

Development of Aluminum Alloy Rear-wheel Hub with Lightweight and High Strength for Off Road Motorcycles

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ABSTRACT

A rear-wheel hub with lightweight and high strength that satisfies the needs for motocross riding and contributes considerably to the vehicle mass reduction has been developed. To reduce material, a hollow structure is used in the thick section of the flange on the sprocket side of the wheel hub, which transmits driving force. The thin-wall design is employed in the straight, cylindrical section of the hub. To maintain necessary strength of the structural part, the die-casting method, which is most suitable for a thin-wall product, is applied. With regard to the casting, the inner structure quality is ensured by applying a molten metal treatment, reducing the amount of gas by evacuating the cavity and providing a squeezing function after plunger ejection. As for the material, an Al-Si-Mg alloy is employed and T5 heat treatment is applied. Thus, the yield strength is improved by 27% and the tensile strength is increased by 30% compared to the conventional material.

1. Introduction

Off road motorcycles for motocross-competitions run on uneven roads with jump sections and tight turns. Therefore, the motorcycles require light handling and high run-through performance. Large impacts, such as jumps when riding, are applied to the suspension parts, which require high strength that can carry these shocks. At the same time, weight reduction is also important in enhancing road-holding ability by reducing unsprung mass. The wheel hub sprocket side flange of off road motorcycles transmits the driving

force, so this section is subject to high loads. Therefore, reducing weight by employing a hollow shape for the thick section of the flange has been considered challenging. This development employed a new material with enhanced mechanical properties, an optimized casting design and casting conditions to allow the use of a hollow shape for the thick section of the sprocket flange side, and thin-walled straight cylindrical section. This resulted in a weight reduction of approximately 10%. Figure 1 shows the appearance of a motocross motorcycle applied to this new technology, and the developed wheel hub. This paper describes the material specifications, casting design, and casting conditions.

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Fig. 1 Appearance of CRF450R and developed wheel hub

2. Development Goals

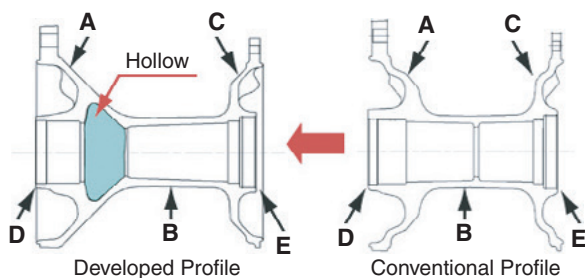
The two main development goals were as follows:

- (1) Reducing weight by 10% or more, to provide weight reduction effects compared to conventional specifications.
- (2) Provide endurance and reliability equivalent to wheel hubs manufactured using conventional manufacturing methods.

3. Technical Elements for Development

3.1. Part Structure

Rear wheel hubs manufactured by integrated molding using the aluminum die cast method are comprised of a cylindrical hub part through which the wheel axle passes, and a brake disk side flange and sprocket side flange, located on either end of this cylinder hollow in the axial direction. The sprocket side flange transmits the driving force, so it is subject to high loads and is normally thicker than the brake side flange on the opposite side. This thick section tends to increase the hub mass, so using a hollow structure for the thick section on the inside of the flange is an effective means of reducing the weight. Figure 2 shows the shapes of the conventional specification hub and the developed wheel hub. In the developed wheel hub, the section of the tapered part connecting the sprocket side flange and the straight cylindrical section has been increased and hollowed out by machining to form a large hollow structure. In addition, the straight cylindrical section uses a thinner new shape to reduce weight.



Profile	Thickness (mm)				
	A	B	C	D	E
Convention profile	4.8	5	6.2	6.3	3.5
Developed profile	3.4	4.75	4.4	4.2	2.5

Fig. 2 Comparison of developed profile and conventional profile

3.2. CAE Analysis

CAE is an effective method of early evaluations of function and performance, utilizing a three-dimensional CAD model, prior to manufacturing prototype parts. Stress analysis was performed by inputting a load to the new shape reduced weight wheel hub model under the assumption of use in an actual motorcycle. Figure 3 shows an example CAE analysis result. The shapes of the locations where high stress occurred were modified based on these results, and the required material strengths of the new shape were then obtained. These requirements were a yield strength of 185 MPa or more (15% increase over the conventional material) and a minimum tensile strength of 250 MPa (20% increase over the conventional material).

