

Development of One-piece Reverse Rim Aluminum Alloy Wheel Using Flowforming Process

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ABSTRACT

In an attempt to increase freedom of design in automobiles, a method of manufacturing aluminum wheels with a reverse rim configuration that realizes lower weight and lower cost has been developed. The configuration of the molds and the machining process for the rim in the GDC flowforming process were modified, and the machining method and machining conditions were optimized. This made one-piece manufacture of reverse rim wheels possible. CAE analysis verified that by converting wheels to reverse rim types, it would be possible to reduce the excessive thickness between the disk surface and the bead drop area of the wheel, reducing the weight of wheels of 18 inches or more in diameter by 5% or more. Next, a prototype of an 18-inch wheel was produced, and it was verified that its weight was reduced in accordance with CAE results. In addition, a prototype of a wheel employed in sports-type vehicles was produced, and it was verified that a weight reduction of 2% or more had been achieved despite the fact that the wheel had been designed to realize reduced weight.

1. Introduction

Aluminum wheels possessing a variety of designs are sold in large numbers by automobile accessory stores and the like as a product that boosts the exterior aesthetics of the vehicle⁽¹⁾. Seeking to customize their vehicles, many users increase (“inch-up”) the wheel size in order to boost freedom of design through the realization of increased diameter.

However, if the wheel is inched-up without changing the external diameter of the tire, the lateral force characteristic on the tire changes due to the tire’s flatness and high internal pressure, and vibration isolation performance also declines⁽²⁾. In addition, if the size of the wheel is increased by one inch, the weight of the wheel generally increases, and acceleration performance and fuel efficiency decline. The increased use of aluminum materials also increases materials costs.

The reverse rim wheel is one of the shapes employed in aluminum wheels. In the case of this wheel, the spokes can be made to appear longer by reversing the shape from the interior to the exterior of the rim and increasing the interior diameter of the exterior of the rim.

However, because it is necessary to manufacture

reverse rim wheels by first splitting and then rejoining the wheel and rim, they are heavier and more expensive than integrally molded aluminum wheels.

The authors therefore developed a method of integrally manufacturing reverse rim wheels by modifying the manufacturing method for mass-produced aluminum wheels.

Figure 1 shows a normal rim wheel and a reverse rim wheel of the same design. As the figure shows, reversing



Fig. 1 Appearance of normal rim wheel and reverse rim wheel

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the rim creates a design like an inch-up wheel. In addition, because it is possible to also reduce excessive thickness, despite the fact that the two wheels have the same design and are the same size, it has been possible to reduce the weight of the reverse rim wheel.

Below, the manufacturing method for reverse rim wheels will be introduced.

2. Overview of Reverse Rim Wheels

First, the structure of the wheel rims will be discussed. Figure 2 shows an external view of the machine that fits the tire to the wheel. Figure 3 shows the process of fitting of the tire, until the tire is mounted on the wheel.

In the process of fitting the tire, the wheel is first fixed to the rotary table of the tire changer machine, the tire is



Fig. 2 Tire changer machine

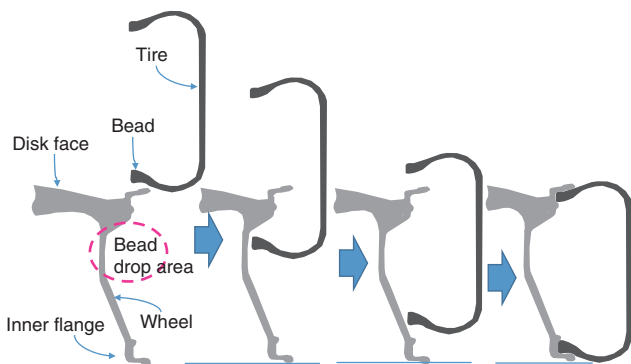


Fig. 3 Tire assembly procedure for normal rim wheel

positioned on it, and the work is performed. In order to allow passage for the tire bead, which is smaller than the external diameter of the wheel rim, a bead drop area with a narrower inner diameter is engineered into the wheel.

