

Large-sized and Lightweight Aluminum Hollow Diecast Subframe Using High Pressure Diecasting

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ABSTRACT

A large-sized, lightweight aluminum, hollow diecast subframe with increased strength was developed. Technology for baking the entire interior of the core, which is the key to realizing a closed section structure, and materials with enhanced castability were applied to the subframe for the first time known to date, and realized a thin wall structure even with high-pressure diecasting. In addition, the use of a seamless closed-section structure increased the package efficiency and achieved weight reduction of approximately 46% while securing the same stiffness as that of a welded steel plate subframe. These developments realized a top-class lightweight subframe.

The developed subframe was mounted in the CLARITY FUEL CELL, and both reduced the vehicle weight and facilitated fuel cell power train installation under the front hood, achieving high package efficiency equivalent to that of a vehicle with an internal combustion engine.

1. Introduction

There is an increasing need to reduce automobile weights in order to reduce carbon and save energy to protect the global environment and to enhance vehicle maneuverability. Technology that enhances both fuel economy performance and maneuverability while at the same time achieving good environmental performance and marketability will become even more necessary in the future. The development of technology that further reduces the vehicle body weight including chassis parts is called for as fuel cell vehicles and electric vehicles start to become popular⁽¹⁾.

The front subframe (Fig. 1) that joins the suspension parts and power plant to the vehicle body is one of the larger-sized chassis parts, and optimizing the front subframe structure to reduce the weight contributes greatly to reducing the overall vehicle weight.

Honda has performed material substitution to aluminum to reduce the subframe weight. For example, technology that uses friction stirring to weld together expanded material and steel plates in automobiles has been developed for diecast parts with an open-section structure that formerly used aluminum high-pressure diecasting (HPDC) and squeeze diecasting⁽²⁾, and this technology has been applied to the ACCORD HYBRID and FIT EV subframes. However, welding parts are needed when creating a closed-section

structure by welding, and securing an efficient section shape given the limited layout space inside the engine and motor compartments becomes an issue. Conventional technology employs an aluminum hollow integrated structure made using gravity diecasting (GDC) and low-pressure diecasting (LPDC), but casting by GDC and LPDC calls for a certain thickness, and weight increase is an issue. Technology was developed that uses a core created by the lamination manufacturing method together with LPDC to reduce the wall thickness in order to reduce weight⁽³⁾, but it was a

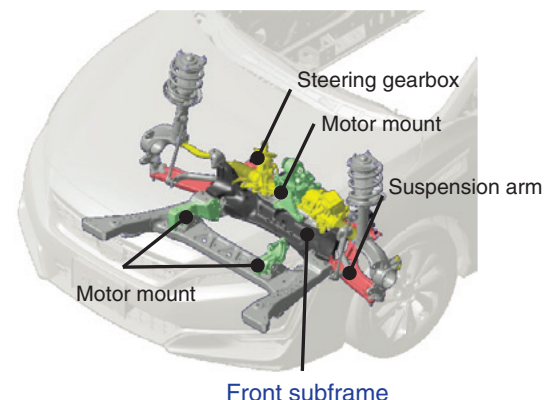


Fig. 1 Front subframe position in vehicle

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Table 1 Overview of subframe manufacturing methods

	GDC	LPDC	HPDC	
Joint	None	None	FSW	None
Thickness	△	△	○	○
Weight	△	△	○	◎
Layout efficiency	○	○	△	○
Productivity	△	○	◎	◎

◎ : Excellent
○ : Good
△ : Acceptable

challenge to secure mass productivity. Table 1 gives the characteristics of closed-section structures created using different manufacturing methods.

Honda developed closed-section technology using aluminum HPDC and applied it to the CBR600RR motorcycle frame. However, this technology welds together small-sized diecast parts with a closed-section structure and diecast parts with an open-section structure manufactured using GDC, so hollow integrated casting was not achieved⁽⁴⁾, and there is room for further weight reduction.

In order to address these issues, a new subframe was developed by using existing facilities with HPDC, which is advantageous for weight reduction, in order to realize large-sized parts with a thin wall closed-section structure⁽⁵⁾.

2. Development Goals

This study set the following goals and developed new subframe manufacturing technology.

- (1) Realization of a large-sized, thin wall closed-section structure using HPDC

Establishment of core manufacturing conditions that can be applied to HPDC and use general-purpose HPDC facilities, and increased core strength to help realize larger products with thinner walls.

