

# Rapid Trial-Production Technique for Aluminum Alloy Engine Components with Hollow Construction using Block Buildup-Brazing

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## ABSTRACT

A process was developed for manufacturing cylinder heads and other such aluminum alloy engine components with hollow construction by means of block-buildup brazing and a high-speed machining technique. This approach does not use a mold as the conventional sand-mold casting technique does, so it was able to manufacture a high-precision cylinder head for preliminary test purposes in a short period of time, and so allow a rapid determination of specifications.

## 1. Introduction

In the initial stages of engine development, there is demand for manufacture of test engines in a short time for the purpose of performance verification and other such activities for the early determination of specifications. However, the trial production of water-cooled cylinder heads and other such integral components with hollow construction ordinarily involves sand-mold casting using a core, and the mold building and casting require considerable

time. The establishment of buildup-brazing technology and high-speed machining from solid material with dividing of the hollow construction made mold-building unnecessary and enabled trial production in a short time.

## 2. Block-Buildup Brazing and High-Speed Machining Technique

Figure 1 shows the fabricating process. Working from a 3D model that is a manufacturing drawing, a 3D

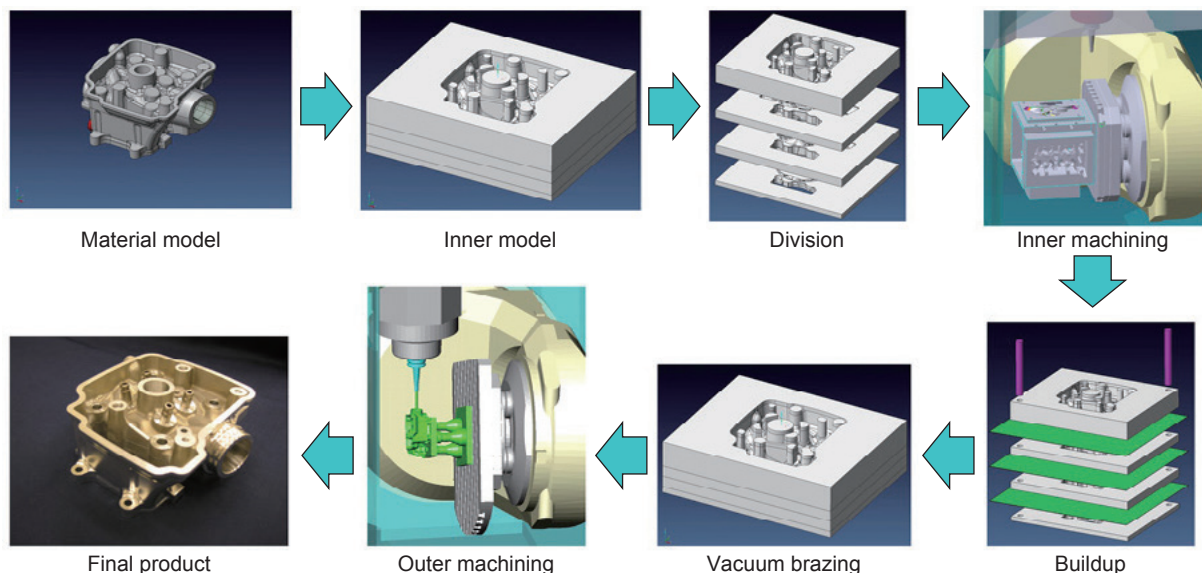


Fig. 1 Rapid trial-production process for engine components with hollow construction

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model that is an extract just of the portion with hollow construction is created. The slice locations are decided as described below in section 4.1. Blocks that are machined to the determined thickness are then subjected to dowel hole drilling. The dowel hole is taken as a machining datum, and the upper and lower surfaces of the portion with hollow construction are subjected to machining using a 3- and 5-axis high-speed machine. Using the dowel hole as a datum, buildup is carried out by placing brazing sheets that are like pieces of aluminum foil 0.04 mm thick in between the individual blocks, then subjecting them to brazing by heating them while pressing them in a vacuum furnace. The block subjected to brazing is then given T6 treatment (JIS H0001-1998), following which it undergoes external surface machining and drilling, the valve seat and valve guide are press-fit, and finish machining is carried out. The component is then complete.