3.3 Manufacturing Method

The die cast method, which has high productivity and allows high accuracy for a thin part, was used as the manufacturing method for the developed wheel hub. However, the die cast method consists of injecting molten metal into a cavity at high speed, so gas inclusions occur more frequently than with gravity die casting (GDC) and low pressure die casting (LPDC). The developed wheel hub machines excess material away from the thick sections. This requires the hub to have higher internal quality compared to conventional parts, thus the following technologies were applied.

3.3.1. Molten metal treatment

- (1) Oxides were eliminated using flux to help achieve and ensure the molten metal quality. Figure 4 shows some oxide confirmation samples made by the K molding method. Here, no oxides were confirmed on the fracture surface.
- (2) Hydrogen gas was reduced by bubbling nitrogen gas, with the flow and time controlled. Figure 5 shows vacuum solidification samples produced under reduced pressure after bubbling. This enabled a reduction in the hydrogen gas level to 0.3 cm³ or less.

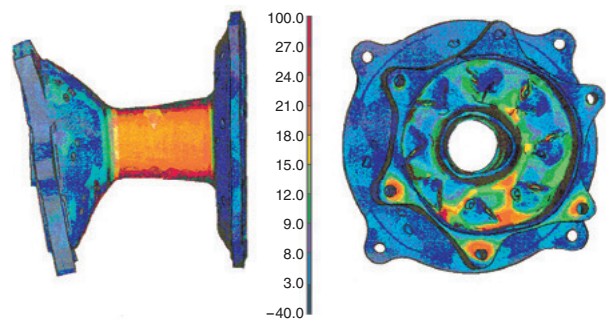


Fig. 3 Stress analysis result of wheel hub



Fig. 4 K-mold sample

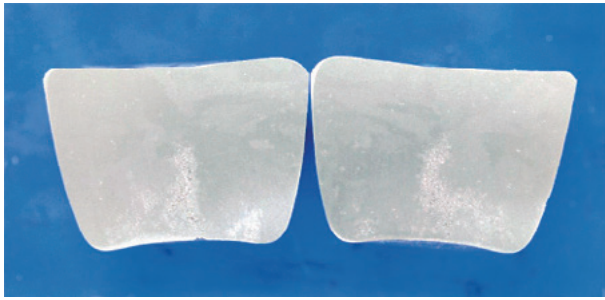


Fig. 5 Vacuum solidification sample

3.3.2. Casting technology

- (1) The injection sleeve used a ceramic sleeve with superior insulating properties, and the temperature was controlled using a heater to prevent rupture chill crystals. Injection sleeve lubrication used a powder lubricant with high molten metal heat insulation characteristics when compared to water soluble lubricants. This prevented a drop in the molten metal temperature.
- (2) The inside of the cavity was depressurized at the same time the die close operation was completed. This negative pressure enhanced the molten metal filling performance and prevented air inclusions when filling. Figure 6 shows the vacuum die casting system configuration.
- (3) The die design, which includes overflow positions, gate positions, gate area, and filling time, and casting conditions were optimized using casting simulations. Figure 7 shows the simulation results. Simulations of the molten metal flow were performed to investigate designs that resulted in an even filling pattern along the overflows. Simulations of gas inclusion were performed to create designs where the gas was driven into the overflows. Simulations of the molten metal temperature were used to determine the casting design and casting conditions that produced no misruns.