- (2) Realization of mass productivity including materials that simultaneously achieve both castability and good mechanical properties

Making use of the advantages of hollow diecasting using a core, which enables to secure fluidity due to lower thermal conductivity, to realize mass productivity using materials suited to diecasting.

- (3) Realization of a top-class lightweight subframe

Weight reduction due to thinner walls, a seamless structure that reduces fatigue starting points, elimination of welding parts in order to increase freedom of layout, and stabilization of product wall thickness.

3. Realization of Large-sized Thin Wall Closed-Section Structure by HPDC

If the HPDC gate speed is too fast, the core will shift or split, resulting in shape defects. If the casting pressure is too high, the core will be crushed and shrink, resulting in thicker product walls. Therefore, the casting conditions were changed from the typical HPDC conditions to reduce the gate speed and casting pressure to within the ranges where the sand core does not break during diecasting (Fig. 2).

3.1. Core Manufacturing Conditions

Figure 3 shows the diecasting process flow. The core

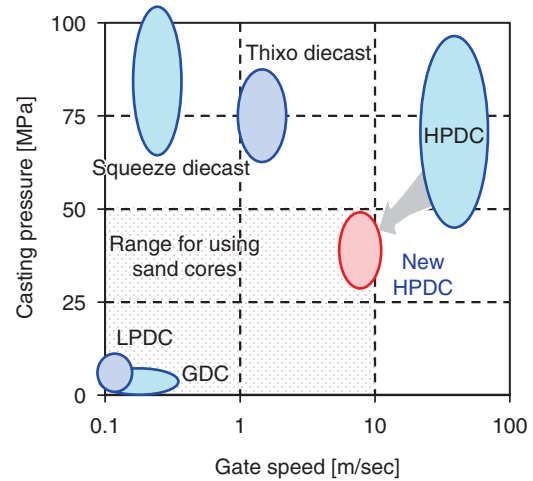


Fig. 2 Target casting pressure and gate speed target

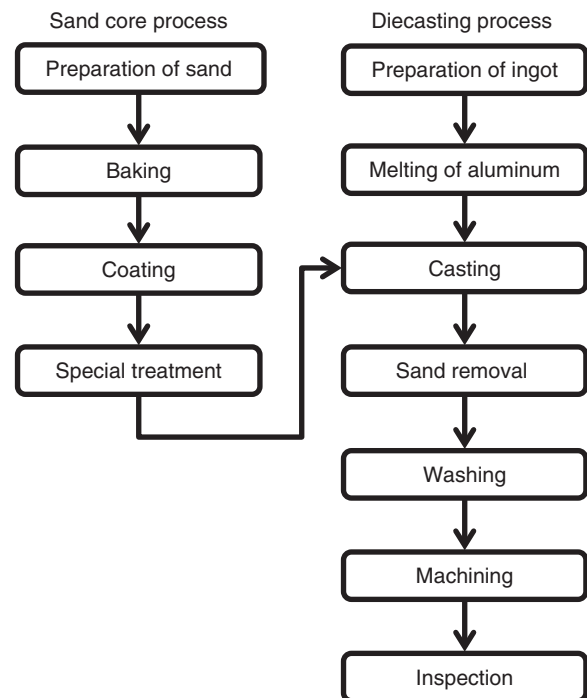


Fig. 3 Manufacturing process

is applied to a large-sized subframe, so it is larger and thicker than a conventional core, which calls for a longer baking process time. In addition, a surface coating material is applied to the core to enhance the melt flow rate and the sand removal performance. The completed core is then fixed in the die and aluminum diecasting is performed. After diecasting is complete, the gate area is struck to vibrate the product in order to break down and discharge the core.

3.2. Hollow Casting Technology

The core was cast by die baking with phenol-type resin-coated sand (RCS) as the core material. Figure 4 shows the cross-section of a core baked using conventional baking conditions. This shows that only the surface parts that contacted the die are baked, and most of the interior was not heated, so the core strength is low. In this condition the core will split or be crushed during diecasting with the result that the product wall thickness will increase, so it is necessary to bake the entire interior of the core. The phenol resin used in RCS starts to harden at a temperature of 160°C or more and degrades rapidly at 400°C or more, so the baking conditions should be set within the range from 160°C to 400°C.

In addition, increasing the baking temperature bakes thick areas of the core more quickly, while thin areas become over-baked, resulting in strength differences by area. Furthermore, over-baked areas are brittle and break easily, so the ideal baking conditions were found that enable evenly baking the entire core (Fig. 5).

