

Development of New FC Separator for CLARITY FUEL CELL

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ABSTRACT

A compact and highly impact-resistant fuel cell separator was developed to enable the CLARITY FUEL CELL fuel cell stack to be mounted under the front hood.

By changing the seal cross-section of the separator from the previous trapezoidal shape with a broad foot section to a rectangular shape for downsizing, the seal width was reduced and stack volume was decreased by approximately 3 L. Also, covering the separator in resin and rubber to help ensure insulation obviated the need for the waterproofing and insulating structures commonly known as enclosure boxes, resulting in a structure that does not require sealing parts in the enclosure. Furthermore, the number of parts was reduced and processes were simplified by forming a flow path structure using the same rubber as the seal materials during seal molding. Impact resistance was also enhanced by providing indented sections made of resin at the four sides of the separator to suppress misalignment of the separator during a collision.

By integrating the production processes of press-forming, resin molding, and rubber molding for making a separator having these structures into a single process, a low-cost manufacturing method that can be applied to mass production was developed.

1. Introduction

Fuel cells (FC) are anticipated as a recycling type of clean powertrain that discharge zero CO₂ and toxic substance emissions.

In 1999, Honda mounted the in-house developed FC stack in a fuel cell test vehicle, and in 2003 announced the Honda FC stack capable of being started in cold regions⁽¹⁾. In 2006, the even more compact and lighter weight V Flow FC stack was introduced⁽²⁾. Moreover, in development of the CLARITY FUEL CELL, the aim was to make the FC stack even more compact and lighter to enable it to be mounted under the front hood⁽³⁾, so the cell was downsized and the impact resistance of the stack was enhanced. In this way, in 2016, a new FC stack that has a stack volume approximately 18 L smaller than that of the V Flow FC stack was unveiled. Figures 1(a)

and (b) respectively show the appearance of the V Flow FC stack and new FC stack. This paper introduces the separator incorporated in the new FC stack (separator for new FC stack).

2. What is a “Separator”?

As shown in Fig. 2⁽⁴⁾, the solid polymer-type FC uses a polymer electrolyte membrane to directly convert chemical energy to electrical energy by the electrochemical reaction between hydrogen and oxygen in air.

Hydrogen electrode (-): $\text{H}_2 \rightarrow 2\text{H}^+ + 2\text{e}^-$

Oxygen electrode (+): $\frac{1}{2}\text{O}_2 + 2\text{H}^+ + 2\text{e}^- \rightarrow \text{H}_2\text{O}$

The polymer electrolyte membrane through which hydrogen ions are conducted is sandwiched between two catalyst layers and gas diffusion layers, a hydrogen electrode and an oxygen electrode (air electrode) form a membrane electrode assembly (MEA)⁽⁵⁾, and this MEA is sandwiched between two separators from both sides to form a cell. Since a voltage of only approximately 1 V can be obtained by one cell even in an open circuit, cells are laminated so that a high voltage is generated.

A separator is a sheet-like part that is sandwiched between each of the cells to perform the role of cutting off hydrogen and air. In addition to functioning to seal the gas and coolant of each cell, it comprises flow paths through



Fig. 1 Appearance of FC stack

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which gas flows and assumes the function of feeding in hydrogen and air. Of all the FC stack components, the separator occupies the largest volume, and this part should be downsized so that the FC stack can be mounted on various types of vehicles. Also, misalignment of the separator should be suppressed so that the FC stack can be mounted at locations under the front hood that are subjected to large impact force during a collision.

Because several hundred separators are used per vehicle, a major issue in the manufacture of separators is how to shorten the production cycle time to reduce costs. Consequently, the molding of separators by using molds is currently being studied. Honda has so far focused on reducing cycle time by downsizing and metallic molding, and has adopted a method of injection molding of liquid rubber to help ensure insulation at press-formed separator metal parts.