### 3. Buildup-Brazing Technology

#### 3.1. Forming the Hollow Construction Part

There is a method of forming the hollow construction part that uses powder rapid prototyping, but it involved issues of strength and precision. Buildup-brazing technology was therefore considered as a technique for manufacturing high-strength, high-precision components more quickly. Methods for joining aluminum materials include pulse electric current bonding<sup>(1)</sup> and diffusion bonding<sup>(2)</sup>, but these have issues with joining strength because of the oxide film residue on the joining surface<sup>(3)</sup>, and this is why the buildup-brazing method, which readily provides joining strength, was chosen (Fig. 2). The buildup brazing-method involves buildup by sandwiching brazing sheet with a lower melting point than the block parent material between the individual blocks. All this is then pressed in a vacuum furnace while subjecting it to preheating to a temperature at which the parent material will not melt. After that, it is subjected to brazing by heating it to a temperature at which only the brazing metal melts.

#### 3.2. Brazing Quality Verification

The block that is subjected to dividing into parts with thickness that allows machining will have a complex joining surface, and variations in surface area and surface contact pressure will occur. As shown in Fig. 2, the application of a load during brazing causes the brazing metal to adhere to the joining surface and stabilizes quality. Brazing quality verification was conducted under the following three headings.

- Surface contact pressure distribution analysis of the joining surface by means of CAE
- Strength analysis of the joining surface
- Accuracy verification of hollow parts by means of x-ray CT

##### 3.2.1. Surface contact pressure distribution analysis of joining surface

Brazing is performed by applying a certain amount of load. Due to the complexity of the joining surface, however, there are concerns about variation in surface contact pressure and instability in brazing quality. CAE was therefore used to conduct surface contact pressure distribution analysis. As shown in the diagrams on the left side of Fig. 3, the surface contact pressure is low (shown in blue) in the vicinity of the valve guide area inside the inlet and exhaust port, which do not have support in their upper parts. Therefore, reinforcement was added in the form of support in their upper parts as a means of equalizing the surface contact pressure distribution. The results are shown in the diagrams on the right side of Fig. 3. An increase in surface contact pressure (shown in green) was confirmed in the reinforcement area.

##### 3.2.2. Joining surface strength analysis

Surface contact pressure analysis can be performed by CAE using a 3D model of the product shape. In strength verification, however, the issue is the adhesive strength of the joining surface. Because of this, test pieces that have undergone brazing with different surface contact

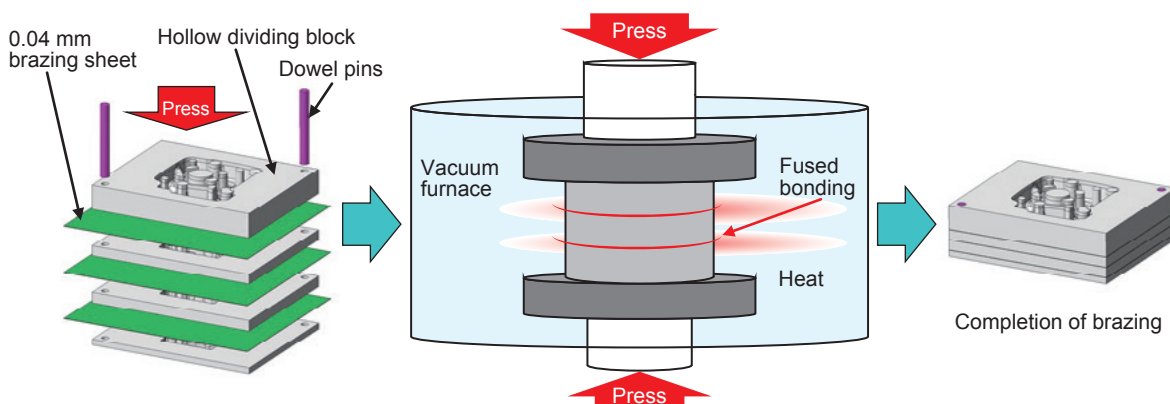


Fig. 2 Block buildup brazing process

pressures and loads are subjected to a tensile test. A logic was established that estimates strength from the combined results of the surface contact pressure analysis and the tensile test. Figure 4 shows the results from the tensile tests at different surface contact pressures. The dotted lines in the graph show the tensile strength of materials A6061-T6 and AC2B-T6. This approach could provide tensile strength approximately 20% higher than the sand-mold casting material.

### 3.2.3. Accuracy verification of hollow parts by means of x-ray CT

Figure 5 shows the deformation that occurs from the press when brazing the water jacket and inlet and exhaust port hollow parts. Deformation within  $\pm 0.2$  mm is shown in gray, and deformation of greater than plus or minus 0.2 mm is shown in other colors. The green portions have deformation of approximately 0.3 mm, and this could be confirmed as being within the allowance shown in the drawing for the 3D model shape.