3.3. Materials that Achieve both Castability and Mechanical Properties and Establishment of Mass Productivity

Aluminum diecast materials used in chassis parts need high strength, high toughness, and corrosion resistance. Therefore, aluminum-silicon (Al-Si) and aluminum-magnesium (Al-Mg) materials are used that have smaller loading amounts of elements such as copper (Cu) and iron (Fe), which adversely affect corrosion resistance. Regarding the material selection, Al-Mg material was selected that exhibits stable strength at a gate speed of approximately 10 m/s, which is one of the casting conditions (Fig. 6). Al-Mg material has lower strength than conventional Al-Si material

Area that looks white is not baked.

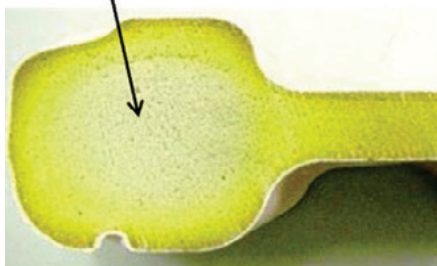


Fig. 4 Sand core cross section after baking

that has been heat-treated, and shrinkage cracks easily occur due to shrinkage at the time of solidification, so it has lower castability and is not often used as a casting material for large-sized thin wall parts. To address these issues, this study added Si to Al-5Mg material, which precipitated Mg_2Si , enhancing the mechanical properties. In addition, this also lowers the liquid phase temperature, so pressure can be transferred until immediately before solidification, which enhances molten metal feeding.

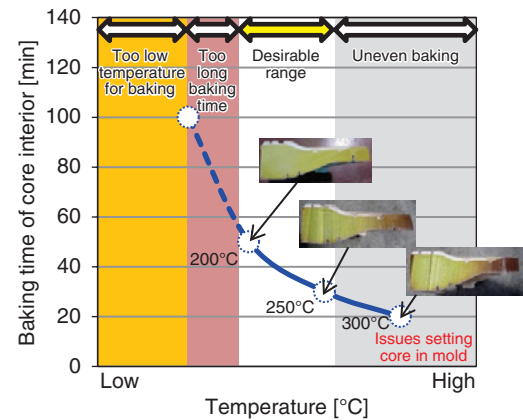
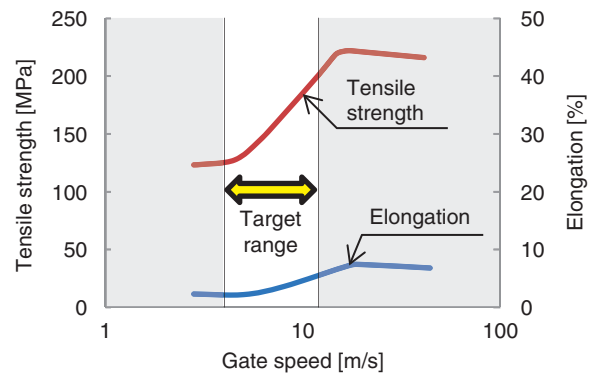
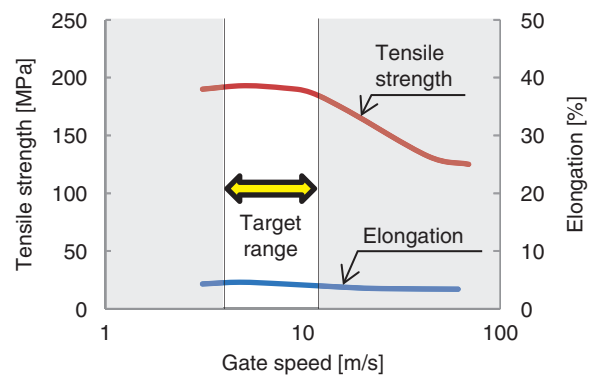


Fig. 5 Relationship between baking time and temperature



(a) Al-Si material



(b) Al-Mg material

Fig. 6 Relationship between gate speed and strength

The Si loading amount was determined by performing casting tests using a sheet-shaped test piece die (length 300 mm × width 100 mm × thickness 6 mm) as a pre-test, and comparing the mechanical properties. Figure 7 shows the relationships between the Si loading amount and the tensile strength (TS), 0.2% yield strength (YS), and elongation (EL). This study determined that a Si loading amount of approximately 2.0% provided the material with the appropriate balance between strength and elongation.

