

Development of High-durability and Low-cost Fuel Cell Bipolar Plate

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ABSTRACT

A bipolar plate for a new structure fuel cell stack was developed jointly with General Motors Company. In order to achieve both lower cost and higher productivity while enhancing the functionality of the bipolar plate in this study, a bipolar plate structure that assumes high-cycle molding was developed. A coating consisting of carbon and titanium is applied to the stainless steel base material before stamping. The seal structure was changed from a multilayer rubber seal structure to a metal bead seal structure formed by stamping after coating and a welded seal structure. In addition, a structure without a rubber coating was adopted for high-cycle molding.

1. Introduction

Fuel cells are anticipated as circulation-type clean plants that do not emit CO₂ or harmful substances in order to address global warming and energy issues⁽¹⁾. Honda has been working on the practical application of fuel cell technology since the 1980s⁽²⁾. This paper discusses the bipolar plate (BPP), which is one of the parts comprising the multilayer cell applied to a new structure fuel cell stack⁽³⁾. The multilayer cell adopts a cell structure that holds a single Unitized Electrode Assembly (UEA) with two BPPs and flows coolant, as shown in Fig. 1.

Figure 2 shows the functions demanded of the BPP.

- (1) Supply hydrogen and oxygen gases to the UEA
- (2) Flow coolant to cool the BPP and UEA
- (3) Seal the hydrogen, oxygen, and coolant
- (4) Provide conductivity between cells

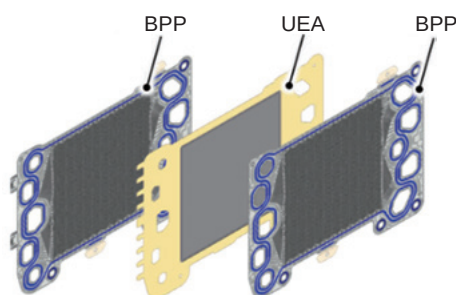


Fig. 1 Structure of BPP and UEA

- (5) Provide corrosion resistance in the power generation environment

In addition, the BPP and UEA account for a high proportion of the cost ratio of a conventional fuel cell stack, as shown in Fig. 3.

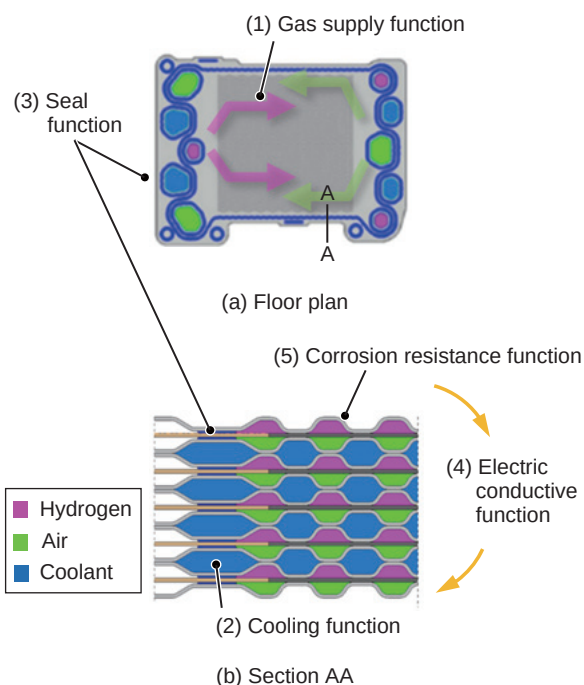


Fig. 2 Main functions of BPP

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The breakdown of the BPP cost structure shows that sealing, coating, and stamping costs account for a high proportion, and lowering these costs was an issue. The conventional BPP⁽⁴⁾ adopted a rubber seal structure using injection molding for the seal function, which resulted in a longer production cycle time and was an issue for mass production. Additional issues included the use of precious metals in coatings for corrosion resistance, and many coating quality inspections in BPP molding.