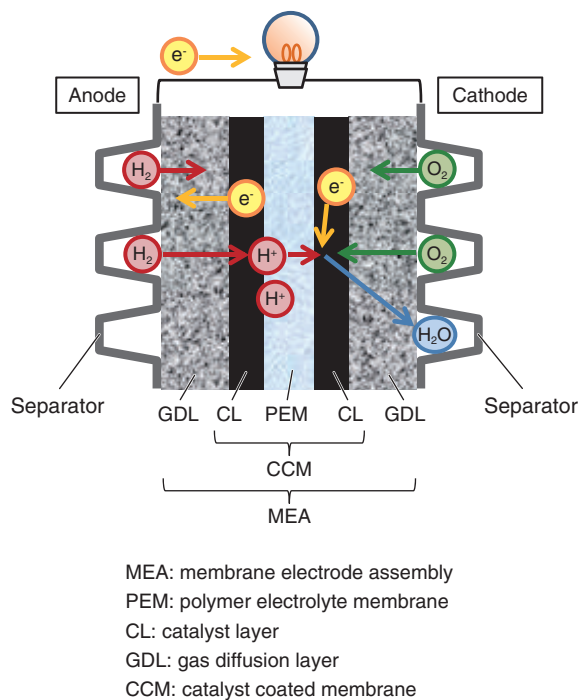


Fig. 2 Mechanism of electricity generation in FC stack

3. Development Goals

A separator was developed with the following structures to resolve the issues described above:

- (1) Seal structure for downsizing the FC stack;
- (2) Insulation coating structure for decreasing the number of parts;
- (3) Flow path structure that uses rubber for simplification of processes; and
- (4) Misalignment suppressing structure for enhanced impact resistance.

4. Features of the New FC Separator

4.1. Basic Structure of the New FC Separator

First, the basic structure of the newly developed FC separator will be explained. As shown in Fig. 3, the authors have continued to use the cell structure used in previous stacks in which two MEAs are held by three separators and that allows coolant to flow to the outer surface. The three fluids – hydrogen, air, and coolant – required for electricity generation are supplied to the electricity generating section of each cell via continuous holes set up at the separator outer periphery.

Next, the overview of development goals (1) to (4) described above will be explained. As shown in Fig. 4, these three structures – (a) gas and coolant seal structure, (b) coating structure that insulates the separator outer periphery, and (c) flow path structure that supplies gas and coolant to the electricity generating section – are molded in rubber. The seal structure should have a thick wall shape since fluids are sealed by counterforce at rubber compression. On the other hand, the insulation coating section should be of a thickness that satisfies electrical insulation requirements and that allows downsizing without rubber compression of that seal being hindered. Also, to increase the electricity

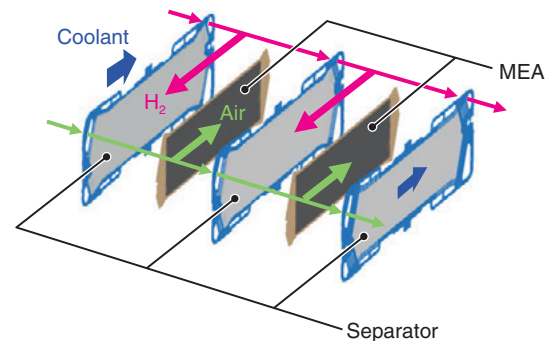


Fig. 3 One cooling layer per two cells

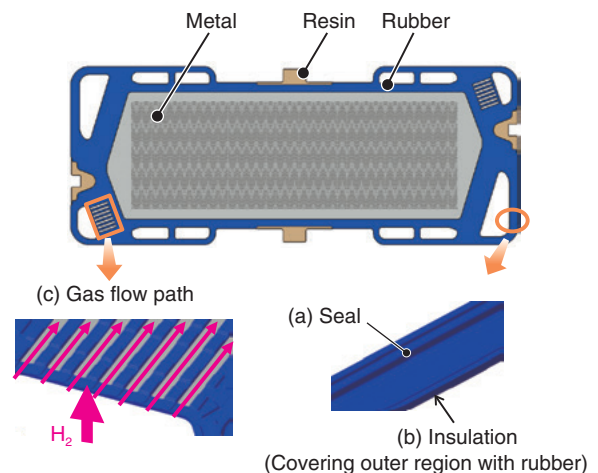


Fig. 4 New separator

generation efficiency, although all reactant gas should flow through fluid paths, some of the reactant gas flows between parts and not via fluid paths, namely, via shortcuts. This needs to be suppressed and reactant gas should be supplied uniformly to fluid paths. Normally, when press-formed separator metal parts are set in a mold for rubber molding and rubber is molded, solid rubber material, for example, is used for molding the rubber by compression [Fig. 5(a)]. However, during rubber molding, high pressure is applied to the metal parts, resulting in the issue of thin metal parts becoming deformed. Also, as it is not easy to make microshapes by compression molding, a manufacturing method of injection molding low-viscosity liquid rubber was adopted [Fig. 5(b)]. This method made it possible to mold rubber on both sides of metal parts without deformation of metal parts by reducing the compacting pressure, as well as to mold a variety of shapes having thicknesses that vary depending on their location. The misalignment suppression structure also uses high-strength resin to absorb the impact force during a collision, comprising a structure integrated with separator metal parts.

