

Development of a Thin, Lightweight Aluminum Wheel by the Multi-gate LPDC Process

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ABSTRACT

The characteristics required for wheel function were clarified and a thin, lightweight aluminum wheel was developed. The method adopted to reduce wheel thickness involved improving the mechanical properties of the materials by modification of the die layout. In the newly developed die layout, the gates that are set at the periphery of the outer rim are positioned at the bottom of the slide die so that the number of gates, their locations, and their shapes can be changed freely as needed. This arrangement made it possible to reduce the thickness of the material and increase the cooling rate. The faster cooling rate resulted in a finer structure, yielding greater elongation, which improved the fatigue strength and increased the toughness of the material. As a result, the thickness of the product in the inner rim and spoke portions was reduced 25%, achieving a 10% reduction in the weight of the wheel. This also shortened the casting cycle time and eliminated the need for a straightening process, therefore improving productivity.

1. Introduction

Demand for aluminum wheels is increasing due to design and weight reduction needs. Die casting processes, which have a high degree of design freedom and allow low cost manufacturing account for the majority of aluminum wheels currently being manufactured. Of these methods, the low pressure die casting (LPDC) process ranks alongside the gravity die casting (GDC) process as a typical manufacturing process for die cast aluminum wheels. Demands to address environmental and energy issues are increasing, and further weight reduction is also required of aluminum wheels.

Against this background, the developed multi-gate LPDC process makes it possible to further reduce the thickness and

weight of aluminum wheels without major changes to the existing LPDC process facilities. At the same time, a higher productivity is also achieved by shortening the casting cycle time. These approaches toward weight reduction and the newly developed LPDC method are introduced below.

2. Weight Reduction for Aluminum Wheels

2.1. Characteristics Required of Aluminum Wheels

When investigating weight reduction for aluminum wheels, first the characteristics required of each part were clarified. Figure 1 shows the name of each wheel part.

In order to ensure the wheel functions of strength and

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endurance, bench tests such as that shown in Fig. 2⁽¹⁾ are generally used. These tests evaluate the characteristics required of wheels separately for each part.

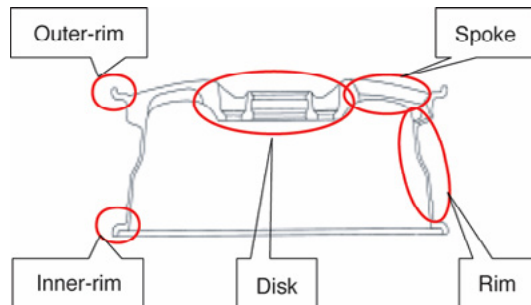
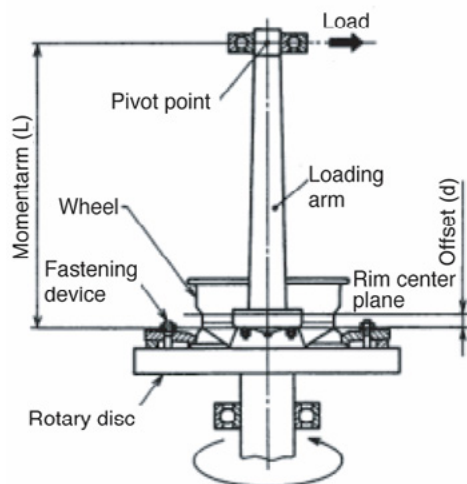


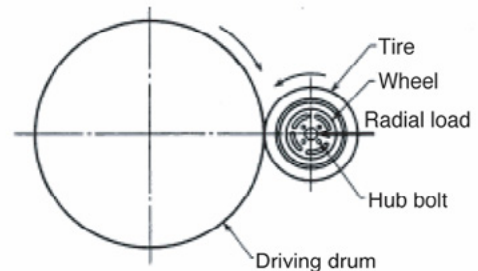
Fig. 1 The part name of the wheel

The rotary bending endurance test (Fig. 2-a) evaluates wheel endurance; it tests the fatigue strength for the area where the spokes meet the disk. The drum endurance test is used to evaluate the fatigue strength for the area where the spokes meet the disk as well as the rim as shown in Fig. 3-b. The drop impact test (Fig. 2-c) evaluates the impact resistance; it tests the toughness in the outer rim area and the area where the inner rim meets the rim as shown in Fig. 3-c.