Wheels in which this bead drop area is positioned close to the disk surface are termed normal wheels. Wheels in which the bead drop area is positioned on the inner flange side, the side opposite to the disk surface, are termed reverse rim wheels. In the case of reverse rim wheels, the tire is fitted from the inner flange side, in the opposite fashion to normal wheels.

Figure 4 shows cross-sections of the structures of normal rim wheels and reverse rim wheels. In the case of (a), the normal rim wheel, the abovementioned bead drop area is positioned close to the disk that forms the design surface. This constricts the design section, and has an effect on freedom of design. By contrast, in the case of (b), the reverse rim wheel, by distancing the section of the rim with the lowest diameter from the disk, any effect on the design section is done away with, enabling the disk to appear larger.

However, because in reverse rim wheels an undercut is produced in the rim by the bead drop area, as shown in Fig. 4(b), the rims are manufactured by splitting parts into two or three and rejoining them by welding or bolting, which increases manufacturing costs.

It was therefore proposed to realize a manufacturing technology that would allow production of reverse rim wheels at the same cost as mass-produced normal rim wheels by modifying manufacturing equipment for mass-produced aluminum wheels to manufacture reverse rim wheels in a one-piece configuration.

In addition, as Fig. 5 shows, in a reverse rim wheel it is possible to reduce the excessive thickness between the disk surface and the bead drop area in a normal rim wheel.

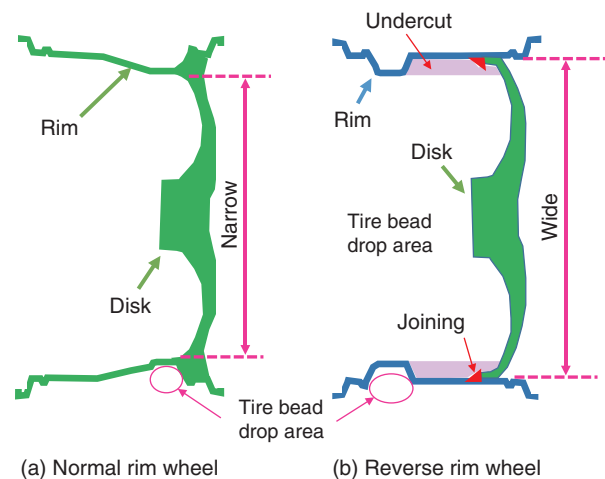


Fig. 4 Sectional view of normal rim wheel and reverse rim wheel

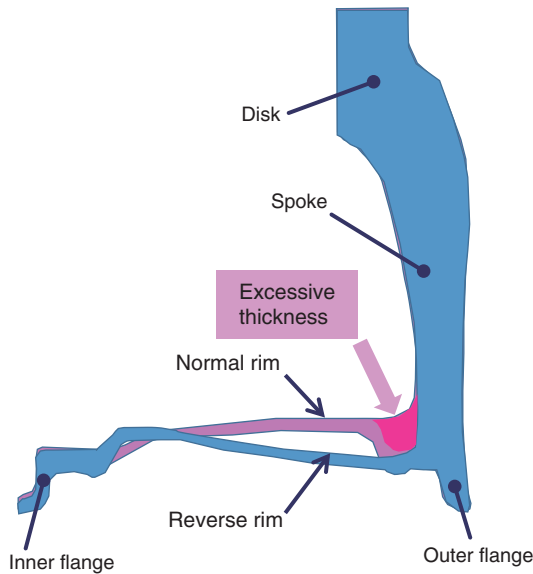


Fig. 5 Image of weight reduction

3. Manufacturing Method for Conventional Aluminum Wheels

The wheels are important parts that transmit input from the road surface to the vehicle body. The wheel and the tire make contact on both sides of the outer flange and the inner flange. Because the outer flange is close to the design surface, it displays a high level of stiffness. The stiffness of the inner flange, however, is low and load stress is therefore high, and because of this it is important to stabilize strength and quality.

