

Development of Peeling-less Casting Billet for Forged Aluminum Suspension Arm

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ABSTRACT

Change to the use of aluminum material is being promoted in order to achieve the important goal of weight reduction. However, the high cost of this material means that weight reduction by this method is currently not progressing. Here we focused on the material cost, which occupies 59% of the manufacturing cost of forged aluminum suspension arms, and developed a new continuous casting technology which does not need peeling. This is called the peeling-less casting billet. To eliminate the peeling process, it was necessary to control material segregation and surface unevenness. Therefore the material content was adjusted (adding Ca) and direct cooling during casting was used, together with adiabatic mold casting and a graphite casting mold, and those problems were overcome. This developed technology eliminated the need for peeling, and in combination with reduced costs due to equipment depreciation, it reduced the cost of forging materials approximately 20%, thus realizing a reduction in cost compared to conventional forged aluminum suspension arms.

1. Introduction

In recent years, the weight of automobiles has been increasing because of the increase in comfort features and measures adopted for safety against collision. Moreover, improvements in fuel consumption are being demanded from the point of view of global environmental protection (reduction of CO₂ and NO_x emissions, etc.) and the need to reduce automobile weight is increasing year after year. Among these, the demand for reducing the weight of suspension, which contributes to better running performance of the car with enhanced riding comfort and handling stability, is especially high.

Honda promoted the use of aluminum suspensions for sports vehicles and fuel-efficient vehicles as shown in Fig. 1, and selected forging as the manufacturing method for the suspension arm, which requires high strength and toughness. However, high costs are incurred in forging which involves many processes, and it has not yet been used in mass-production vehicles. Thus, low cost aluminum forgings are in demand.



Fig. 1 Applied examples of forged aluminum suspension arms

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2. Conventional Techniques and Development Goals

2.1. Cost Structure of Forged Aluminum Parts

Figure 2 shows the cost structure of forged aluminum parts. The percentage of material cost in the forging cost is high at 59%, of which 16% is the cost of peeling of the billet used for forging. Normally, peeling is performed to avoid macroscopic segregation of surface layer and unevenness of the surface because of solidification shrinkage, which occur during the cooling process.

Moreover, the extrusion billet, which does not require peeling, may also be considered as the forging material, but extrusion costs become higher than the peeling costs, leading to a large increase in the overall cost.

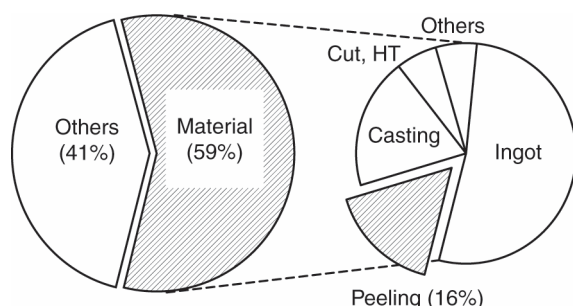


Fig. 2 Conventional cost composition of forged aluminum suspension arm

2.2. Issues in Conventional Techniques

Figure 3 shows the Direct Chill Casting (DC casting) method^{(1),(2)}, which is a typical continuous casting method. The method consists of a two-stage cooling process. Molten aluminum in the mold forms a solidified shell because of the cooling of the water-cooled mold (primary cooling). Most of the residual part solidifies because of direct water-cooling from the lower part of the mold (secondary cooling). As shown in Fig. 4, this casting method causes unevenness on the billet surface because of solidification shrinkage that occurs with the cyclic two-stage cooling, and moreover, macroscopic segregation of the surface layer occurs. This may give rise to surface defects, reduction in strength, and reduction of resistance to corrosion of forging parts. Therefore, the billet surface is removed by the peeling process. Research for improvement of DC casting generally focused on minimizing the contact between the mold and the molten metal. That is, the focus was mainly on reduction of primary cooling capacity, and as shown in Fig. 5, hot top