When investigating thickness and weight reductions, the outer rim was excluded from thickness reductions due to a priority on styling and limitations of the tire bead assembly design. In addition, the disc was also excluded from thickness reductions due to limitations of the hub mounting layout. Therefore, investigation of thickness and weight reductions focused on the spokes, inner rim and rim.



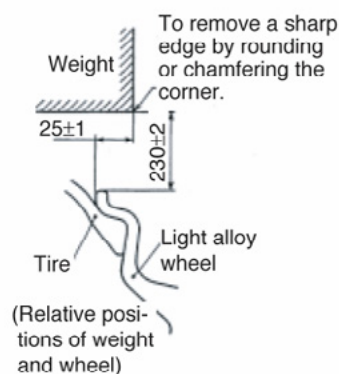
a) Bending endurance test apparatus (example)



Remarks 1 The width of the drum shall be provided with a surface flat and wider than the overall width of the tire to be used in the test of the wheel.

2 The diameter of the drum shall be, at least, 1700mm.

b) Radial load endurance test apparatus (example)



c) Impact test apparatus for passenger car (example)

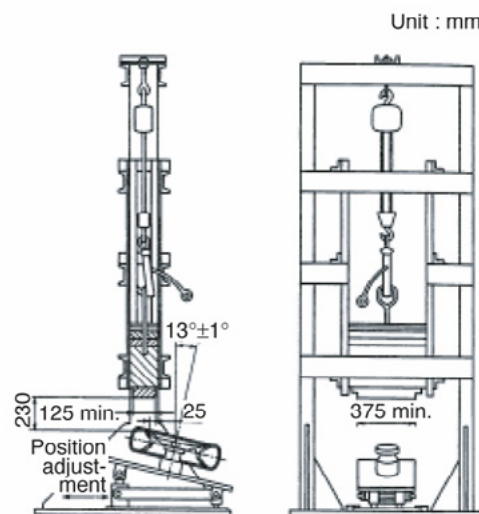


Fig. 2 Test apparatus for the wheel

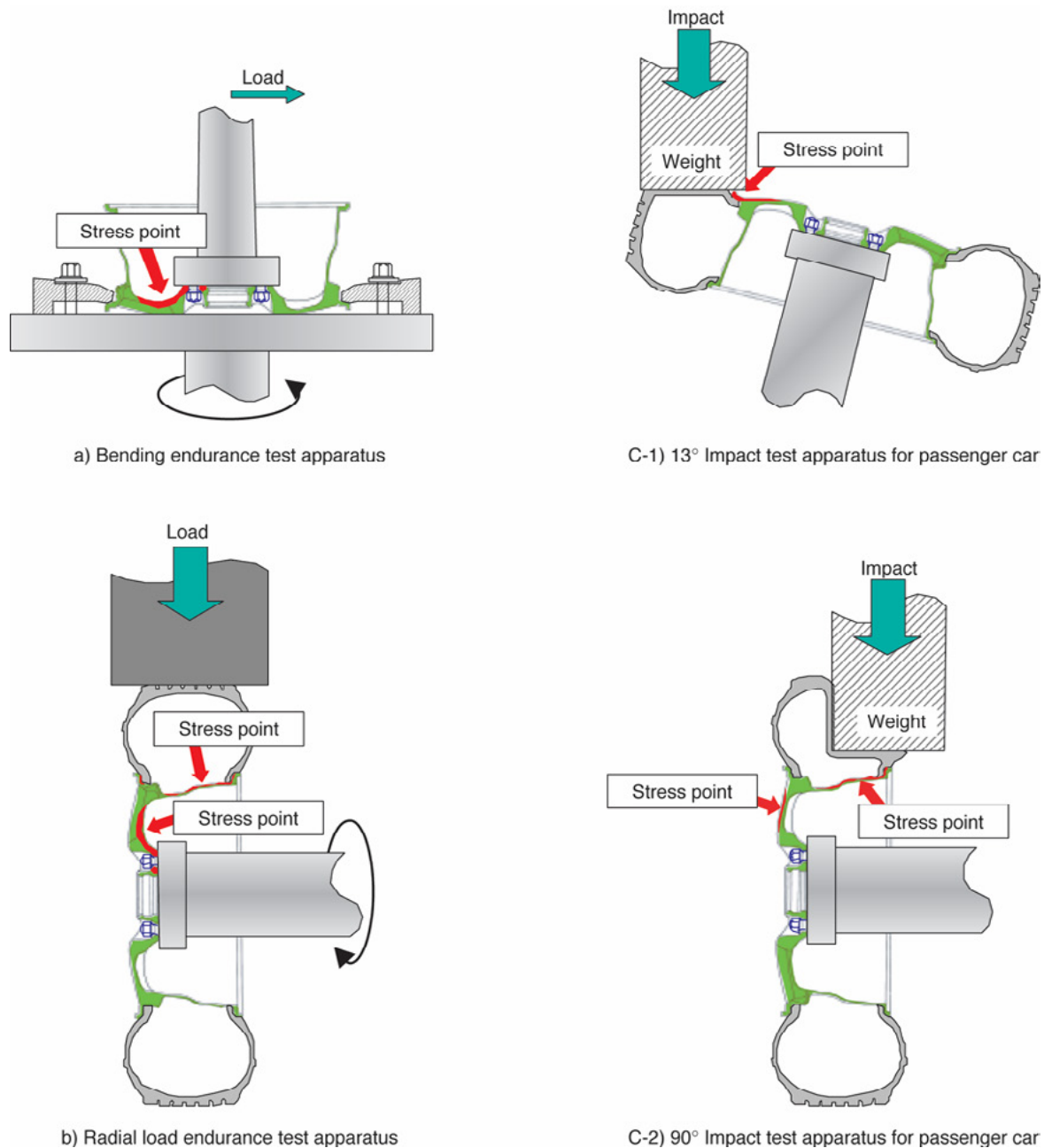


Fig. 3 Stress point by the wheel test apparatus

2.2. Improvement of Mechanical Properties

In order to reduce the thickness and weight while maintaining the wheel strength and endurance, it is essential to improve the mechanical properties of the materials.

This development assumed that the melting furnace and heat treatment furnace would be shared in order to utilize existing LPDC facilities. Therefore, the material used was the AC4CH-T6 material that is generally used for die cast aluminum wheels. Table 1 shows the typical chemical composition of the AC4CH material used in this development.