Materials used in subframes need both high elongation to satisfy the vehicle crash performance and high strength to reduce the vehicle weight. Strength and elongation typically have a trade-off relationship, so the optimum material needs to be selected in accordance with the purpose of use. A part die was therefore used to confirm the change in mechanical properties in more detail in the Si loading amount range of 1.8% to 2.2%. Figure 8 shows the tensile test piece sampling positions. As in the pre-test, the tensile strength

peaked at 2.0%, but the Si loading amount was set to 1.8% in consideration of toughness, which is a part requirement characteristic (Fig. 9).

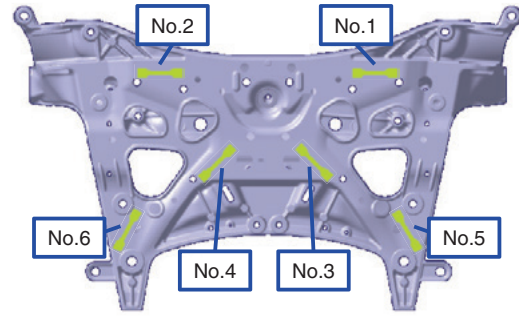


Fig. 8 Tensile test piece sampling positions

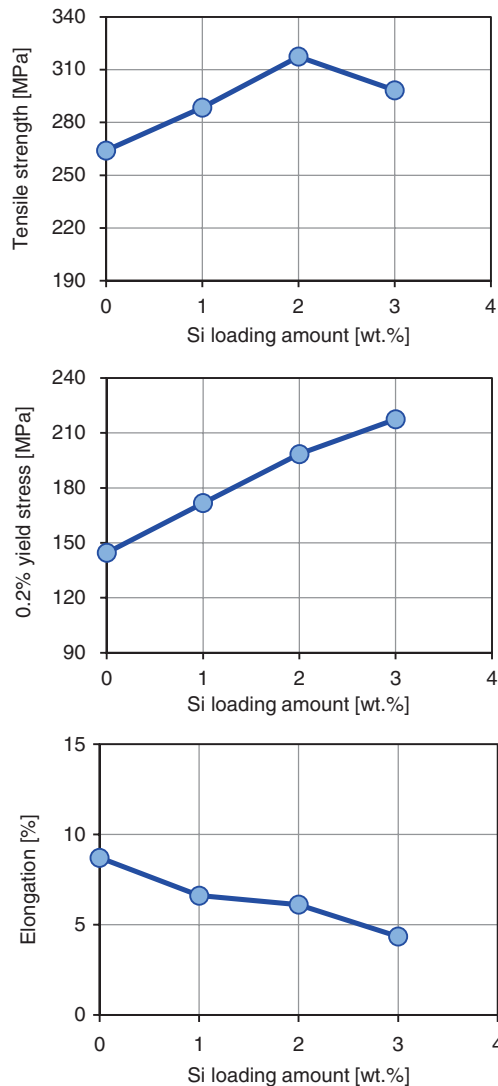


Fig. 7 Change in mechanical properties of test piece by Si loading amount to Al-5Mg material