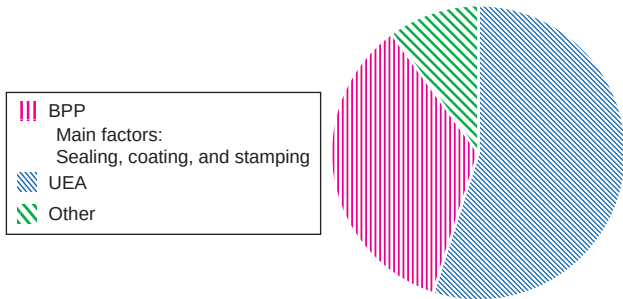


Fig. 3 Breakdown of conventional fuel cell stack cost

2. Development Goals

In order to achieve both lower cost and higher productivity while enhancing functionality compared to the conventional structure, a BPP structure that assumes high-cycle molding was developed.

Figure 4 shows a table comparing the conventional and new BPP structures. In order to achieve the target production volume set as a new structure, a seal structure that simplifies the manufacturing and inspection processes was needed. Therefore, the multilayer rubber seal structure was changed to a metal bead seal and welded seal structure. It was also necessary to achieve lower coating material and processing costs. Therefore, the coil was changed from the conventional gold-plating coating to a graphite-like carbon (GLC) coating.

The conventional BPP provided insulation with a perimeter rubber coating structure, but the new structure sets creepage and clearance distances and adopts a structure without a perimeter rubber coating, which enabled elimination of the insulation inspection process.

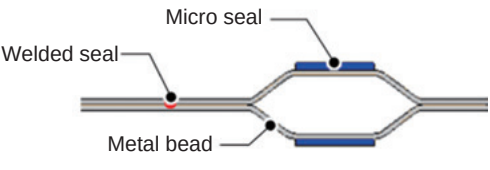
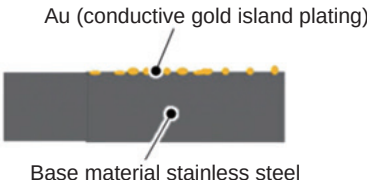
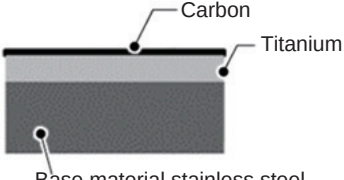
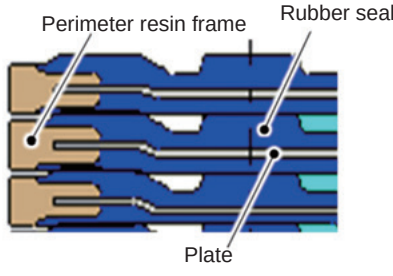
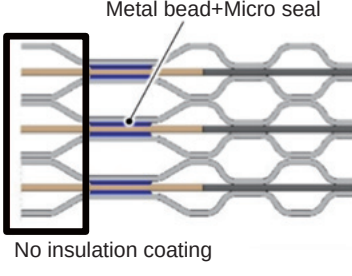
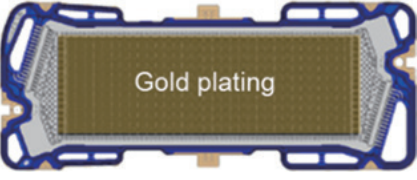
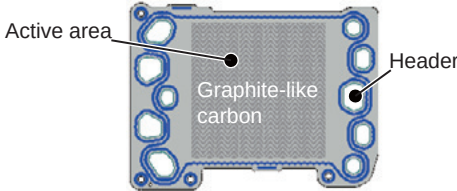
	Conventional BPP structure	New BPP structure
Seal structure	 Rubber seal Plate	 Micro seal Welded seal Metal bead
Coating structure	 Au (conductive gold island plating) Base material stainless steel	 Carbon Titanium Base material stainless steel
Outer insulation structure	 Perimeter resin frame Rubber seal Plate	 Metal bead+Micro seal No insulation coating
External shape	 Gold plating	 Active area Graphite-like carbon Header

Fig. 4 Comparison of conventional and new BPP structures

3. Features of New BPP Structure

3.1. Feasibility of Metal Bead and Welded Seal Structure

The metal bead seal (MBS) structure consists of (a) metal bead parts molded by stamping and (b) micro seal rubber, as shown in Fig. 5, and seals by the reaction force in lamination and compression. In addition, cooling channels are formed by (c) welding Plate-A and Plate-B.