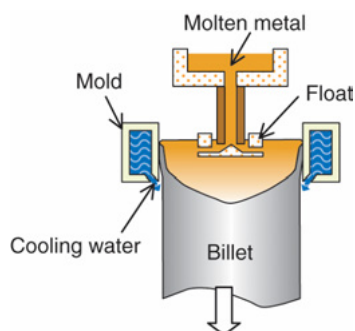


Fig. 3 Schematic of direct chill casting method

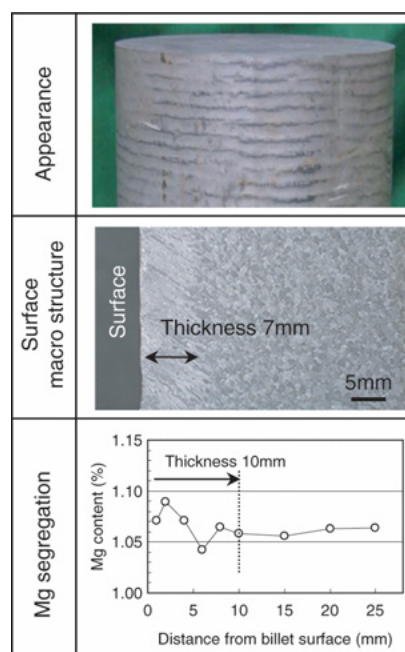


Fig. 4 Surface quality of direct chill casting billet

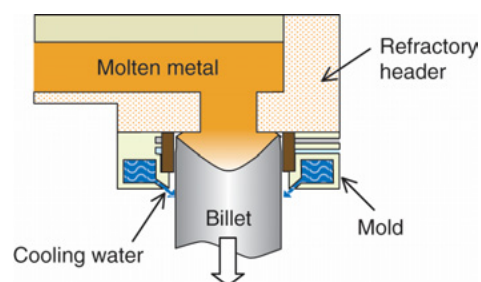


Fig. 5 Schematic of hot top casting method

casting^{(1),(3)} was considered as an improved casting method. However, even with this casting method, unevenness of billet surface and macroscopic segregation of the surface layer could not be eliminated, therefore peeling is being carried out.

2.3. Development Goals

The casting process using the method of cooling from the billet surface does not completely remove surface defects. The following items were considered for establishing a casting technique that would reduce the difficulties as far as possible:

- (1) Avoiding two-stage cooling process (mold material and cooling process)
- (2) Optimization of casting conditions (speed of casting and amount of cooling water)
- (3) Strengthening the solidified shell of the uppermost layer (material composition)

The goal is to improve the quality of the billet surface, which becomes the forging material, to enable elimination of peeling work, and to reduce casting costs.

3. Peeling-less Casting Technique

3.1. Mold Material and Cooling Process

To eliminate the two-stage cooling in the conventional technique, heat insulating mold structure^{(4), (5)} in which the

As the mold does not have the cooling function was adopted. As shown in Fig. 6, while the refractory product is used in the mold holder, graphite was used as mold material because of its superior thermal conductivity to reduce the temperature gradient between molten metal and mold. Moreover, the benefit of the self-lubricating performance of graphite is that the molten aluminum can smoothly pass through the inner mold wall, thus improving the smoothness of the billet surface. Graphite reacts strongly with water vapor near the aluminum solidification temperature (casting temperature) of 700 °C. This affects the mold life. Therefore, graphite with its excellent oxidation-resistance was used.

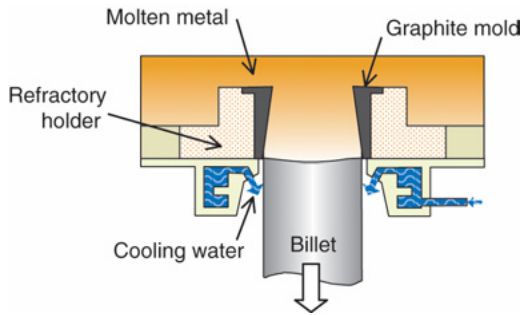


Fig. 6 Schematic of developed casting method

3.2. Casting Speed and Amount of Cooling Water

Because only direct water-cooling was used during casting, the effect of the cooling speed on the quality of billet became pronounced; therefore, improvement in the surface quality was attempted by controlling the casting speed and the amount of cooling water which dominate cooling speed. As shown in Fig. 7, optimization of casting speed and amount of cooling water made it possible to achieve the manufacturing conditions of billet with excellent surface quality.

Figure 8 shows the relationship between the casting speed and the quality of appearance of billet when the amount of cooling water is fixed. As the delay in the casting speed increases, longitudinal streaks and surface protrusions occur, and this reduces the quality. It is necessary to set the highest possible casting speed in the range where no leakage of molten metal occurs from the viewpoint of productivity.