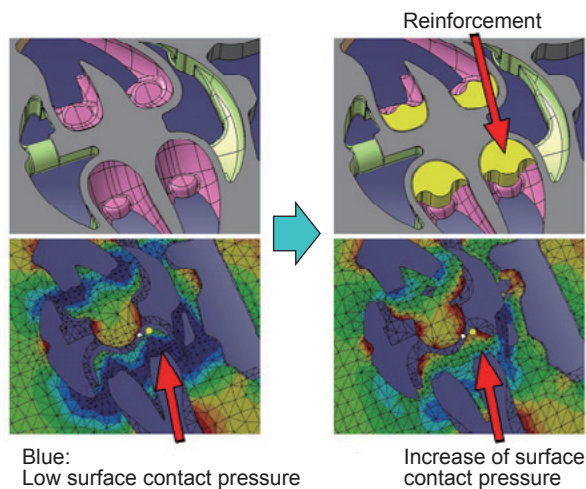


Fig. 3 Equalizing of surface contact pressure

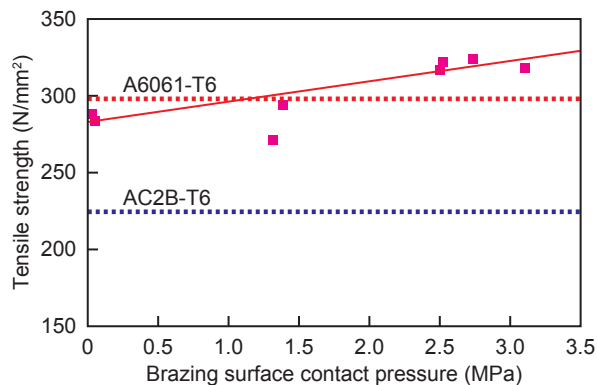


Fig. 4 Comparison of calculation of surface contact pressure and measurement of brazing tensile strength

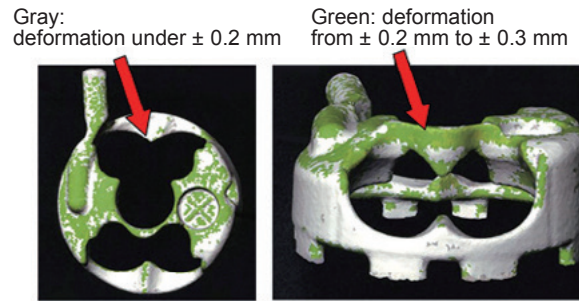


Fig. 5 Measurement of hollow construction deformation by using X-ray CT

## 4. Rapid Dividing and High-Speed Machining Technology

Performing mechanical machining in a short period of time requires a 3D model dividing technique, a rapid programming technique for 3D machining data, and optimization of high-speed machining technique.

### 4.1. Optimum Dividing Technique for 3D Model

When dividing into a greater number of pieces, the undercut area (impossible machining area using 3-axis machining) diminishes accordingly. However, the decrease in individual stiffness means that deformation occurs from the press during brazing. These factors are taken into consideration as the hollow-shaped part is divided into cross-sectional slices at locations that will not result in the formation of a separated island shape. The dividing locations are further subjected to optimization (Fig. 6) for the shortest possible tooling and machining time by a combination of 3-axis machining, 5-axis machining, and other such methods.

### 4.2. Rapid Programming Technique for 3D Machining Data

Ordinarily, 3-axis machining equipment is called a vertical machining center. This refers to equipment that has three axes (X-axis, Y-axis, and Z-axis) and performs

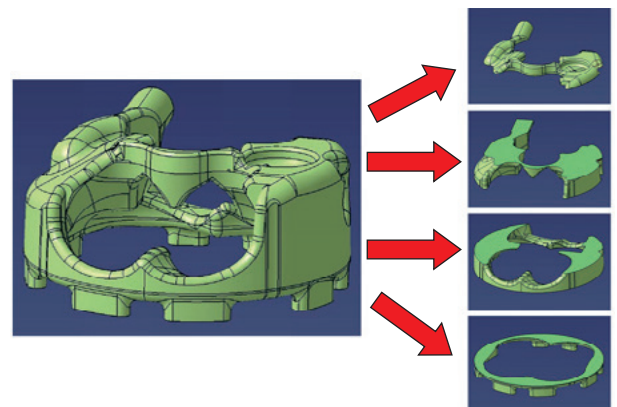


Fig. 6 Optimum dividing of hollow construction

mechanical machining by numerical control. The tool only moves vertically (Z-axis) in relation to the table and it is not capable of machining overhang parts. The 5-axis machining equipment has two further axes in addition to the three axes, and it is constructed so that the tool (Z-axis) can be tilted to any angle. This enables machining of overhang parts that 3-axis machining equipment is incapable of. When pieces divided into slices are all to be subjected to machining only by 5-axis machining equipment, a collision check is conducted of the holder and spindle for every tool angle. Since this increases the machining data programming time, the basic rule is to perform 3-axis machining from the upper and lower surfaces.