Refining the structure is known to be an effective method of improving the mechanical properties without changing the material or the heat treatment. The mechanical properties of elongation and impact energy value increase significantly as the dendrite arm spacing (hereafter "DAS II")⁽²⁾, which

represents the structure size, decreases⁽³⁾. This tendency is also clearly evident in the manufacture of aluminum wheels, with elongation increasing greatly as DAS II becomes finer as shown in Fig. 4. In addition, increasing the cooling rate results in a finer DAS II⁽⁴⁾, so increasing the cooling rate is an effective method for improving the mechanical properties.

Increasing the elongation normally leads to greater toughness, so using a finer DAS II to increase the elongation in the outer rim and area where the inner rim meets the rim is effective for improving the wheel performance in the drop impact test.

On the other hand, it has been reported that there is also a correlation between fatigue strength and elongation⁽⁵⁾. The test results in this development also showed a correlation between fatigue strength and elongation as shown in Fig. 5,

Table 1 AC4CH chemical composition

	(wt.%)					
	Cu	Si	Mg	Zn	Fe	Mn
JIS standard	0.20 Max	6.5 ~ 7.5	0.25 ~ 0.45	0.10 Max	0.20 Max	0.10 Max
A representative example	0.003	7.10	0.320	0.005	0.121	0.016
	Ni	Ti	Pb	Sn	Cr	Al
JIS standard	0.05 Max	0.20 Max	0.05 Max	0.05 Max	0.05 Max	Bal.
A representative example	0.005	0.120	0.005	0.000	0.001	Bal.