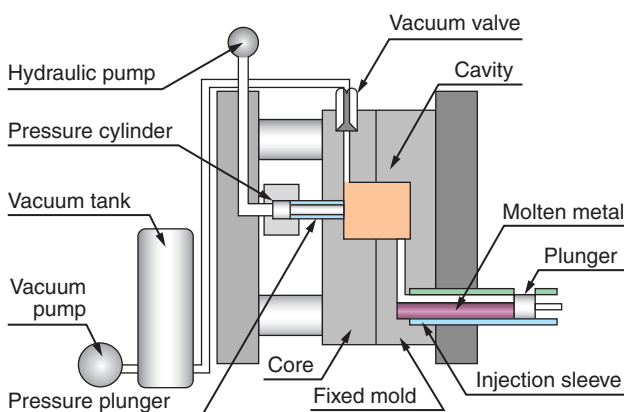


Fig. 6 Outline of vacuum die casting system

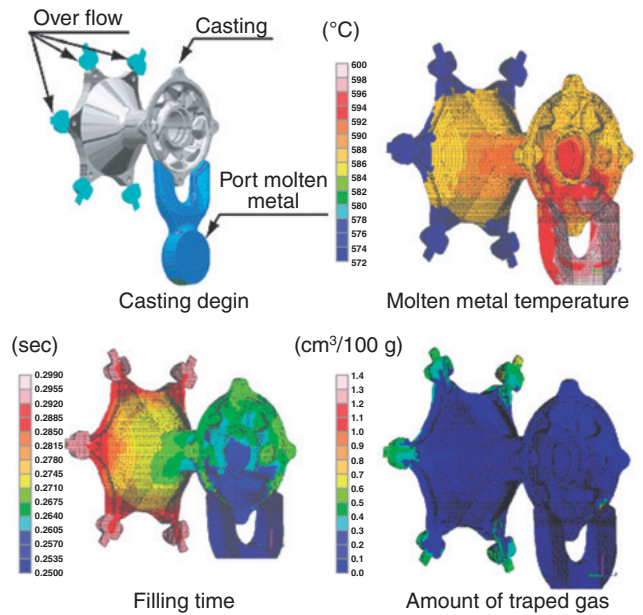


Fig. 7 Simulation of molten metal flow

- (4) The thick section of the sprocket side flange was squeezed after plunger ejection. This effectively pressurized the molten metal before solidification and reduced the occurrence of shrinkage cavities, blowholes and other casting imperfections.

3.4. Materials Specifications

New materials that specified the component ranges of alloys added to an Al-Si-Mg base were used to satisfy the required material strength of a lightweight wheel hub. Table 1 shows a comparison of the chemical composition.

Contents of additive compositions were as follows.

- (1) The Si content was set at 9.5 to 11.5% mass to provide good casting performance.
- (2) Fe is an effective element for preventing seizure to the metal die, but crystallizes acicular Al-Fe-Si compounds, which is a factor that impedes ductility. Therefore, the Fe content was set at 0.15% mass or less.
- (3) Mn 0.5 to 0.8% mass content was included to prevent metal die seizure due to the reduction in the Fe content.
- (4) Sr 0.01 to 0.02% mass content was included to refine the eutectic Si. Refinement of the eutectic Si is an effective means of enhancing elongation properties.
- (5) Adding Mg can increase the material strength by precipitating Mg_2Si during the aging treatment. Increasing the Mg content increases the yield strength but deteriorates ductility. Therefore, the Mg content was set at 0.4 to 0.5% mass in consideration of the balance between the yield strength and ductility required for a wheel hub.

Table 1 Chemical composition

	Si	Fe	Cu	Mn	Mg	Zn	Ti	Sr	P	Sn	Ni	Other
Developed alloy	9.5 - 11.5	≤0.15	≤0.03	0.5 - 0.8	0.15 - 0.50	≤0.07	0.04 - 0.15	0.010 - 0.015	≤0.001	—	—	≤0.10
Conventional alloy	8.5 - 11.0	≤1.0	1.0 - 2.5	≤0.3	≤0.2	≤1.0	—	—	—	—	≤0.3	—

Figure 8 shows the metallic structure of the developed alloy. The eutectic Si has been refined, and there are no acicular intermetallic compounds.

3.5. Heat Treatment

T5 heat treatment was used to obtain the necessary yield strength. In order to obtain the maximum effects with T5, quenching should be performed from high temperatures to create a super-saturated Mg solid solution and large amounts of Mg_2Si should be precipitated by artificial aging. Figure 9 shows the aging curves. Water quenching was used and the aging time conditions were set at 170 °C x 7 hours to obtain the maximum strength. Figure 10 shows the yield strength properties produced by the different quenching methods after casting. When aged at the same temperature, 170 °C, water quenching increased the yield strength by 10% compared to air quenching. This is thought to be because the rapid cooling during quenching increased the Mg solid solution amount, which provided effective age hardening. Compared to the F material, the yield strength increased 25% by using the water quench method. Figure 11 shows the relationship between time after removal from the die until water quenching and the yield strength. The yield strength was high when

quenching was performed shortly after removal from the die, and decreased as time until quenching increased. This is because the work temperature drops as time passes. In order to obtain the required strength, water cooling was performed within 10 seconds after removal from the die. The quenching tank was controlled to a temperature of 60 °C or less at all times in order to reliably obtain the required strength.