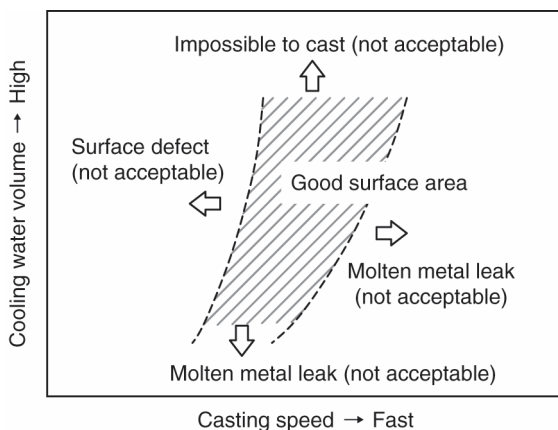


Fig. 7 Relationship between cooling speed and casting quality

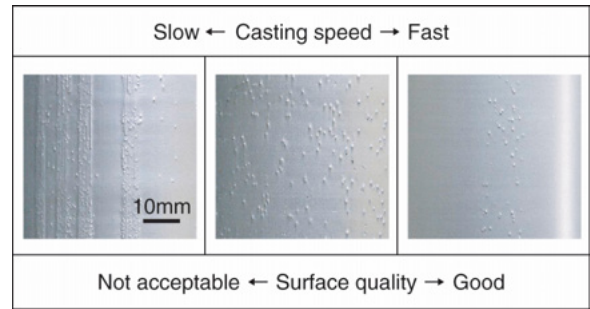


Fig. 8 Relationship between casting speed and casting quality

3.3. Material Composition

The goal to date has been to improve billet surface quality by setting the casting conditions and selecting the optimum mold material. However, surface protrusions have been noticed as shown in Fig. 8, and a smooth surface has not been achieved yet. As shown in Fig. 9, the solidified shell around the solidification boundary surface breaks and molten metal leakage occurs because of the friction force created when the mold comes in contact with the shell. By increasing the strength and ductility of the solidified shell, the protrusions were inhibited. Starting with Be^{(6),(7)}, which creates an oxide film preferentially on the billet surface during solidification, attention was also paid to Sc, Ca and Sr⁽⁸⁾, which increase the surface tension of molten aluminum. These elements were added to the 6061 alloy, which is the base alloy, and the effectiveness in improving the surface quality of billet using the developed casting method was confirmed. As shown in Fig. 10, the effectiveness on elimination of surface protrusions by the addition of Be and Ca was confirmed, but the use of Be was shelved because of environmental concerns. Optimization of amount of Ca to be added to obtain the same effects was implemented, and the optimum amount to be added was set in the range of 50 ppm – 150 ppm. Figure 11 shows the billet surface quality for amount of Ca added.

Figure 12 shows the cross section of the Ca-added billet structure cast using the developed casting method. The thickness of the macro segregation layer obtained by conventional technology was 7 mm and the concentration segregation of Mg was 10 mm. In contrast, however, in the developed casting method, there was no macroscopic segregation layer, and there was an extremely thin microstructural layer of about 150 μm (hereafter referred to as "chilled layer"). Moreover, there was almost no segregation of Mg. The internal structure was also a very fine

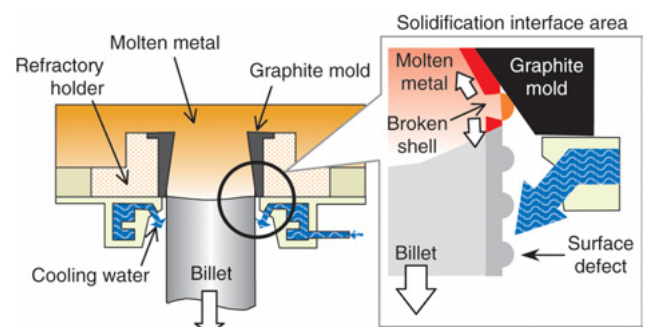


Fig. 9 Generating mechanism of surface defect

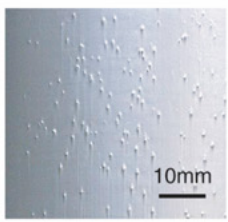
	Base metal	Base metal + Be	Base metal + Sc	Base metal + Ca	Base metal + Sr
Appearance					
Surface quality	Not acceptable	Good	Not acceptable	Good	Not acceptable