3.1.1. MBS structure settings

In MBS structures that make use of metallic elasticity, there is the issue that if the bead is subjected to a high load, the necessary seal line pressure may not be achieved due to plastic deformation, and gas or coolant may leak. The line pressure is the value obtained by dividing the load generated on the seal part by the length of the seal line.

When the vehicle vibrates in driving, the vibration also propagates to the stack, and a high load is generated on the BPP seal parts. A bead cross-sectional shape was set that can generate the line pressure needed to keep the seal function even in this case. Furthermore, the deceleration in a vehicle collision generates an internal load, and thus a shape that receives the load on the periphery of the BPP was provided, as shown in Fig. 6, to help prevent plastic deformation of the metal beads.

The compressive load characteristics of the MBS structure vary depending on the cross-sectional shape of the bead and the planar layout of the seal line. The compressive load characteristics can be changed by adjusting the bead cross-sectional shape (bead width), as shown in Fig. 7. The compressive load characteristics can also be changed according to the plane radius and angle of the seal line, as shown in Fig. 8. The above characteristics were used to achieve a design with uniform in-plane characteristics, which helped to prevent leaks due to local reduction of seal line pressure.

3.1.2. 2Hit stamping of flow channel area and MBS

In the new BPP structure, the amount of flow channel area warpage increases in stamping, resulting in uneven contact pressure in lamination and increasing the contact resistance of the active area. Therefore, measures were taken to enhance the amount of warpage. It was also necessary to provide sealing performance such as in the event of a vehicle collision, and thus measures were taken

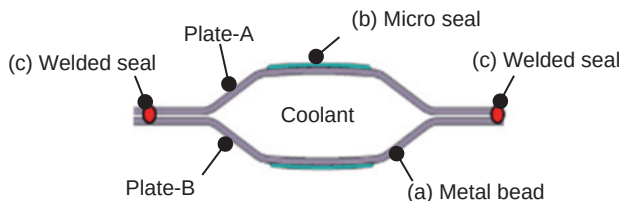


Fig. 5 Cross-sectional structure of MBS

to increase the compressive load characteristics of the MBS.

As shown in Fig. 9, the reason for the flow channel warpage is that the inside of the flow channel stamp area becomes longer than the outside of the flow channel stamp area in the direction perpendicular to the flow channels. This difference is produced by springback in flow channel stamping.