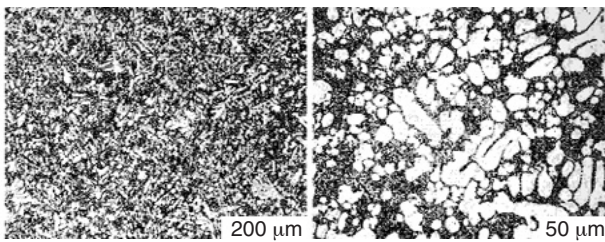


Fig. 8 Microstructure of developed material

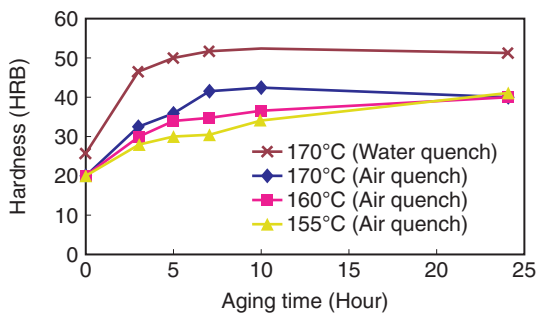


Fig. 9 Aging curve of developed material

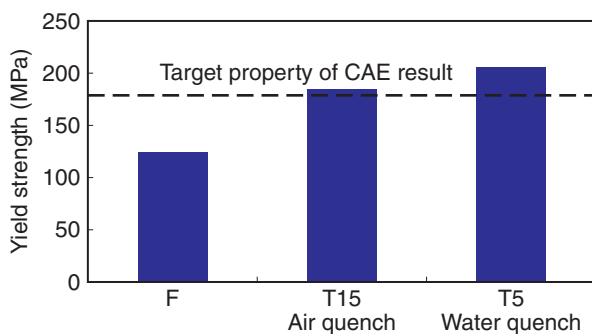


Fig. 10 Yield strength of each quench method

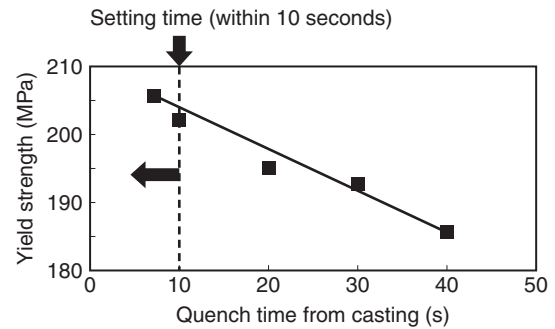


Fig. 11 Relationship between yield stress and quench time from casting

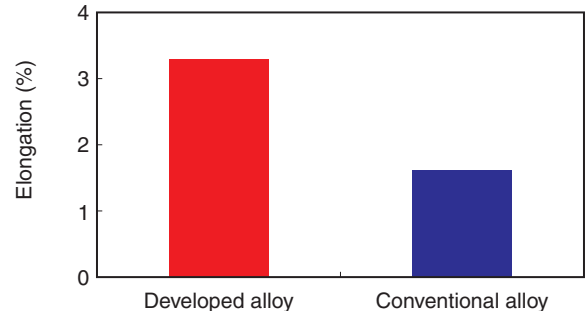
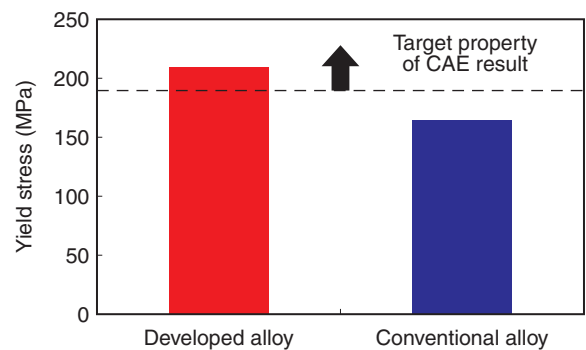
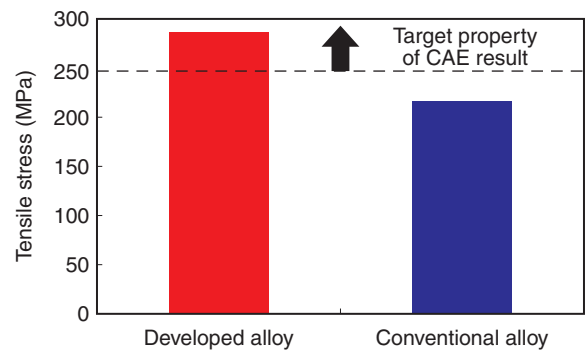


Fig. 12 Mechanical properties of developed alloy and conventional alloy

4. Test Results

Adopting the new shape reduced the mass from 1 065 grams for the conventional material, to 957 grams, for a weight reduction of 10.1%.

4.1. Mechanical Properties

Figure 12 shows the mechanical property results obtained. The developed material with the above specified heat treatment applied was able to achieve a yield strength of 206 MPa, a tensile strength of 286 MPa, and an elongation of 3.3%, which are increases of 27%, 30%, and 106%, respectively, when compared to the conventional material.

4.2. Internal Quality

Figure 13 shows internal quality of the wheel hub material. The internal quality obtained was the same high level as that of conventional die cast parts, including the thick section of the sprocket side flange and the straight cylindrical section.