4.2. Seal Structure for Downsizing the FC Stack

Before considering downsizing, lengthening the life of seals to ensure a service life equal to that of gasoline engine vehicles was studied. Generally, compressive permanent sets of seals can be reduced and seals can be made to last longer by compressing them at a lower compression ratio. In order to obtain a high seal load even at a low compression ratio, a shape that would be less likely to spread in the lateral direction at compression was targeted, and the cross-section from the previous trapezoidal shape with a broad foot section was changed to a new rectangular shape. Figure 6 shows the results of using finite element structural analysis to compare stress in rubber under an equivalent seal load. It can be seen that, with this new

shape, an equivalent seal load is obtained at a compression ratio lower than that with the previous shape. By changing the shape of the cross-section, the required seal load at a lower compression ratio can be obtained (Fig. 7), and as a result, the amount of reduction in the seal load can be reduced and durability can be enhanced as shown in Fig. 8.

Next, the seal width was decreased from that in previous specifications. Seals approximately 1000 m or more in

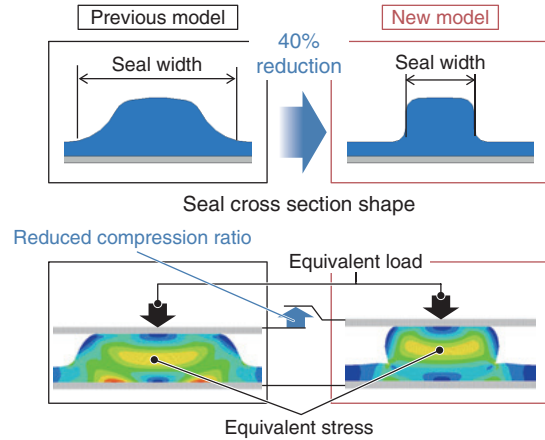


Fig. 6 Stress distribution in seal compressed state

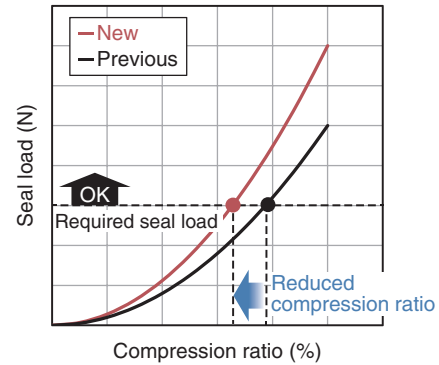


Fig. 7 Comparison of compression ratios

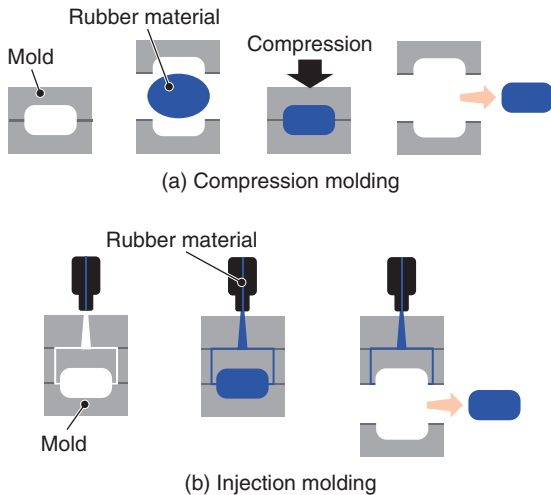


Fig. 5 Comparison of rubber manufacturing methods

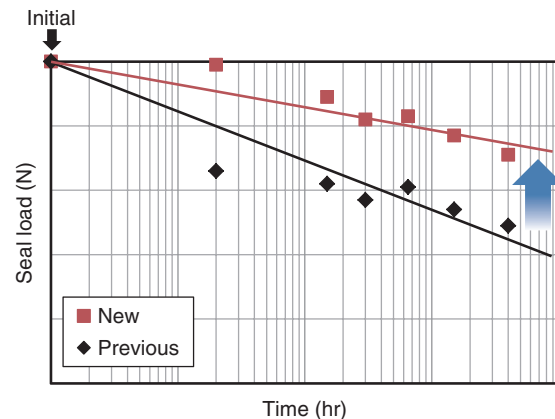


Fig. 8 Comparison of seal load behavior

length are used in each FC stack. For this reason, the stack volume can be reduced if the seal width can be decreased. However, ensuring sealing performance with misaligned parts as shown in Fig. 9 becomes a challenge if the seal width is reduced too much on a stack in which thin metal sheets and seals are repeatedly laminated.