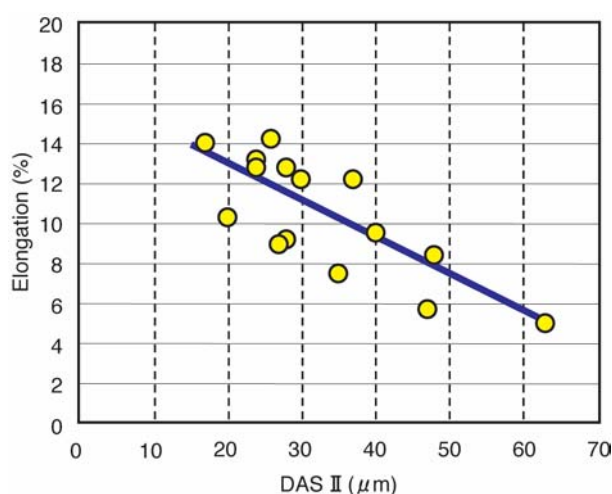


Fig. 4 Relation between DAS II and elongation of the Aluminum wheel

and the high cycle fatigue strength in particular was found to be more dependent on elongation than yield strength. The fatigue strength required for aluminum wheel durability is mainly the high cycle fatigue strength, so increasing the elongation is effective for improving aluminum wheel durability.

These results show that increasing the elongation for the area where the inner rim meets the rim and in the spokes is effective for reducing aluminum wheel weights. That is to say, efficient thickness and weight reduction can be achieved by increasing the cooling rate to improve the fatigue strength and toughness in these areas.

3. Issues for LPDC Process Aluminum Wheels

3.1. LPDC Process Issues

Using a finer DAS II is effective for improving the mechanical properties of die cast aluminum wheels including those made using the LPDC process, and to achieve this it is necessary to increase the cooling rate.

Figure 6-a shows schematic drawings of the center-gate systems most commonly used with the aluminum wheel LPDC process. The center-gate LPDC process uses a system that fills the entire product with molten metal from a single

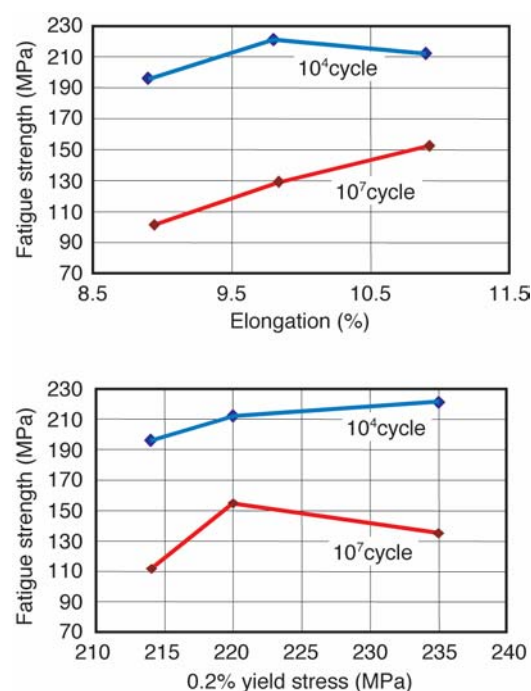


Fig. 5 Relation between fatigue strength and 0.2% yield strength/elongation

gate located in the center of the wheel. This requires a thick section to ensure metal flow and also directional solidification for excellent internal quality. This thick section not only lowers the cooling rate, but also increases the molten metal filling time.

The side-gate system shown in Fig. 6-b provides gates in two locations on the rim in order to increase the cooling rate compared to the center-gate system. However, there is a limit to how thin the section can be made due to the need to ensure metal flow from the rim to the center portion of the disc.

3.2. Conventional Multi-gate LPDC Process

Using multiple gates has been considered as an improvement method that both increases the cooling rate and shortens the filling time in the LPDC process. Figure 7 shows an example that further expands the above-mentioned side-gate system to pursue the merits of multiple gates. Molten metal is filled from four gates located on the outer