Fig. 10 Influence of additional element

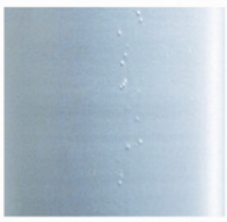
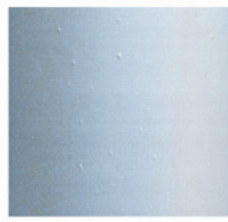
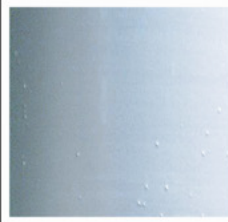
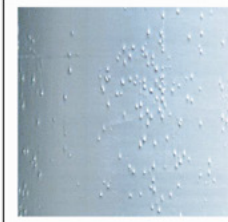
	10ppm	50ppm	75ppm	150ppm	200ppm
Appearance					
Surface quality	Not acceptable	Good	Good	Good	Not acceptable

Fig. 11 Influence of Ca quantity to surface quality

macro structure formed because of quenching by direct water-cooling.

As mentioned above, use of the heat insulating mold, optimal setting of the casting conditions as well as addition of small quantity of Ca made it possible to produce a smooth billet surface and to restrict the non-uniformity of the structure to a minimum, enabling a peelingless cast billet to be obtained.

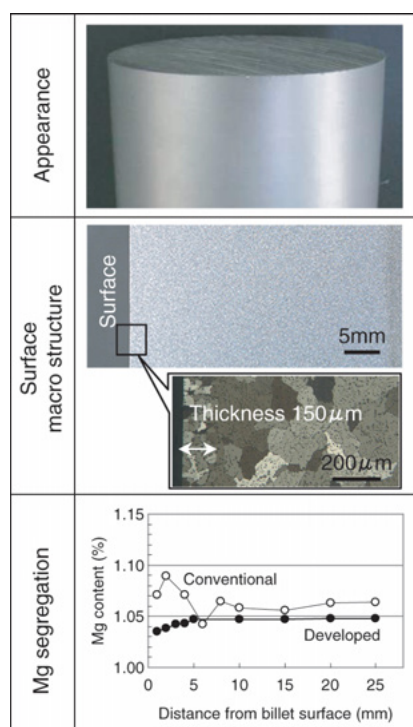


Fig. 12 Surface quality of developed billet

4. Mechanical Properties/ Characteristics of Parts

The effects of the residual chilled layer and addition of Ca on the peelingless cast billet used in the forged arm were confirmed.

4.1. Effects of Residual Chilled Layer

A chilled layer formed due to quenching when casting remains on the surface of the forging, if the billet is forged without performing peeling. To confirm this effect, hot flat forging at a tempering ratio of 80 % was implemented horizontally in the billet axial direction on the conventional and the developed materials, and the effect of the residual chilled layer was studied.

Figure 13 shows the mechanical properties of the test specimen cut from the flat forging. The strength and Charpy impact values were the same regardless of the existence of a chilled layer. However, from the data for damage probability $P = 0.1$, the fatigue strength improved by approximately 20 % compared to the conventional technology with no chilled layer. It is believed that a reinforcing effect was observed because the structure became microscopic due to the quenching action in the developed casting method and a chilled layer existed on the surface.

4.2. Effect of Adding Ca

Figure 14 shows the mechanical properties of the test specimens cut from inside the forged arm of the developed and the conventional materials. Generally, the Ca atoms in Al are considered to form compounds between metals by bonding with Si atoms, reduce the amount of Mg_2Si that contributes to the strength of the 6061 alloy, and reduces the strength⁽⁹⁾. However, in the range of addition of 50-150 ppm,