The use of increasing wheel diameters in recent years has made the inner flange a section for which it is still more necessary to increase strength and toughness and give attention to quality management.

Aluminum wheels can be manufactured by both forging and casting processes. Forged parts are very strong, but their manufacture is high in cost. Because of this, casting is normally employed in the manufacture of aluminum wheels for mass-production vehicles.

There are two methods employed for this casting process: Low-pressure die cast (LPDC) and gravity die cast (GDC).

Figure 6 shows the LPDC manufacturing process. Because the inner flange, a part requiring strength, is distant from the gate through which the molten metal is introduced to the mold, the molten metal solidifies rapidly, producing fine grain sizes in the aluminum alloy, which increases strength.

Figure 7 shows the GDC manufacturing process. When employing GDC, casting can be performed using simpler equipment than LPDC, but because the molten metal is introduced from the inner flange, solidification is slow,

and the crystal grains increase in size. As a result, it is not possible to realize the same level of strength and toughness as LPDC⁽³⁾.

In the GDC manufacturing process, therefore, a flowforming machine is installed after the casting line. After the casting of the aluminum wheel material (preform), the material is again preheated, and the strength and toughness

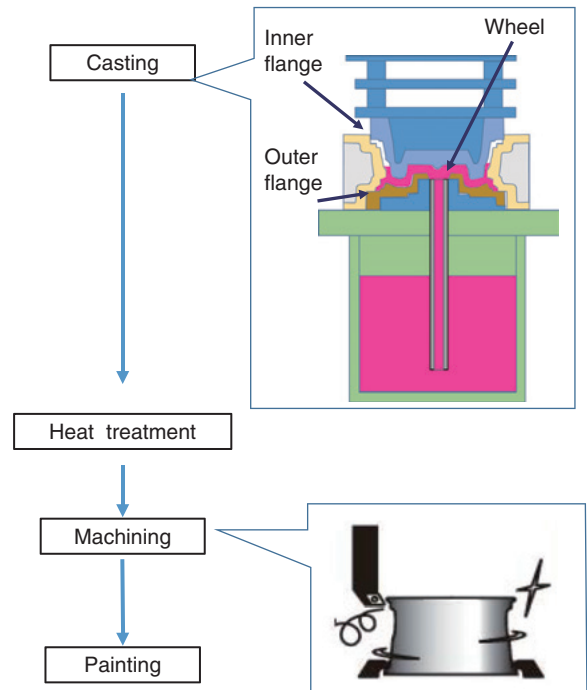


Fig. 6 LPDC production process

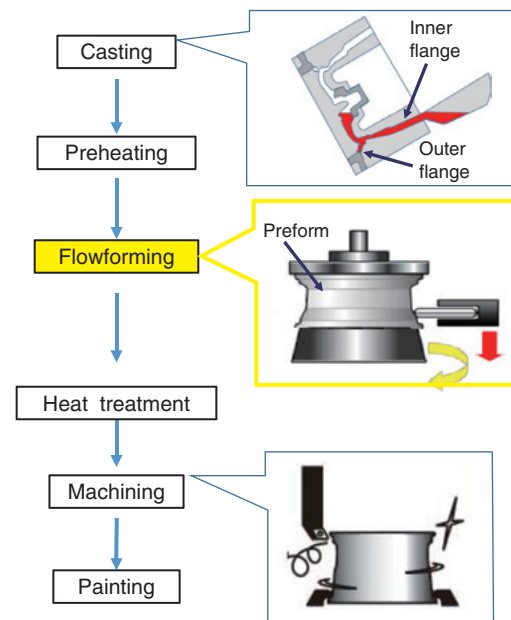


Fig. 7 GDC production process

of the inner flange are increased by deformation processing.

Figure 8 shows the flowforming manufacturing process. The preheated preform is molded by pressing the disk surface into the flowforming machine using the upper plate, fixing it in place, and rotating it using rollers that rotate from the exterior while pressing it against the mandrel. This process makes it possible to obtain the necessary strength and toughness in the inner flange.