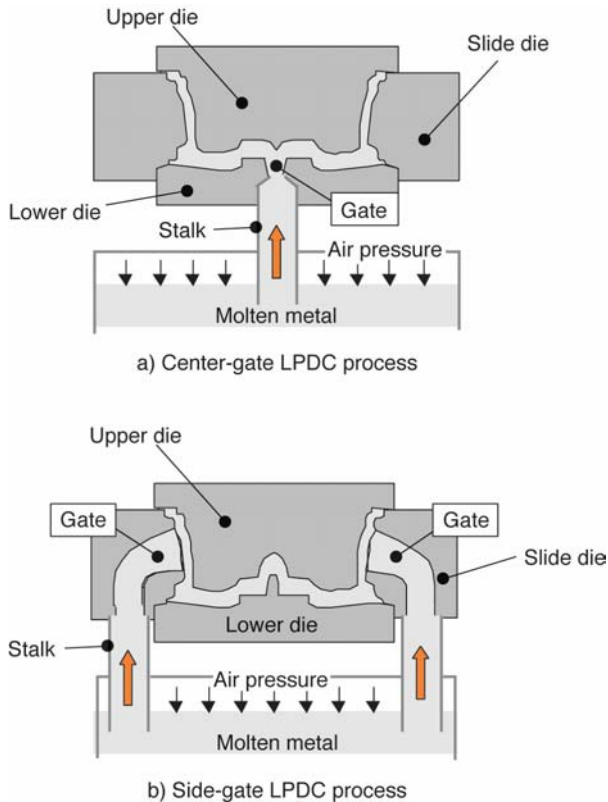


Fig. 6 Schematic illustration of the LPDC process

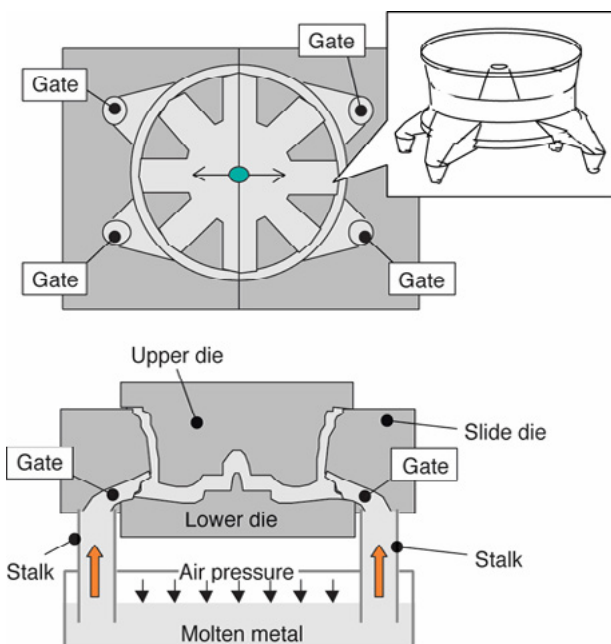


Fig. 7 4-gate LPDC process

rim, so metal flow is easily ensured and a thin section can be used. As a result, the cooling rate can be increased and at the same time the die filling time is also shortened, so this is expected to improve both the mechanical properties and productivity.

However, when using multiple gates with the

conventional LPDC process, there are numerous limitations on the gate positions, such as number and shape in order to avoid interfering with the sliding motion of the slide die when the gating system opens. This meant that conventional multi-gate systems had to be designed in full consideration of productivity. This was a major issue for the LPDC process, which offers a superior degree of design freedom, and is why there are few examples of mass production using a multi-gate system.

Thus, the issues for reducing the weight of LPDC process aluminum wheels can be summarized as follows.

- The thick section makes it impossible to increase the cooling rate, which is a factor hindering improvement of both mechanical properties and productivity.
- Using multiple gates has been attempted as an improvement measure, but the gate settings are subject to limitations, so these effects were insufficient.

4. New Multi-gate LPDC Process

4.1. Overview of the New Multi-gate LPDC Process

The new multi-gate LPDC process was developed as a new process that is capable of solving the above-mentioned issues for wheels produced by the LPDC process. Figure 8 shows a schematic drawing of the new multi-gate LPDC process.

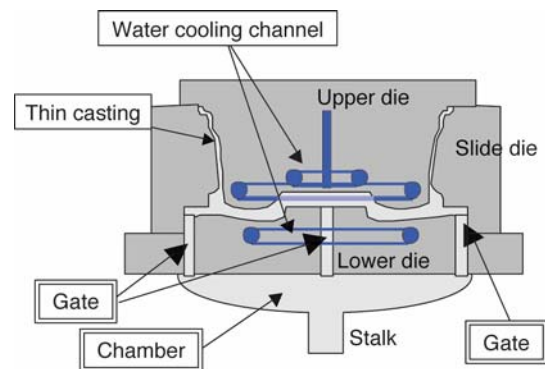


Fig. 8 New multi-gate LPDC process

This multi-gate system allows sliding without the gates interfering with slide die separation by using the bottom surface of the slide dies as the upper surface of the gates that are set at the periphery of the outer rim as shown in Fig. 9. As a result, the gate positions and the number of gates can be set freely as needed, thus improving metal flow which was an issue for using multiple gates with the LPDC process. In addition, in order to use multiple gates freely in the desired locations, a chamber was provided between the stalk and the die, allowing molten metal to be supplied to each gate without increasing the number of stalks. Furthermore, a high cooling rate was obtained by enhancing the water cooling capability of the upper die in order to reduce DAS II.