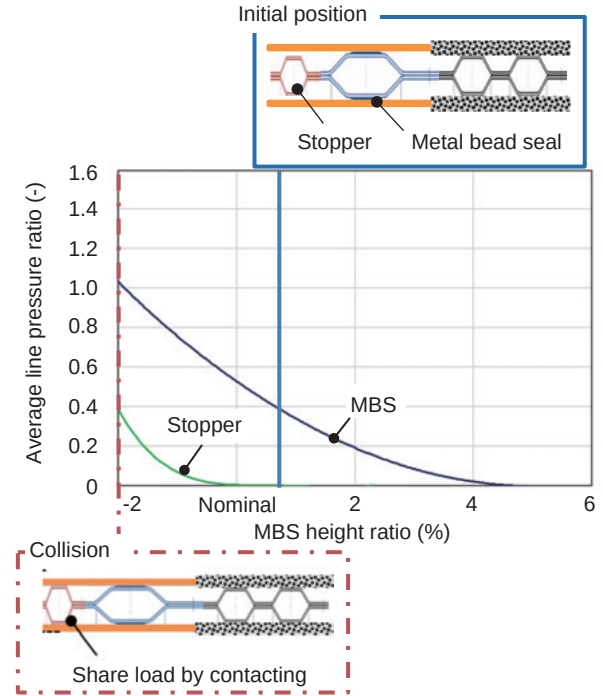


Fig. 6 MBS and stopper line pressure

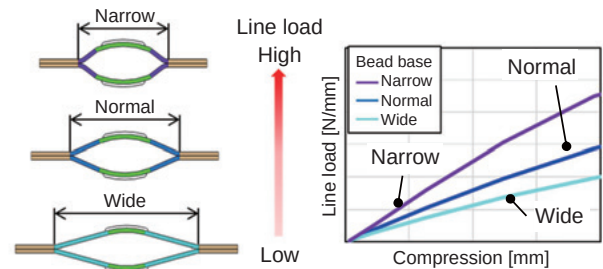


Fig. 7 Metal bead width and line load property

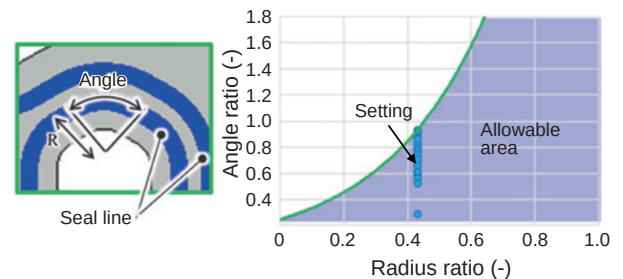


Fig. 8 Plane radius and angle setting

As a countermeasure, the flow channel stamping process was divided into two stages, as shown in Fig. 10. A two-stage stamping process flow channel structure was adopted in which the springback produced in the first stamping process stage (1Hit) is absorbed by bending the ridge line in the second stage (2Hit).

When the contact pressure of the active area was checked with Fuji film paper, this was confirmed to have the effect of helping to reduce contact pressure variance, as shown in Fig. 11. As shown in Fig. 12, the amount of flow channel area warpage was lower for 2Hit stamping specifications compared to only 1Hit stamping.

Next, in order to increase the MBS strength, a 2Hit-

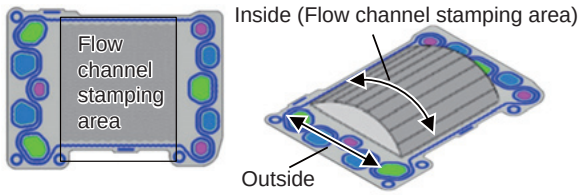


Fig. 9 Image of stamping area springback

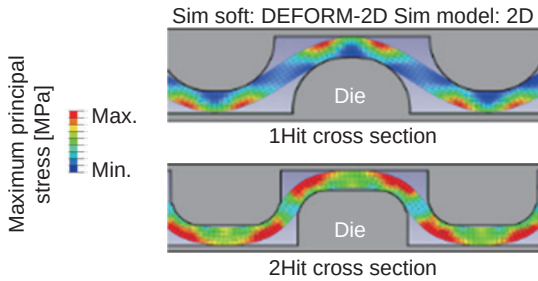


Fig. 10 1Hit and 2Hit of flow channel stamping process

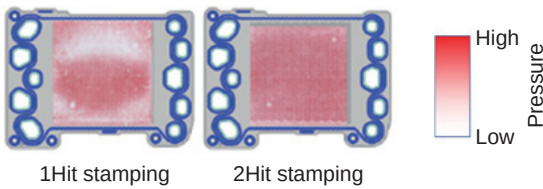


Fig. 11 Pressure of active area

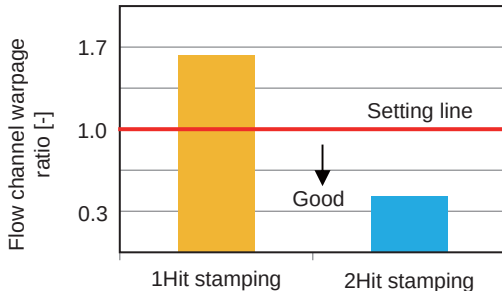


Fig. 12 Warpage of flow channel

type structure was adopted within the same process as flow channel stamping, and work hardening of the base material was applied. A 2Hit metal bead seal structure was adopted that applies work hardening to the entire cross section by stamping the center of the MBS in the first stage and stamps the final MBS shape in the second stage, as shown in Fig. 13.