In both manufacturing processes, following molding, a heat treatment is again applied, and machining and coating are performed in order to finish the product.

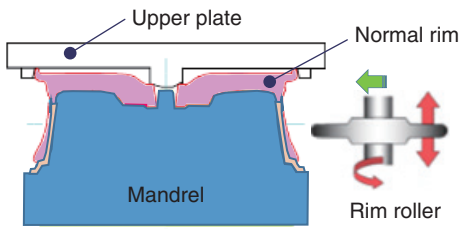


Fig. 8 Flowforming for normal rim wheel

4. Manufacturing Method for Reverse Rim Wheel

4.1. Rim Molding Method Using Flowforming

Because the reverse rim shape has an undercut section, the amount of machining increases when using LPDC, and the yield declines. In addition, in order to reduce cost increases, it is desirable to utilize standard equipment and processes without modification as much as possible.

The development discussed in this paper, therefore, selected GDC as the manufacturing method to mold the undercut section with a modification of part of the flowforming equipment and processes.

In order to mold a shape with a narrowed inner flange side on the same manufacturing line as conventional shapes, a method was considered in which a material that has the inner flange side open to the exterior is produced as usual at the casting stage, and a reverse taper is molded in the following stage using flowforming.

In conventional flowforming, because the section subject to ironing processing is constantly in contact with the mandrel, the center of the wheel does not deviate, enabling processing to be performed using a single roller on one side.

However, because in the case of a reverse rim wheel there is part of the section being processed that is not in contact with the mandrel, under a load from a single direction the rim becomes eccentric, hindering processing.

In order to reduce rim eccentricity during processing, a method employing two opposed rollers to apply a load to both sides simultaneously was proposed, as shown in Fig. 9.

Figure 10 shows the mandrel and rollers of the

prototype processing machine with the two opposed rollers positioned so as to be symmetrical in relation to the central axis of the mandrel.

Figure 11 shows the status of flowform processing using the prototype machine.

4.2. Setting of Optimum Processing Conditions

The control items for flowform processing conditions for mass-produced normal rim wheels include processing temperature and roller ironing conditions. In flowform