For this reason, flat sections were provided at the seal upper surface, producing a shape that is difficult for a drop in seal load to arise even with parts in a misaligned state. Moreover, the distribution of the seal load was predicted by finite element structural analysis. Although a region in which two seals do not overlap is formed when parts become misaligned and out of position, it can be seen that the rigidity of the metal sheets in between generates a seal load in that region, as well (Fig. 9). Because part of the region in which the seals do not overlap is regarded as seal width, the actual seal width becomes larger than the width in which the seals are overlapping. The width was further reduced by the amount of increase in seal width due to this effect.

The width in which the required seal load could be ensured was ascertained, and the seal width was reduced by approximately 40% and the stack volume was decreased by approximately 3 L from the previous specification.

4.3. Insulation Coating Structure for Decreasing Number of Parts

Separator metal parts using high voltage should be electrically insulated from the outside. In one generally known method, rather than providing individual separators with an insulating structure, separators are stored in an enclosure box with waterproofing and insulation functions⁽⁶⁾. In this development, however, a structure that gives separators an insulating coating was achieved by seal rubber molding as described above, and at the same time, by covering the outer periphery of separator metal parts in rubber. Giving separators an insulating coating obviates the need for the waterproofing and insulating structure of enclosure boxes, enabling a structure that does not require sealing parts in the enclosure.

Figure 10 shows the outer circumference insulating structure of the separator. Resin is outsert molded on metal parts and rubber is formed to cover that resin. Metal is insulated from the outside by adhering the boundary

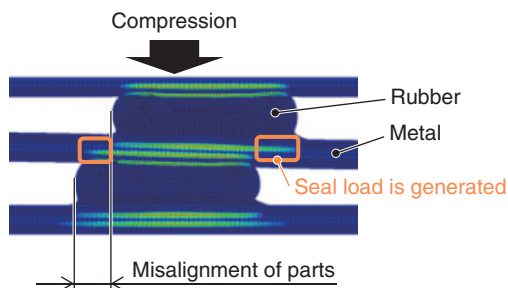


Fig. 9 Cross section of seal

between the resin and rubber during molding. The adoption of this structure improved insulation.

4.4. Flow Path Structure Using Rubber to Simplify Processes

Although a separator needs both inlet and outlet to supply fluids to the electricity-generating section, a structure for affixing variously shaped metal or resin parts to the separator is commonly used. However, securing and fastening the variously shaped metal or resin parts required in this case increases costs.

In this development, sealing rubber molded by the manufacturing method described above was applied and, at the same time, rubber was used in forming the fluid inlet and outlet. The fluid inlet and outlet should intersect with the seal of a different layer isolating each of the fluids. This was achieved by the bridge pier structure as shown in Fig. 11. Since this is an integrated structure formed by

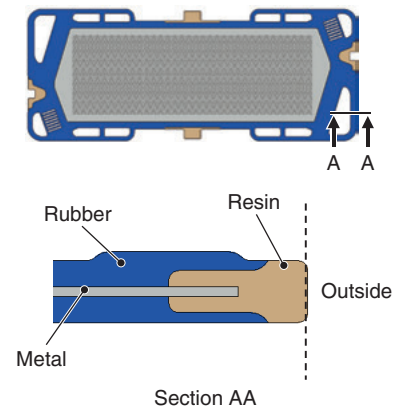


Fig. 10 Electrical insulation structure

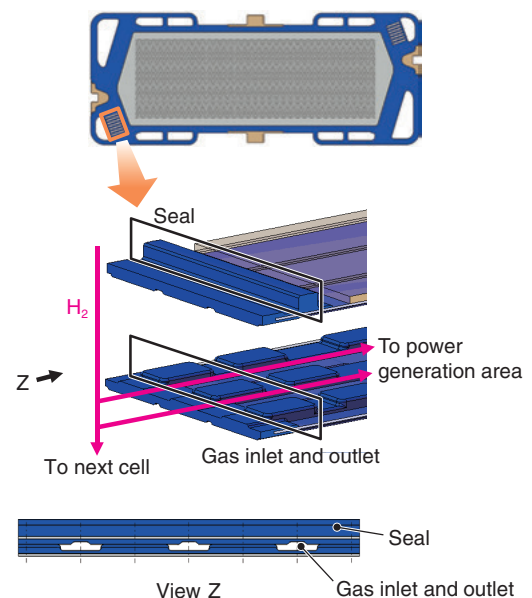


Fig. 11 Fluid inlet and outlet structure

a mold, dimensional accuracy is high, which also makes it effective for the stable supply of fluids.