This increased the strength had the effect of increasing the most amount of the compressive load characteristics of the MBS, as shown in Fig. 14.

3.1.3. Micro seal settings

The new BPP structure has a structure with micro seals placed on top of metal beads, as shown in Fig. 5. This results in a structure that can help lessen the drop in the seal line pressure due to compression set and keep the seal function as shown in Fig. 15. However, a thin seal makes it a challenge to keep the seal function in the event that foreign matter contaminates the seal in manufacturing.

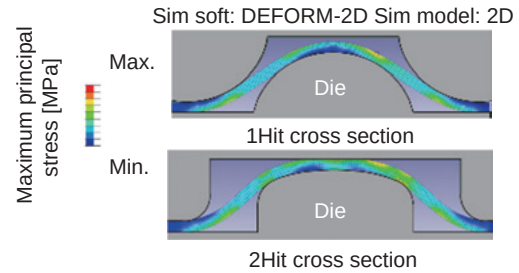


Fig. 13 1Hit and 2Hit of MBS stamping process

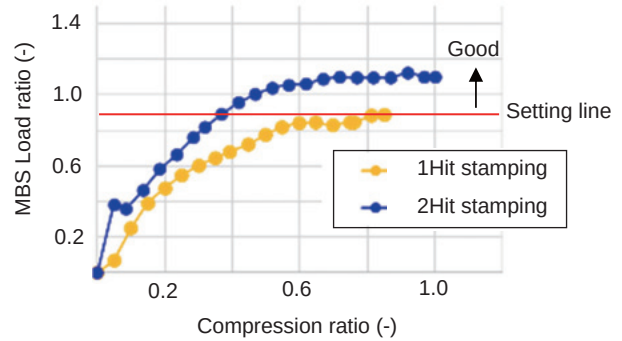


Fig. 14 MBS load characteristics

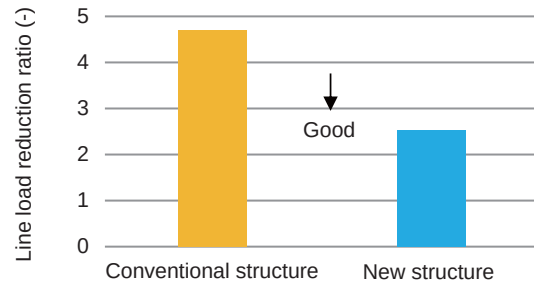


Fig. 15 Line load reduction comparison

Reduction of contamination by foreign matter calls for manufacture in a clean environment, but this is a factor that increases manufacturing costs. Therefore, the optimal thickness and width of the micro seal were set as shown in Fig. 16 based on the seal thickness that can keep the seal function even in the event of contamination by foreign matter and the manufacturing environment control conditions.

3.1.4. Welded seal structure settings

The BPP interface adopts a structure in which the coolant is sealed by joining the plates together by welding, as shown in Fig. 5. The weld width is defined as the faying length (FL), as shown in Fig. 17. The FL is set to provide bonding strength, as shown in Fig. 18, so that the joint does not break even when the operating pressure of the gas and coolant is applied to the weld.