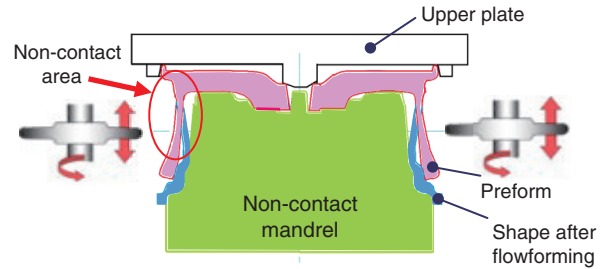


Fig. 9 Non-contact mandrel for reverse rim wheel

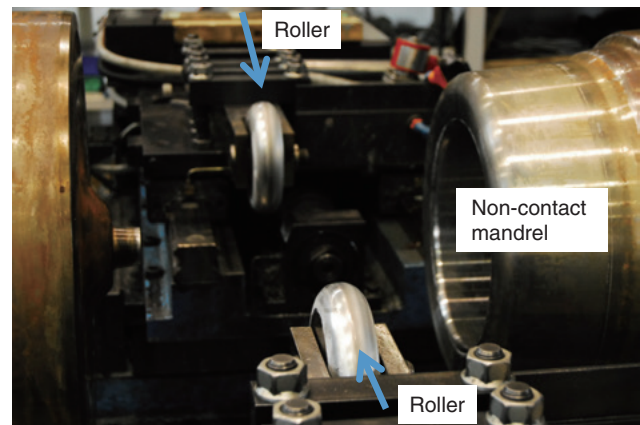


Fig. 10 Proposed test machine for flowforming

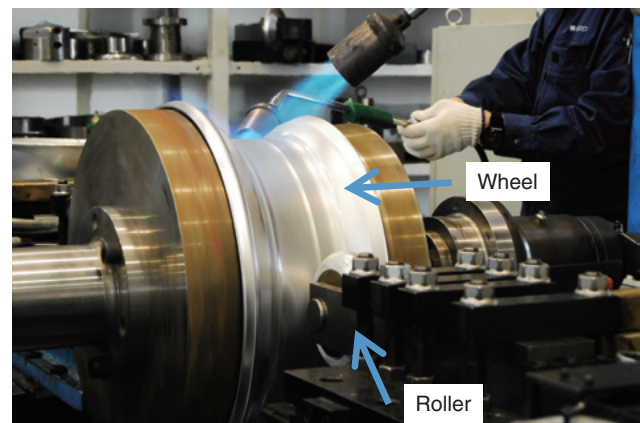


Fig. 11 Flowforming trial using two rollers

processing, costs can be reduced by using enormous loads during molding to reduce the number of roller applications. However, because there are areas that do not make contact between the reverse rim preform and the mandrel, if excessive loads are applied to the rollers, considerable strain is generated in the rim and cracks form in the part.

In order to respond to these issues, it is necessary, having taken into consideration the capacity of the equipment, to perform flowform processing while controlling the load.

The two related items, processing temperature and the number of roller ironings, were therefore focused on, and conditions were optimized.

First, the setting of processing temperature will be discussed. The preheating temperature of the casting material during flowform processing is an important factor in reducing the roller pushing load during processing. Figure 12 shows high-temperature material characteristics determined using a test piece cut from a JIS AC4CH (the aluminum alloy employed in wheels) aluminum alloy wheel. The yield strength of AC4CH aluminum alloy declines with increasing temperature, while elongation displays the opposite tendency⁽⁴⁾.

Because the flowform processing temperature for mass-produced normal rim wheels is around 300°C, a test using a flowformed prototype was conducted at this temperature. As shown in Fig. 13(a), cracks formed in the inner circumference of the rim. Based on the results of this preliminary test, flowform processing was conducted at 400°C, at which yield strength is approximately halved and elongation is doubled, and here, no cracks appeared in the rim.

In order to help prevent cracks from occurring and verify the optimum processing temperature range with consideration of mass production, processing tests were conducted at various temperatures. Table 1 shows test results for each temperature. At temperatures of 380°C and higher, no cracks occurred, but when the temperature became too high, there was a significant decline in material strength, and there was concern that the wheel material

Table 1 Test results of temperatures

Temperature	300°C	350°C	380°C	400°C	420°C	450°C
Result	Crack	Crack	No crack	No crack	No crack	No crack

would be deformed when retrieved from the preheating furnace or by transport robot chucking during transport or when set in the mandrel, which would be undesirable in terms of mass production; 400°C was therefore set as the temperature condition.

Next, tests were conducted in order to determine the optimum number of times for ironing of the rim by the rollers. In the case of flowform processing of mass-produced normal rim wheels, the roller responsible for forming the rough shape irons the rim one or two times and the roller responsible for forming the inner flange rolls the rim once, completing the process in a total of two or three ironings. By contrast, in the case of flowform processing for a reverse rim wheel, because it is necessary to process the abovementioned sections that do not make contact with the mandrel bit by bit, the number of ironings increases. Prototype tests were then conducted, varying the setting for the number of ironings. Figure 14 shows the trajectory of roller motion.