Next, this section explains the structure that uses rubber to suppress shortcuts that allow some of the reactant gas to avoid the fluid paths and flow to gaps between parts. As shown in Fig. 12(a), when molding rubber on press-formed metal, the mold should be pressed against the metal, requiring a mold press fixture to prevent outflow of rubber. Because metal is in close contact with the mold in that section, rubber cannot be molded in the forming of a space. Electricity generation efficiency drops because gas that cannot contribute to electricity generation flows to that space. In response to this issue, ribs such as that shown in Fig. 12(b) are formed in rubber and the space that has been formed until now is filled in with rubber. As a result, gas making a shortcut while the mold press fixture is secured can be reduced. This gas shortcut suppression structure using rubber is an effective measure since it has a high degree of shaping freedom and can also be applied to microgaps.

Next, the features of the manufacturing method for the gas shortcut suppression ribs will be explained. Uneven shapes from which molded shapes cannot be removed simply by splitting the mold in two are generally called “undercut,” as illustrated by the slide mold shown in Fig. 13(a) in which the mold is split. However, a slide mold cannot be situated near rib forming since there exist press-formed parts. In this development, the angle of the rib was studied and an easily molded shape was established to enable rubber to be removed by a two-way extraction mold without being damaged and without the use of a slide mold, by a method called “forced extraction” as shown in Fig. 13(b).

4.5. Misalignment Suppressing Structure for Enhanced Impact Resistance

In mounting the FC stack under the front hood, impact resistance should be enhanced since the impact force on the FC stack in the event of a frontal collision increases when compared with previous mounting on the center tunnel.