This new multi-gate system makes it possible to shorten

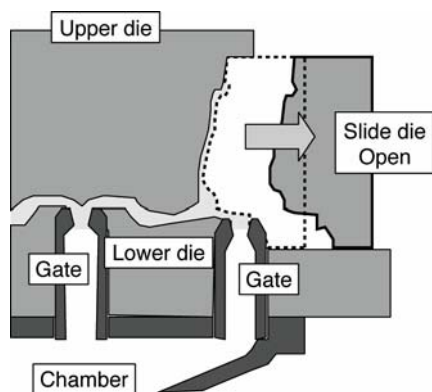


Fig. 9 Gating system of new multi-gate LPDC process



a) New multi-gate LPDC process

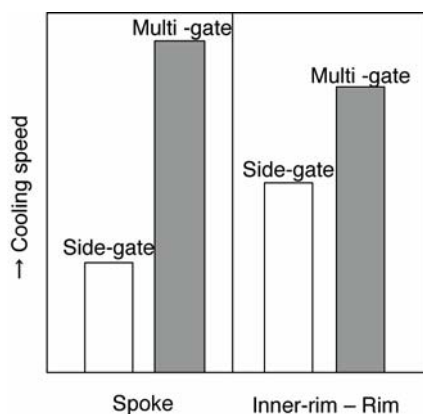


Fig. 10 Comparison of cooling speed



b) Side-gate LPDC process

Fig. 11 The section of the castings by LPDC process

the molten metal flow length, ensuring sufficient metal flow even when a thin section is used compared to the side-gate system. The use of thin sections and improved die cooling capability achieved a cooling rate approximately three times faster in the spokes. (Fig. 10)

Using this type of process made it possible to improve the mechanical properties by reducing DAS II.

4.2. Weight Reduction Effects of the New Multi-gate LPDC Process

Figures 11-a) and 11-b) show section photographs of castings manufactured using the new multi-gate LPDC system and the side-gate LPDC system. Compared to the side-gate LPDC system, the new multi-gate LPDC system reduced the material thickness of a 15-inch $\times$ 6.5 JJ aluminum wheel by 33% in the rim and 25% in the spokes, and also reduced the casting weight by 37%.

The non-material effects of the new multi-gate LPDC system are described below in comparison with the side-gate LPDC system.

4.2.1. Mechanical properties

Figure 12 shows the refinement effects on the DAS II size, which is important for improving toughness in order to reduce weights.

The area where the inner rim meets the rim and the spokes provide large weight reduction effects, and DAS II refinement effects of approximately 30% and 20%, respectively, were seen in these areas. As a result, elongation also increased by approximately 50% and 70%, respectively.

4.2.2. Weight reduction effects

These improvements in toughness made it possible to reduce the product thickness by 25% in the spokes and by 7% to 25% in the rim as shown in Fig. 13. This made it possible to reduce the total product weight by 10% without sacrificing strength performance.