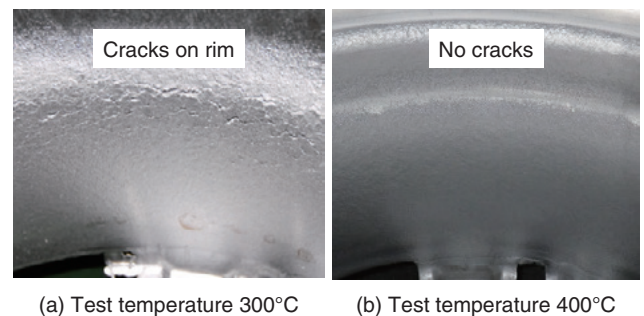


Fig. 13 Interior of rim after flowforming process

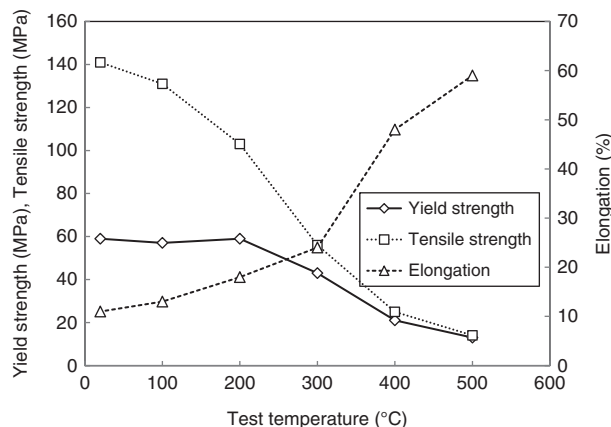


Fig. 12 Mechanical properties of JIS AC4CH

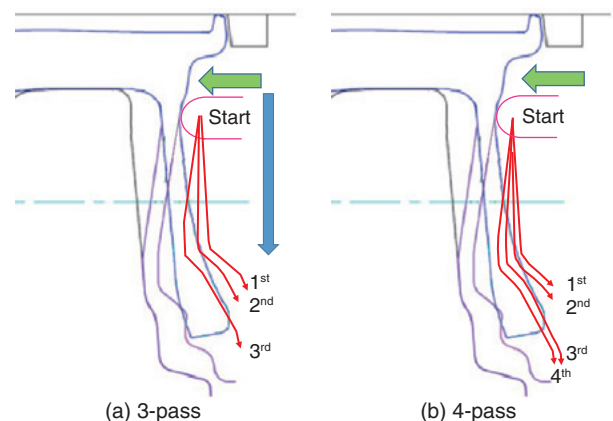


Fig. 14 Motion of roller while flowforming

The rollers applied loads from the start position in the direction of the green arrows, while moving in the direction of the blue arrows along the trajectories represented by the red lines. Processing was performed at various trajectories in order to disperse strain. At three ironings, the degree of processing per ironing was too high, and cracks appeared in the inner surface of the rim. By performing four ironings, however, it was possible to control the occurrence of cracks.

As the above results indicate, modifying the flowform processing method and optimizing the processing conditions enabled the creation of a production technology that would manufacture reverse rim wheels at the same cost as mass-produced normal rim wheels.

5. Verification of Effects

5.1. Prediction of Effect on External Appearance and Weight Reduction using CAE

Figure 15 shows the results of calculations, using 3D models, for the conversion of four wheels of differing sizes and designs into reverse rim wheels.

For all of the products, the conversion to a reverse rim type made the wheel look larger in diameter while reducing the weight of the wheel.

In the case of wheels A, B, and C, which had standard designs, the effect of weight reduction became greater as the size of the wheel increased.

For example, SUV tend to have large-diameter wheels due to their massive bodies. By using reverse rim wheels, the wheels will appear larger without inching up, and both

the weight reduction realized by inching up and the weight reduction realized by changing to a reverse rim wheel of the same size can be expected.

In addition, in the case of wheel D, a lightweight wheel developed with the aim of reducing weight, it was possible to realize a further reduction in weight by conversion to a reverse rim type.

5.2. Verification of Reverse Rim Wheels in Actual Vehicle

The CAE results for the effect of the reverse rim wheels were verified using models A and D in Fig. 15. Model A visually appeared larger in diameter, as shown in Fig. 1. In addition, the weight of the wheel was 650 g lighter than a normal rim wheel, matching the effect predicted by CAE results.

Wheel D, the lightweight model, is the wheel used in the 2015 model year Civic Type-R (size: 19 inches x 8.5 J). Figure 16 shows the reverse rim version of this wheel. In the reverse rim type, the spokes increased in length to 464 mm from the 440 mm of the normal rim type, and appeared approximately 1 inch longer.

