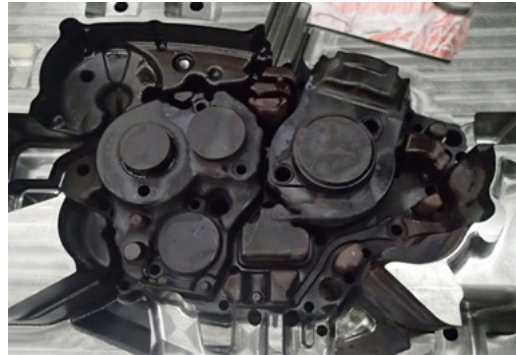


Fig. 23 Appearance of cavity

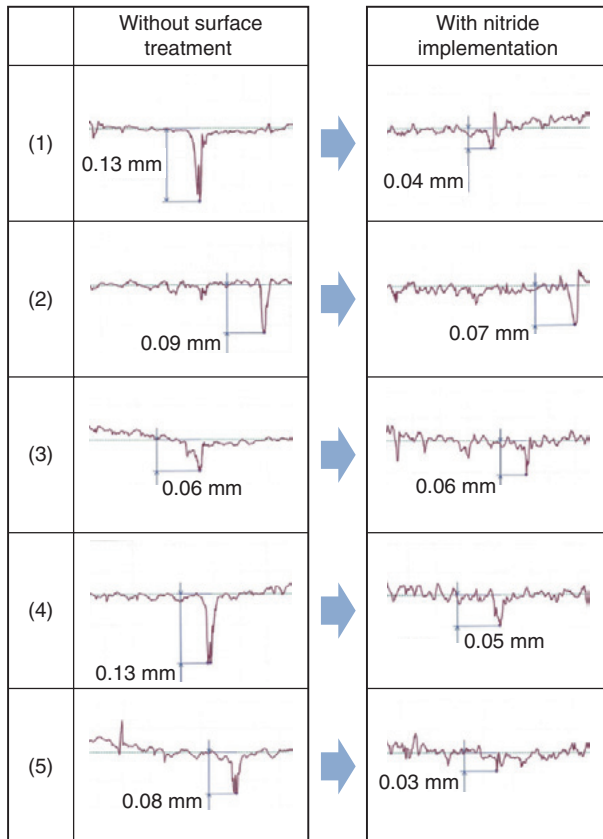


Fig. 22 Measurement results of transferred ditches depths on molded parts at corresponding locations of heat checks

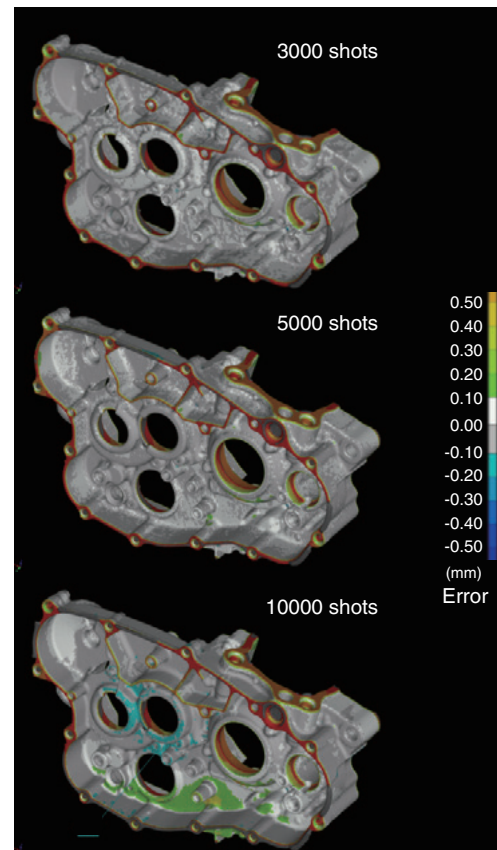


Fig. 24 Shape comparison results of whole shots

There was no damage in the protruding part (6 mm in diameter, 12 mm in length) shown in Fig. 25 and considered as the weakest part of the die. There was no chipping or large crack in other parts of the die.

The overview of the product at the 10000th shot is shown in Fig. 26. Though heat cracks with patched patterns are transferred in some areas, it was not as significant as to affect the marketability. It has been confirmed from the tests that the FCD die developed through this project has the targeted durability.



Fig. 25 Shape section after 10000 shots



Fig. 26 Raw material appearance after 10000 shots

- (2) After filling the graphite die with the molten metal and applying pressure, the die should be cooled to allow solidification. In doing so, it is possible to fabricate FCD die cavity having shape preciseness with a deviation less than ± 0.1 mm and free of internal porosity.
- (3) The control of basic metal structures of FCD to a combination of ferrite and pearlite improves heat crack resistance. The higher the ferrite ratio, the less the heat checks occur.
- (4) Reduction of Mn content in FCD improves heat checks resistance.
- (5) The formation of ridges on the opening of heat check due to plastic deformation can be prevented by the soft nitriding treatment.

References

- (1) Anzai, K., Aoyama, S., Niiyama, E., Ebisawa, M., Nagasawa, O., Kaneuchi, T., Hayano, I., Motohashi, T., Sawada, T., Ishikawa, T., Asada, J., Kinoshita, Y., Kuboki, I., Murakami, M., Mizuno, R., Itamura, M., Kanno, T., Kikuchi, T., Nishi, N.: Chuutetsu sei Daikasuto Kani Kanagata ni Kansuru Chousa Kenkyuu, Japan Die Casting Association, p. 96 (2009) (In Japanese)
- (2) Rin, W., Kawabata, M.: Mechanism of Eutectoid Transformation of Ductile Iron with Ferrite-Pearlite Duplex Structure, Hitachi Kinzoku Technical Reviews, Vol. 28, p. 20-25 (2012) (In Japanese)
- (3) <http://www.nbk-okamoto.co.jp/DataBook/d220.htm>
- (4) Tsujii, N.: Kanagata no Hason Keitai to Jyumyou Koujyou Taisaku, Sanyo Technical Report Vol. 7, No. 1, p. 65-71, (2000) (In Japanese)

4. Conclusion

Through the studies of manufacturing method of HPDC dies suitable for small-volume production, the new method that satisfies requirements on the shape preciseness, the internal quality and the die life has been developed, allowing reduction of die manufacturing period to a half. The knowledge acquired through the project is described below.

- (1) When employing graphite for a forging die, liquid metal forging should be performed after heating the graphite die to a temperature above 700°C. In doing so, a good quality free of fault on the cavity surface is attainable.

■ Author ■



Takunori KITAMURA



Hiroki NAGURA