4.3. Bending Fatigue Strength

Figure 14 shows fatigue curves for the developed and conventional materials. In motocross competitions the wheel hub receives a large load from jump landings on an order of 10^3 times, and the total over the life of a racing motorcycle is thought to be 10^5 times or less. The developed material shows a 10 to 15% increase in fatigue strength compared to the conventional material for a number of cycles from 10^3 to 10^6 times. Thus, the developed

material provides sufficient performance as a wheel hub for motocross motorcycles.

4.4. Torsional Endurance Test

Discrete torsional endurance tests to evaluate the number of cycles to fracture were conducted by fixing the sprocket with the spokes, wheel rim and sprocket attached to the wheel hub, and then applying a certain torque to the rim. As shown in Fig. 15, the number of cycles attained until the wheel hub fractured was approximately 70% higher for the developed material than for the conventional material.

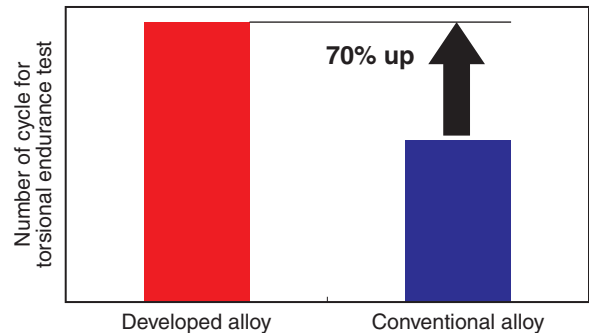


Fig. 15 Comparison of torsional endurance test results

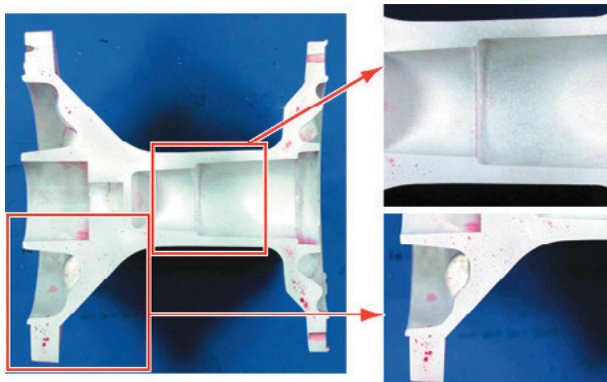


Fig. 13 Internal quality of wheel hub

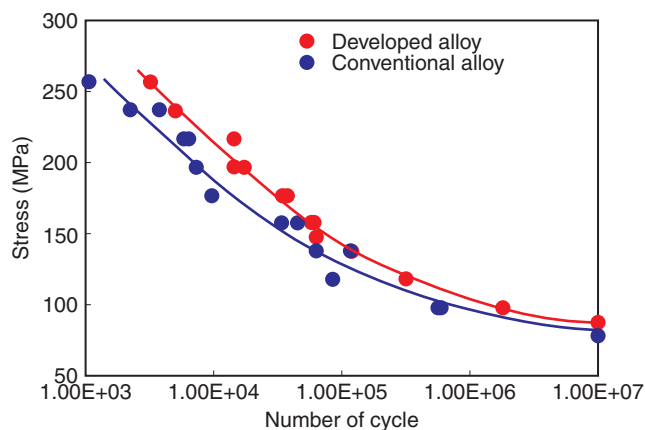


Fig. 14 Fatigue strength of developed alloy and conventional alloy

5. Conclusion

- (1) A reduction in the thickness of various wheel hub sections was achieved utilizing new materials, optimizing the heat treatment conditions and making use of the increase in strength.
- (2) Optimization of the casting design and casting conditions helped to realize good internal quality in the thick sections of the wheel hub, which allowed a hollow-machined shape. This enabled the development of a rear wheel hub with lightweight and high strength that achieved a weight reduction of 10.1% (-108 g) compared to the conventional part.

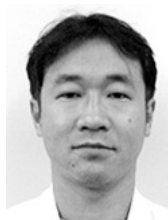
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References

- (1) Watanabe, S.: Jidousha Buhin you Kou Ensei Daikasuto Goukin no Kaihatsu, AI-arui, Dec, p. 13-17 (2002) (In Japanese)
- (2) Handbook of Advanced Aluminum Technology, Light Metal Publishing Co., Ltd
- (3) Kenkyu Houkoku 74 Daikasuto no Tyuzou Kekkan to Taisaku, Japan Foundry Engineering Society (1996) (In Japanese)

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