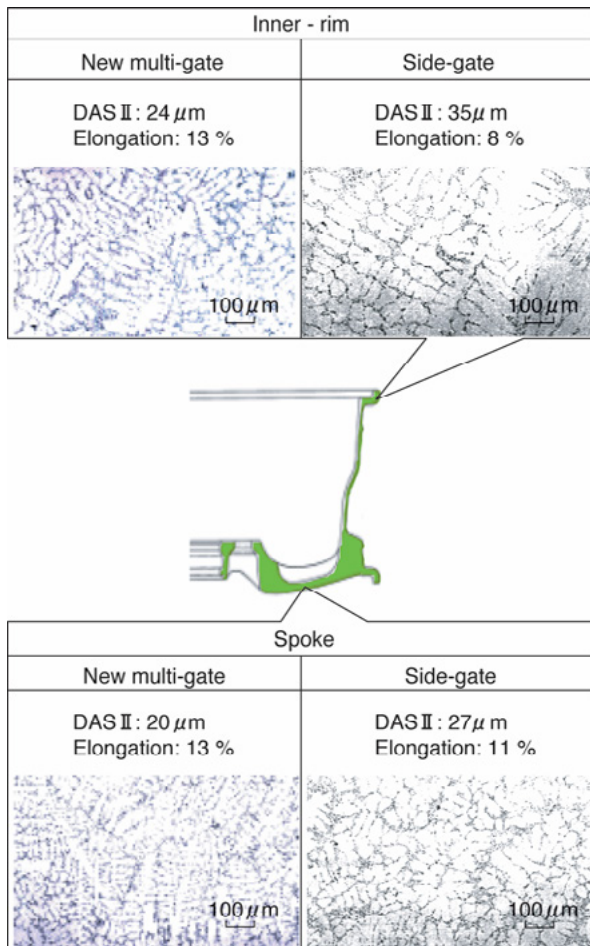


Fig. 12 Relation between DAS II and elongation

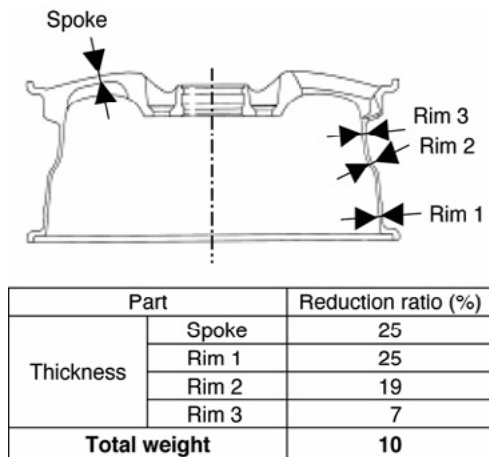


Fig. 13 Comparison of the thickness

4.3. Improvement of Productivity

In addition to the effects described above, the new multi-gate LPDC process also produced the following effects related to productivity.

4.3.1. Cycle time

Figure 14 shows the casting cycle time reduction effects. The long casting cycle time is a major issue related to LPDC

process productivity. In particular, the long die filling time and cooling time are the main factors.

The new multi-gate LPDC process has a thin section, reduced casting weight and short cooling time. This means that of the casting processes from the pressure rise process to the clamping process, the filling, feeding and cooling process times are shortened, thus shortening the total time to 75% of the conventional casting cycle time.

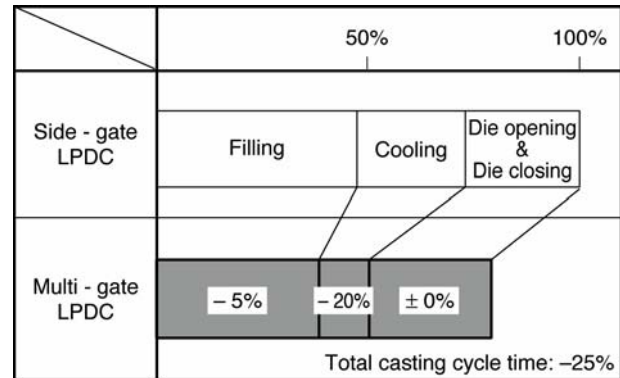


Fig. 14 Comparison of the thickness

4.3.2. Other effects

The multi-gate system also reduced the temperature gradients during solidification, thus effectively reducing the residual strain induced during solidification. This eliminated the need for a straightening process after casting which had been necessary for the LPDC process thus far.

5. Conclusion

Aluminum wheels manufactured using the new multi-gate LPDC process take advantage of the gates located at the periphery of the outer rim positioned at the bottom of the slide die, so the gates can be freely designed as needed, and the thickness of the material can be reduced. This has provided the following results.

- (1) An increased cooling rate produced a finer structure, which improved the mechanical properties. As a result, the thickness in the inner rim and spoke portions was reduced by 25%, achieving a 10% reduction in the total weight.
- (2) A 25% reduction in the casting cycle time and elimination of the straightening process improved productivity.

This paper described the new process using the example of a 15-inch $\times$ 6.5 JJ size wheel, so these results will vary depending on the wheel size and design. Recent wheels are tending toward larger diameters, so application of this multi-gate LPDC process can be expected to provide even greater weight reduction effects in the future.

6. Acknowledgements

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