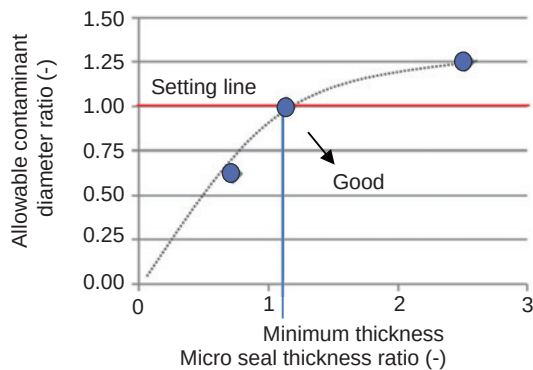


Fig. 16 Micro seal thickness setting

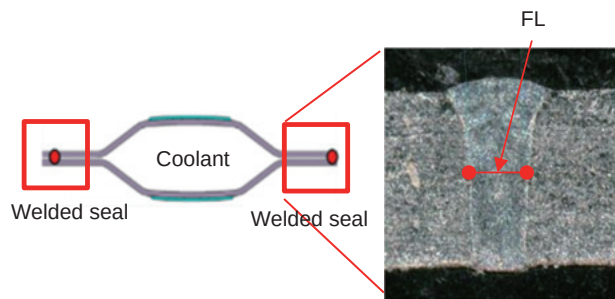


Fig. 17 FL Cross-sectional structure

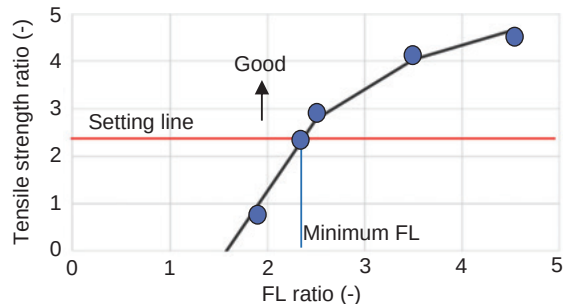


Fig. 18 FL and tensile strength

On the other hand, the bonding strength of the weld is generally enhanced by increasing the amount of heat input in welding to increase the width of the joint. However, large welding heat input may result in BPP warpage, which is a seal inconsistency factor. Therefore, the welding heat input condition was set to satisfy the amount of BPP warpage, as shown in Fig. 19. In addition, sensitization may occur in stainless steel welding⁽⁵⁾. Sensitization may cause stress corrosion cracking with the result that the seal function cannot be kept, so the welding conditions are set to help reduce the possibility of sensitization.

3.2. Achievement of Both Lower Cost and Corrosion Resistance Function with GLC Coating

In the conventional BPP, the surface of the stainless steel is treated with gold (sea-island structure gold plating) and then a passive film is formed on the exposed stainless steel areas to achieve both conductivity and corrosion resistance.

BPPs generally use stainless steel as the base material, and it is known that in an acidic corrosive environment with high temperature and humidity, iron ions are eluted due to damage to the passive film in the exposed stainless steel areas, which can reduce the durability of the ion exchange film⁽⁶⁾. This calls for enhancement of corrosion resistance performance for BPPs with stainless steel as the base material.

The newly developed BPP enhances corrosion resistance while suppressing exposure of the stainless steel base material and providing conductivity by coating the stainless steel base material with a GLC layer and an intermediate titanium (Ti) layer, which are less expensive than the conventional gold treatment, as described in Fig. 4 in the previous chapter.

In addition, the GLC layer and intermediate Ti layer are continuously coated on the stainless steel base material, and there is no need to coat the BPP by batch processing after stamping, which enhances production efficiency. The GLC layer and intermediate Ti layer provide reliable corrosion resistance, and coating with GLC and Ti layers helped to reduce the amount of iron ion elution to about 1/30 that of stainless steel even in an acidic corrosive environment with

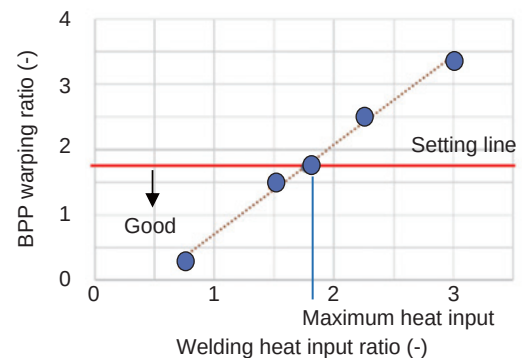


Fig. 19 BPP warpage by welding heat input

high temperature and humidity.