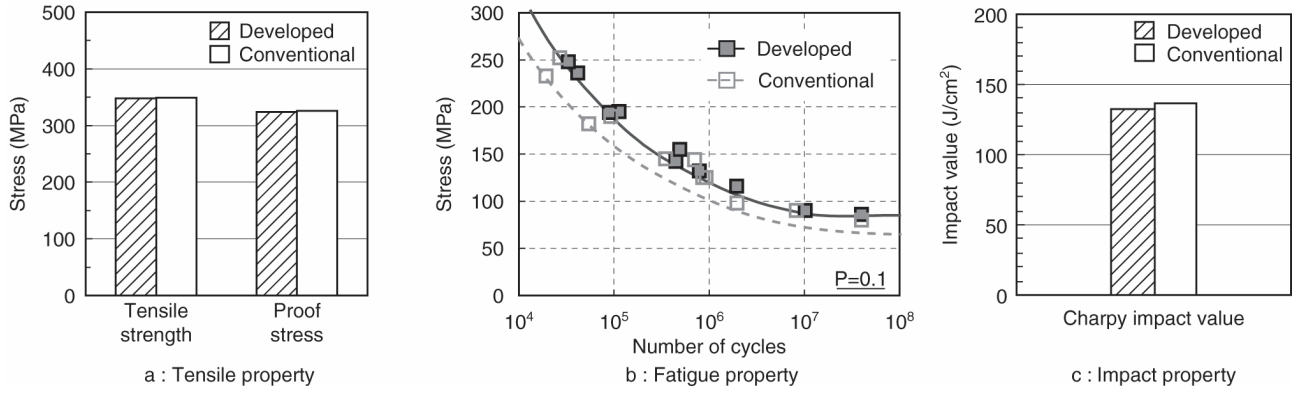


Fig. 13 Influence of residual chilled layer in flat forging

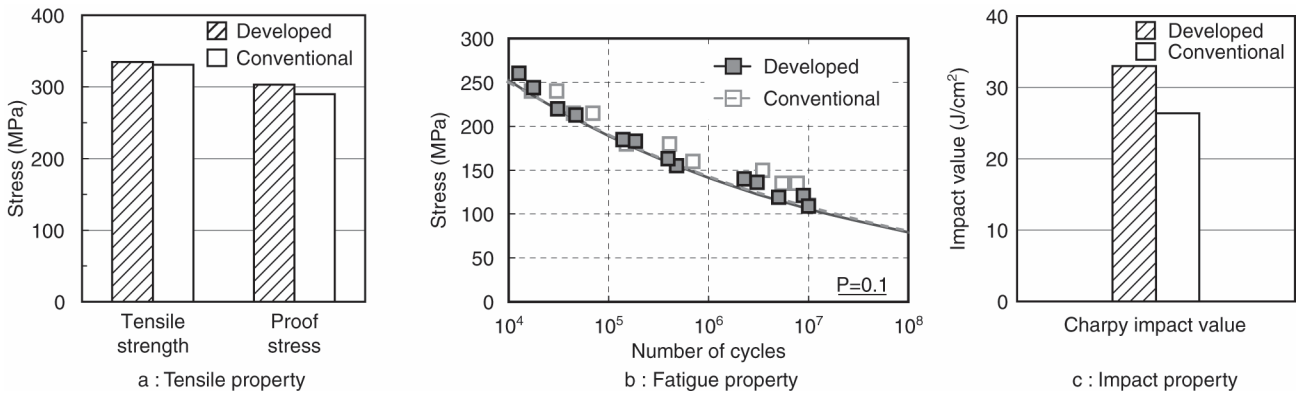


Fig. 14 Influence of Ca addition in forged arm

the value indicated was greater than the value when no Ca was added. In particular, the impact value in the developed casting method improved by 25 % compared to the conventional material. This is because of the effect of the microscopic structure due to the developed casting method.

As mentioned above, forged parts made by using peelingless cast billet showed excellent mechanical properties compared to conventional technology. Moreover, it was also confirmed that there were no concerns in the strength, durability, and corrosion resistance of the arm.

5. Practical Example

The developed technology enabled the elimination of the peeling process, which was necessary in the past. Elimination of the peeling process enabled a reduction of about 20 % of the material cost to be achieved because of elimination of straightening of casting billet and reduction in depreciation cost of equipment. Further, by application of the developed method to the mass production of the front lower arm in the 2005 year model LEGEND, we achieved a reduction in weight of approximately 43 % compared to the cast iron arm. Figure 15 shows the front suspension and Fig. 16 shows the front lower arm of the LEGEND.



Fig. 15 External view of front suspension



Fig. 16 Front lower arm

6. Conclusion

Research was carried out to develop a cast billet with excellent surface quality that does not require the peeling process, which was necessary in the past, for the manufacturing of aluminum forged suspension arms. The results of the research and development were as follows:

- (1) A peelingless cast billet was developed by adding Ca, using a graphite mold, and optimizing the casting conditions.
- (2) Compared to the conventional cast billet using the peeling process, it was possible to reduce the material portion of the forging cost by 20 %.

7. Acknowledgments

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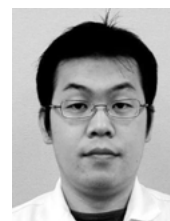
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