The machining conditions when 3-axis machining (tool, stepover, toolpass type, etc.) are registered as a template for each machining shape. This enables use of the template to easily configure the machining condition for each machining part, which enables high-speed programming of the machining data. With this approach, the undercut area is subject to automatic detection and 5-axis machining is kept to the necessary minimum.

#### 4.3. 5-Axis High-Speed Machining Technique

The respective machined surface roughness is configured for the inlet and exhaust port, combustion chamber, and other such functional surfaces, as well as for other, external surfaces and the like. The configured machined surface roughness is taken as a basis for reducing the machining time by means of a machining condition that takes maximum advantage of the machine capacity. Machining utilizes two 5-axis machining machines. On the 5-axis complex machine, a special jig (Fig. 7) is used to enable continuous machining of the upper and lower surfaces with a single tooling configuration. On the 5-axis machining center, a special index jig (Fig. 8) is used to enable machining of four sides with a single tooling configuration. These measures were taken for tooling time reduction and for schedule reduction with unmanned operation.

### 5. Feasibility Verification

#### 5.1. Application to Off-road Race Engine

A cylinder head for the purpose of verifying performance was created (Fig. 9) by changing the position of the exhaust manifold. Compared to conventional sand-mold casting, this product shortened the manufacturing schedule by 60% and reduced the manufacturing cost per unit by 75%. The product was also capable of application in a preliminary test without any issues related to strength.

### 6. Conclusion

A block-buildup brazing and high-speed machining technique was established and yielded the following results.

- (1) The manufacturing schedule could be shortened by 60% relative to the sand-mold casting technique.
- (2) A cost reduction of 75% per unit was achieved relative to use of the sand-mold casting technique to manufacture a preliminary test product.
- (3) The machining consists entirely of processes for removal (cutting, grinding, etc.), and so enables manufacture of high-precision components.

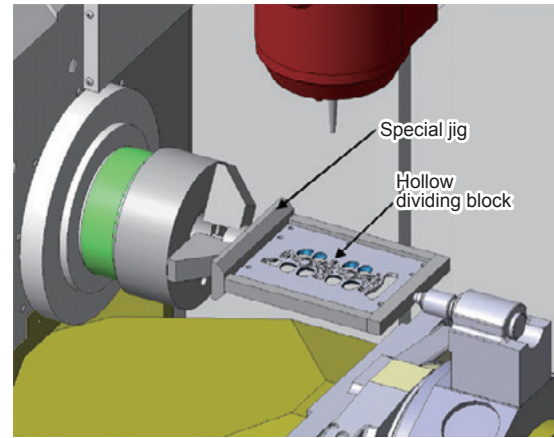


Fig. 7 Special jig for 5-axis integrated mill turn center

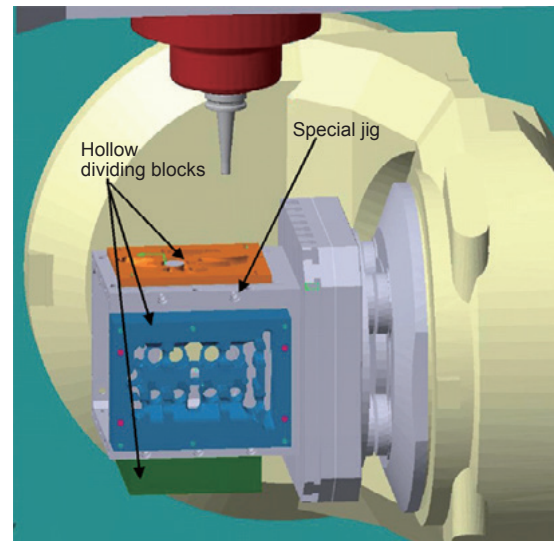


Fig. 8 Special jig for 5-axis machining center



Fig. 9 Final product

## Afterword

Schedule reduction is an issue that should always be addressed in quality manufacturing. This article used the example of a water-cooled cylinder head with a hollow construction part to introduce a rapid-trial production technique that incorporates buildup-brazing technology and rapid dividing and high-speed machining technology to determine how quickly the example product could be brought to use in a preliminary test. The surface contact pressure distribution analysis utilizing CAE, in particular, yielded knowhow about the use of reinforcement for the purpose of reducing deformation due to press during brazing. This provided a deeper understanding of how brazing quality could be enhanced. The intention is eventually to apply this understanding to preliminary tests of multi-cylinder engines.

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