By contrast, if stamping is performed after surface treatment, the GLC layer and intermediate Ti layer become cracked due to elongation of the base material in stamping and scratched due to rubbing against the die, and exposure of the stainless steel base material was confirmed, as shown in Fig. 20.

It is known that the amount of iron ion elution from the BPP depends on the degree of exposure of the stainless steel base material. Therefore, when setting the cross-sectional shape of the flow channel, it is important to set a shape that takes into account elongation of the base material in stamping in order to suppress the degree of exposure of the stainless steel base material. By suppressing the stainless steel exposure ratio after stamping, the newly developed BPP achieved an amount of iron ion elution 1/10 that of conventional BPPs, as shown in Fig. 21, which also helped to lower the coating process cost.

3.3. Establishment of High-cycle Stamping of Flow Channel and Metal Bead Seal Parts

3.3.1. Elimination of resin molding and insulation inspection process

Conventional BPPs provided insulation with a perimeter rubber coating structure, but the new structure sets creepage and clearance distances based on IEC60664-1⁽⁷⁾ for the cell (power generation parts), as shown in Fig. 22. In addition, adoption of a structure without a perimeter rubber coating enabled elimination of the insulation inspection process. Compared to the previous model, this helped to reduce the amount of rubber used by 6% per cell and the amount of resin used by 54%.

It also helped to reduce the resin molding and insulation inspection processes.

3.3.2. Productivity concept

Figure 23 shows the production process flow for the conventional and new structures. Surface treatment