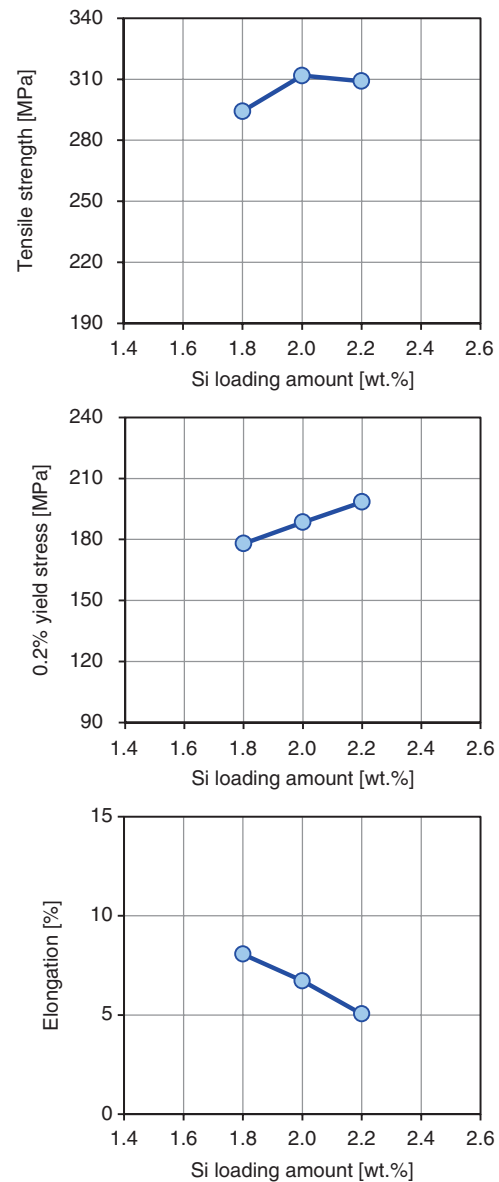


Fig. 9 Change in mechanical properties of subframe by Si loading amount to Al-5Mg material

4. Realization of a Top-class Lightweight Subframe

Development of this new subframe used aluminum hollow diecast technology, so the closed-section structure is seamless instead of the conventional welded structure. However, depending on the subframe shape, the molten metal that flowed into the die during casting deforms and damages the core due to the casting pressure, so a structure that prevents this damage is needed. This study therefore set the core holding positions during casting at opposing positions on the top and bottom of the subframe. This suppressed core deformation during subframe casting and stabilized the product wall thickness (Fig. 10). In addition, core strength analysis was performed for different casting pressures during aluminum filling, the stress generated on the core was quantified, and a product shape was found that helps prevent stress concentration in the core (Fig. 11). Furthermore, a uniform cast wall thickness is usually set to enhance castability, but casting analysis and product

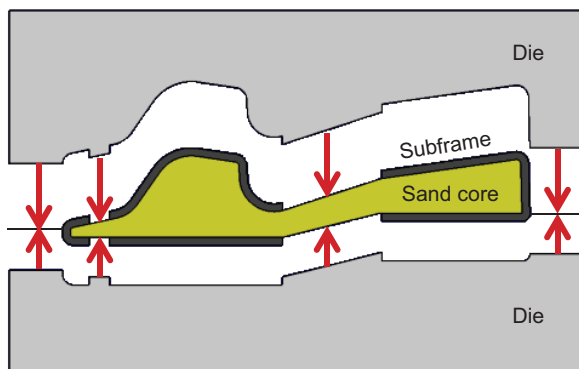


Fig. 10 Sand core holding positions

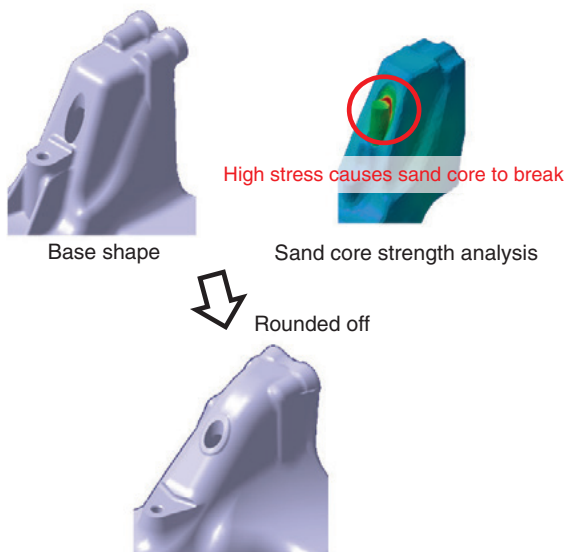


Fig. 11 Design using sand core strength analysis

design were performed in parallel. This enabled the use of a variable wall thickness that positions the necessary material in the necessary locations, achieving a structure that is both lightweight and has high stiffness. Specifically, the wall thickness of the suspension lower arm and steering gearbox mounting area that contributes greatly to maneuverability was set to 3.5 mm to ensure support stiffness, the wall thickness of the suspension mounting areas was set to 2.5 mm to ensure bolt tension, and the wall thickness of the lower surface area was set to 3.0 mm to enable absorption of crash energy without separating. This enabled to realize both the ideal stiffness distribution and high strength level demanded of the subframe (Fig. 12).

In addition, welded parts are unnecessary and seamless casting can be performed, which ensured high stiffness with a space-saving design compared to conventional weld joining (Fig. 13). As a result, a lightweight subframe layout with good stiffness that also ensures crash performance could be achieved even within the restrictions of the limited motor compartment space of the CLARITY FUEL CELL.