The conversion to reverse rim types increased the interior space of the wheel, giving the wheel a sporty impression. Figure 17 shows the wheels mounted on an actual vehicle.

Size	Normal rim wheel	Reverse rim wheel	Weight reduction
Wheel A 18 × 7.5J	 12.40 kg	 11.75 kg	-0.65 kg -5.24%
Wheel B 19 × 8.0J	 13.56 kg	 12.48 kg	-1.08 kg -7.96%
Wheel C 20 × 8.5J	 15.08 kg	 13.95 kg	-1.13 kg -7.49%
Lightweight wheel D 19 × 8.5J	 11.91 kg	 11.66 kg	-0.25 kg -2.10%

Fig. 15 CAE results for appearance and weight

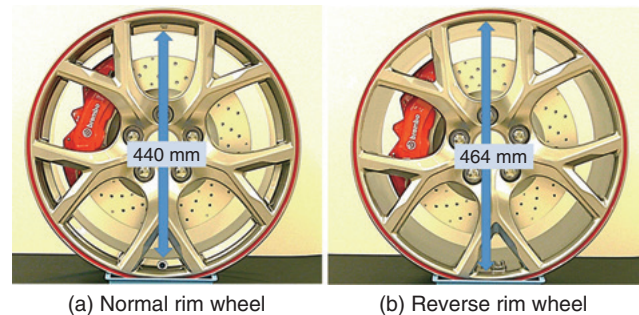


Fig. 16 Appearance of normal rim wheel and reverse rim wheel



Fig. 17 Reverse rim wheel on sport type car

It was possible to reduce weight by 250 g per wheel, matching the results of the CAE analysis.

Figure 18 shows the sections in which weight was reduced through the application of reverse rim wheels. The green section shows the section in which weight was reduced. Despite the fact that the weight of the wheel had already been reduced, conversion to a reverse rim type had the effect of reducing weight as a result of the removal of excessive thickness between the disk surface and the bead drop area.

As indicated above, the conversion to reverse rim wheels realizes increased freedom of design through the visual appearance of increased diameter equivalent to that of an inch up wheel when the design is the same as that of a normal rim wheel, and the reduction in excessive thickness makes it possible to reduce the weight of a wheel of 18 inches or more in diameter by 5% or more. It was also verified that it is possible to realize a weight reduction of 2% or more even in a wheel designed for reduced weight.

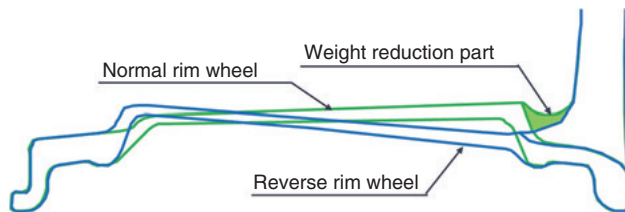


Fig. 18 Area in which weight is reduced in reverse rim wheel

6. Conclusion

The application of the manufacturing technology and method developed in the project discussed in this paper made possible one-piece manufacturing of reverse rim wheels, which simultaneously make the wheel appear larger in diameter while reducing its weight.

- (1) A type of flowform processing using opposed rollers was proposed, and a method of manufacturing reverse rim wheels as an inexpensive one-piece configuration using existing line equipment was developed.
- (2) For flowform processing, the preheating temperature was set at 400°C and the number of ironings by the roller was set at four, realizing optimum processing conditions that would not produce scratch marks such as cracks and micro-cracks.
- (3) It was shown that the shape predicted by CAE could be realized and that the target weight reduction effect could be obtained.
- (4) It was verified that the conversion to reverse rim wheels permits increased freedom of design through the appearance of increased diameter equivalent to that of an inch up wheel when the design is the same as that

of a normal rim wheel, and the reduction in excessive thickness enables reduction of the weight of a wheel of 18 inches or more in diameter by 5% or more. It was also verified that it was possible to realize a weight reduction of 2% or more even in a wheel designed for reduced weight.

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