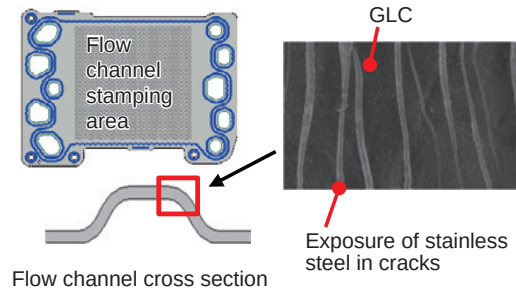


Fig. 20 Coating cracks on surface of flow channel

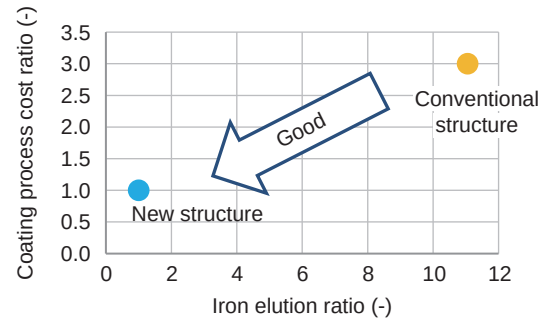


Fig. 21 Iron elution of BPP

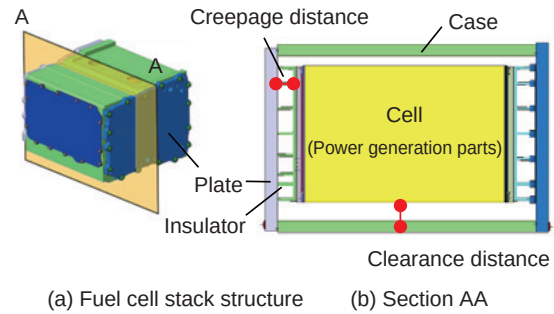


Fig. 22 Layout of creepage and clearance distances

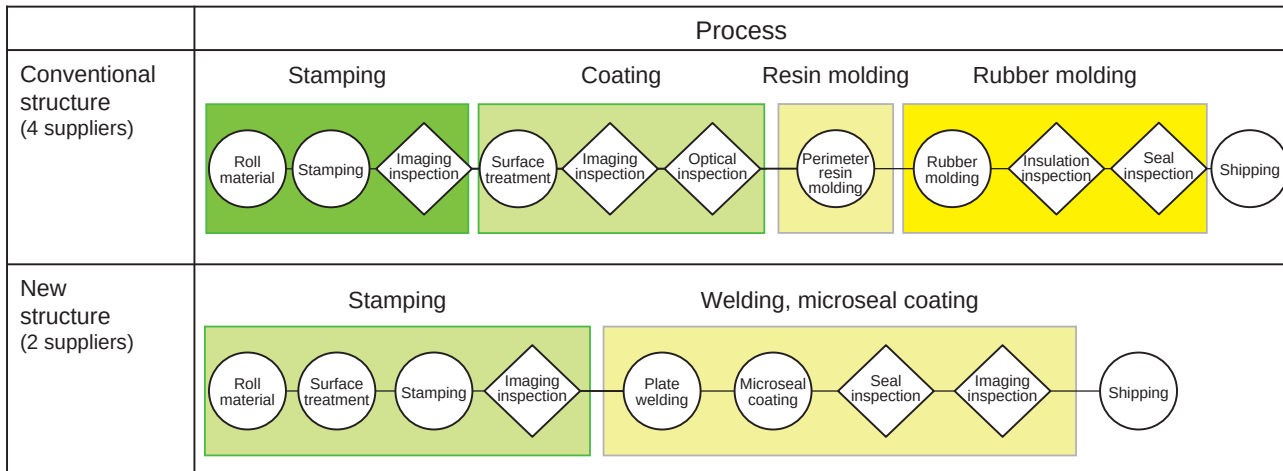


Fig. 23 Comparison of BPP processes between conventional and new structures

was conventionally performed in a separate process after stamping, but with the new structure, stamping is performed with a GLC-coated coil, which enables shortening of the process time while enhancing the cycle time.

Figure 24 shows the details of the MBS and flow channel area stamping process. The aforementioned 2Hit stamping is performed, and the laser engraving and inspection processes for quality control are fully automated.

By fully automating the resin molding, insulation inspection, laser engraving, and inspection processes, the new BPP structure achieved a production cycle time 1/20 that of the previous structure.

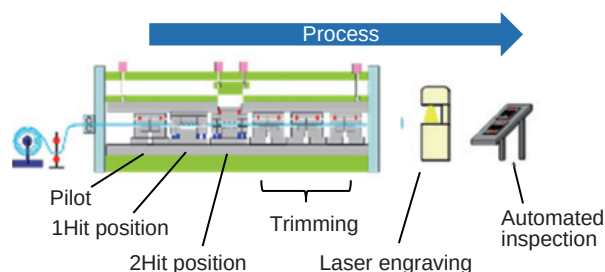


Fig. 24 Progressive stamping process flow

4. Conclusion

By enhancing productivity and reviewing materials and functions, a new BPP structure was developed that simultaneously achieves the seal function, corrosion resistance performance, and cost reduction. The following results were obtained.

- (1) The metal bead parts were designed with a cross-sectional shape and planar layout that provide uniform in-plane compressive load characteristics, and a load-bearing structure was provided to enhance sealing performance in a collision. In addition, use of a metal bead and micro seal structure achieved a structure that can help lessen the drop in the line pressure and provide the seal function. The welding conditions of the welded seal part were set to help prevent BPP warpage and sensitization and to provide bonding strength.
- (2) A 2Hit die structure is adopted and springback in stamping is suppressed to enhance flow channel warpage. At the same time, the metal bead seal parts were also changed to a 2Hit die structure and work hardening was added, enabling enhancement of the compressive load properties of the MBS.
- (3) By applying a GLC coating to the coil and adopting a shape that takes into account the flow channels and suppresses the degree of exposure of the stainless steel in stamping, the amount of iron ion elution could be reduced to 1/10 that of the conventional structure.
- (4) With the new structure, stamping is performed with a GLC-coated coil, which enabled shortening of the

process time while enhancing the cycle time. In addition, creepage and clearance distances based on IEC60664-1 were set for the cell (power generation parts), and a structure without a perimeter rubber coating was adopted.

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