The mechanical properties were confirmed by cutting a test piece from the product and measuring the tensile strength, 0.2% yield strength, and elongation. Judging from the performance requirements of the applied part, the results confirmed that yield strength and elongation that stably meet or exceed the target values could be obtained. In addition, the performance was also confirmed by static destruction tests and durability tests under actual vehicle input conditions.

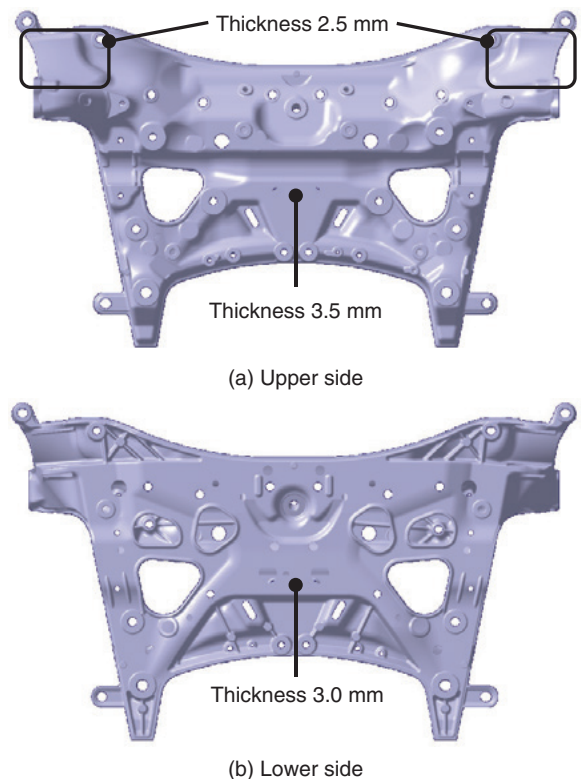
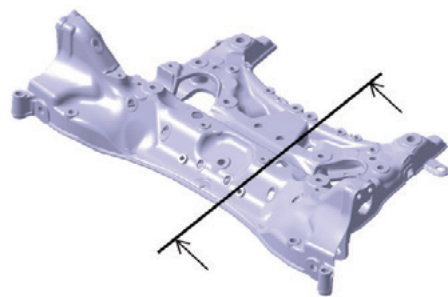
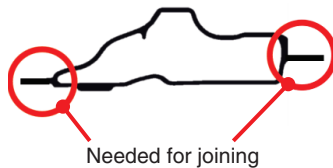


Fig. 12 Subframe thickness



(a) Section cut area



(b) Conventional subframe



Seamless closed section structure

(c) CLARITY FUEL CELL subframe

Fig. 13 Structure of closed section

The shape of the newly developed aluminum hollow diecast subframe was optimized by measures such as material substitution from steel plate to aluminum and elimination of welding parts. This achieved weight reduction of approximately 46% compared to the conventional part, and realized a top-class lightweight subframe (Fig. 14).

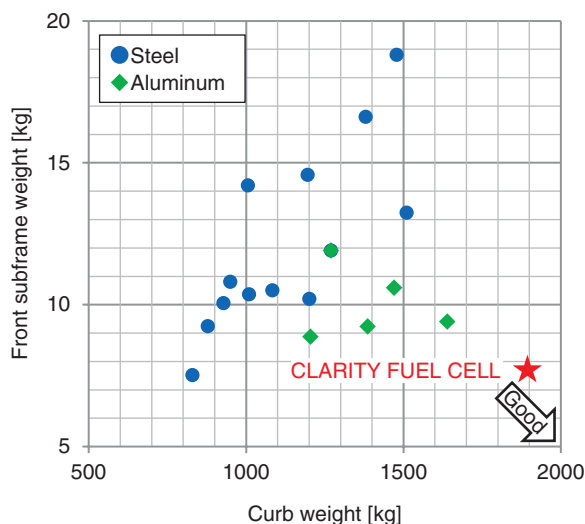


Fig. 14 Subframe weight

5. Conclusion

This study reduced the weight of the front subframe, which is one of the largest chassis parts, and established an HPDC production method that can be applied to mass production.

- (1) Core casting technology was developed that can be applied to HPDC, and conditions were established that enable even baking of the entire interior of a large-sized core.
- (2) A chemical composition that satisfies both castability and mechanical properties was created by adding 1.8% Si to non-heat treatment-type Al-5Mg materials
- (3) The developed aluminum hollow diecast subframe achieved weight reduction of approximately 46% compared to a conventional subframe formed by pressing and welding steel plate. This realized a top-class lightweight subframe.

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