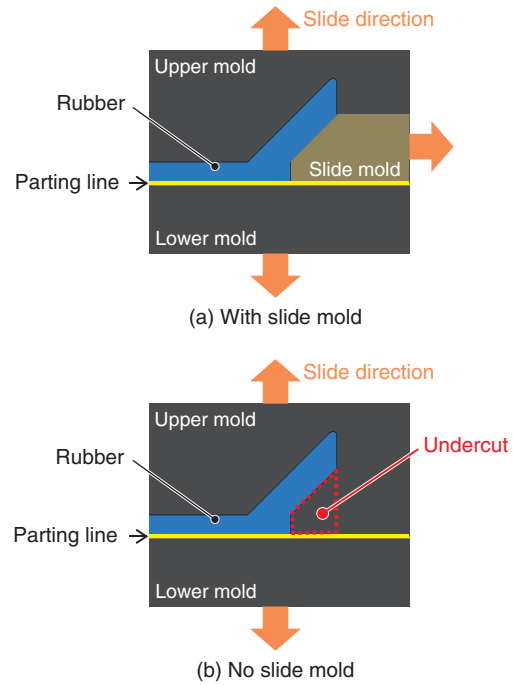


Fig. 13 Rubber undercut shape

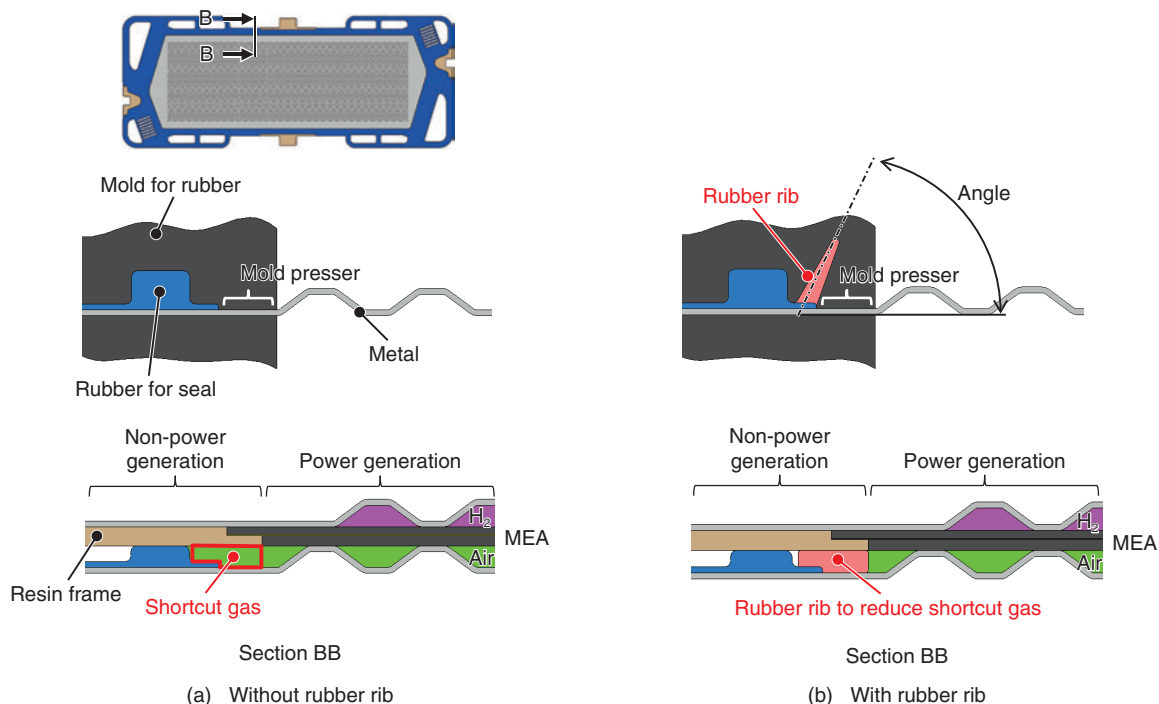


Fig. 12 Rubber rib to reduce shortcut gas

Major impact force applied on the separators of a stack, which is a laminated body, could result in misalignment of parts. For this reason, a bar connection single-box stack structure capable of suppressing cell misalignment was developed. This structure provides indented sections at the four sides of the separator as shown in Fig. 14, and connects the end plates at both ends of the stack by means of bars to hold the indented sections on the separator. Because these indented sections use injection molding of high-strength resin to form an integral structure on the metal separator, insulation between the connection bars and separator, which is a high-voltage area, can be ensured.

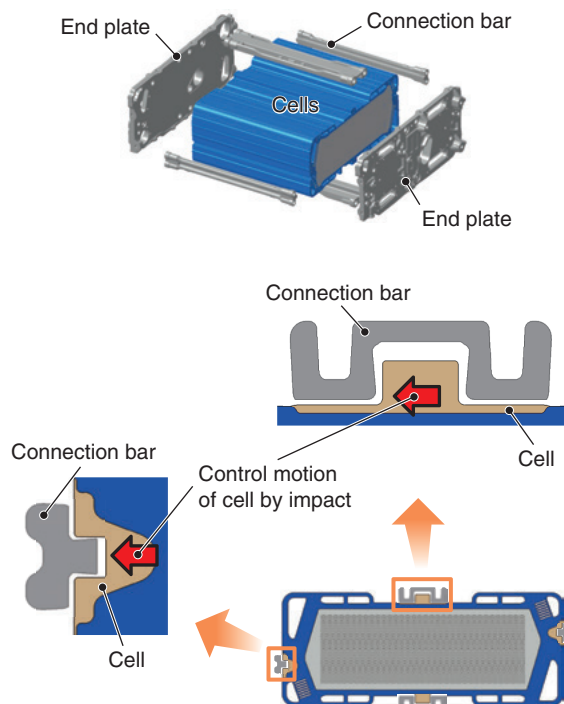


Fig. 14 Separator with high impact resistance

5. Conclusion

Listed below are the benefits of the compact and highly impact-resistant new FC separator that was developed using a manufacturing method that can be applied to mass production:

- (1) Application of finite element structural analysis to optimize the seal cross-section of the separator seal to a rectangular shape decreased the seal width by approximately 40% over previous separators while enhancing durability, also reducing the volume of the stack by approximately 3 L.
- (2) The structure of the separator insulation coating does not require sealing parts in the enclosure.
- (3) Use of rubber at fluid inlets and outlets reduced the

number of parts and simplified processes. In addition, the amount of gas that cannot contribute to electricity generation was reduced by means of gas shortcut suppression ribs made using a forced extraction manufacturing method characteristic of rubber.

- (4) Mounting of the fuel cell stack under the front hood was enabled by providing indented sections made of resin at the four sides of the separator to increase impact resistance.

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