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Development of a new structural fuel cell and stack

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ABSTRACT: The newly developed structural fuel cell stack for fuel cell vehicles achieves more than twice the durability and one-third the cost of previous fuel cell stacks while maintaining their basic performance.

To improve the durability of the fuel cell stack, we controlled the operating environment, improved the electrolyte membrane durability by reducing iron elution from the bipolar plates, and suppressed the degradation of the catalyst by specifying the contact angle of the bipolar plate to mitigate unstable power generation. To reduce the cost of the fuel cell stack, we achieved the same net power as the previous fuel cell system with fewer cell stacks. Major cost reductions include the use of metal beads for the sealing structure of the bipolar plate, adopting a rubber coating-less structure, applying Pt alloys to the electrode catalyst of the Unitized Electrode Assembly to reduce the amount of Pt, and reducing the thickness of the electrolyte membrane.

KEY WORDS: fuel cell stack, durability, cost, bipolar plate (BPP), electrolyte membrane, catalyst,

1.INTRODUCTION

Global warming has become so severe that in July2023, UN Secretary-General António Guterres warned that the earth has entered the era of global boiling(1). At COP28, the 28th Conference of the Parties, in 2023, it became clear that humanity is falling short of achieving the 1.5°C target of the Paris Agreement adopted at COP21 in 2015(2). Meanwhile, moves are underway to reduce and absorb greenhouse gas emissions, which are a factor in rising temperatures.

Hydrogen, in particular, is important to help achieve not only carbon neutrality but also energy resilience(3).

Fuel cells are anticipated as circulation-type clean energy sources that do not emit CO_2 or harmful substances, addressing global warming and energy issues. In the late 1980s, we focused on the potential of hydrogen energy and began basic research on fuel cells(4). As a result, we have more than doubled the durability and reduced the cost to one-third of that of previous fuel cell stacks while maintaining the output performance of the newly developed fuel cell stack.

Based on this evolution, as shown in Fig. 1, we are considering expanding its application to four other areas: commercial vehicles, stationary power sources, construction machinery, and new fuel cell vehicles (FCEVs).

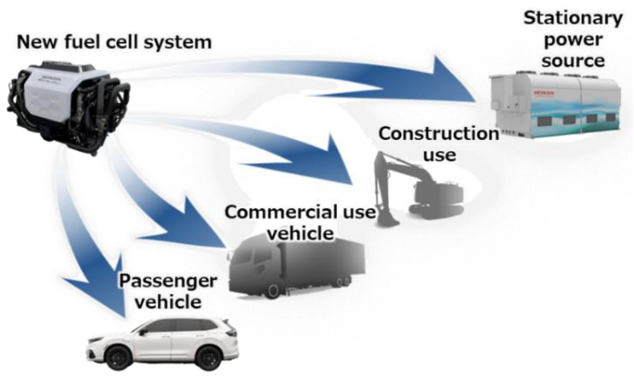

Fig. 1 Expanding application of fuel cell system

2. IMPROVED DURABILITY OF FUEL CELL STACKS

The new fuel cell stack achieves more than twice the durability by combining the stack structure and control, applying the following technologies:

・Improved electrolyte membrane durability through temperature and humidity control

・Reduction of iron elution by changing bipolar plate (BPP) coating

・Ensuring power generation stability by specifying the contact angle of the BPP

2.1. Dealing with chemical degradation of electrolyte membranes

The effects of temperature, humidity, current, and O_2 partial pressure as degradation factors on the electrolyte membrane were confirmed using the experimental design method through single cell testing. A degradation model of the electrolyte membrane, shown in Equation (1), was constructed. Equation (1) shows the amount of chemical degradation stress, while Equation (2) shows the relationship between the amount of stress and molecular weight retention rate. To ensure durability, we developed this degradation model and controlled the operating environment.

$$S_C = \exp\left(C_{Temp} \times Temp + C_{RH} \times RH + C_J \times J + C_1\right) \times C_{P_{O2}} \times P_{O2} \quad (1)$$

$$Mw = exp(C_{Sc} \times S_C \times t) + C_2 \quad (2)$$

S_C = Chemical degradation stress
Mw = Molecular weight retention rate
t = Time
Temp = Temperature
RH = Humidity
J = Current density
P_{O2} = O_2 partial pressure
C = Coefficient for each degradation element

As Eq. (2) shows, the degradation model consists of temperature, humidity, current density, and oxygen partial pressure. In particular, as low humidity accelerates membrane degradation all at once, operation is controlled so that the humidity input to the stack is kept above a certain level to help ensure durability[5].

Fig. 2 compares the electrolyte membrane's molecular weight retention rate as calculated in Eqs. (1) and (2) based on operating history during FC system durability testing with actual values measured after durability testing was completed. The range of measured values indicates variation among measured values at multiple locations by their stacking position and within the cell plane. The measured values show that degradation progressed more than the predicted values suggested. Although it was confirmed that the necessary durability was maintained, this discrepancy is presumed to be because of accelerated degradation caused by iron contamination. It has been confirmed that when deterioration acceleration caused by the maximum amount of iron mixed in during durability testing is taken into account, it nearly matches the lower limit of variation of actual measured values.

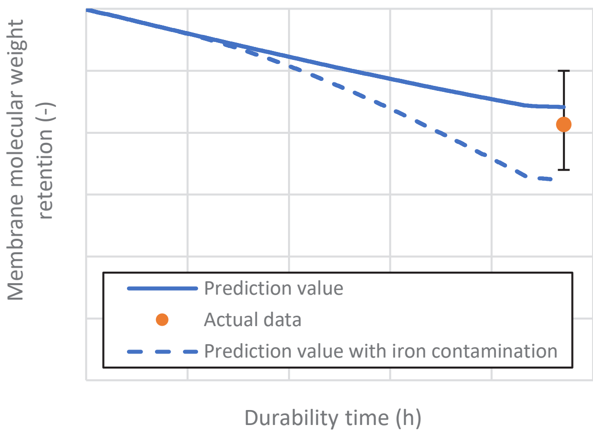

Fig. 2 Membrane degradation comparison of actual and prediction at FC system durability test

2.2. Reduction of iron elution by changing BPP coating

The chemical degradation of the electrolyte membrane in a polymer electrolyte fuel cell accelerates due to iron contamination[6] , making it necessary to reduce iron elution from the BPP substrate. BPPs generally use stainless steel as the base material, and it is known that in an acidic corrosive environment with high temperature and high 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 electrolyte membrane. Therefore, BPPs based on stainless steel need to improve corrosion resistance.

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

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 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. 3.

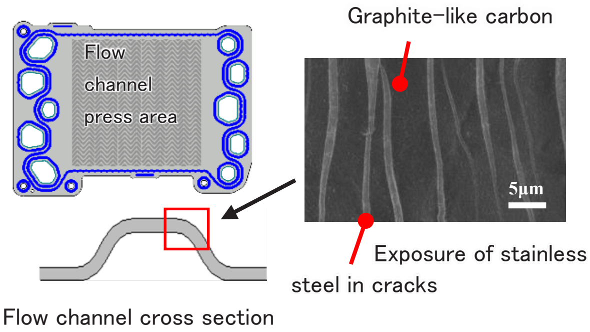

Fig. 3 Coating cracks on surface of flow channel

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. 4, which also helped to lower the coating process cost.

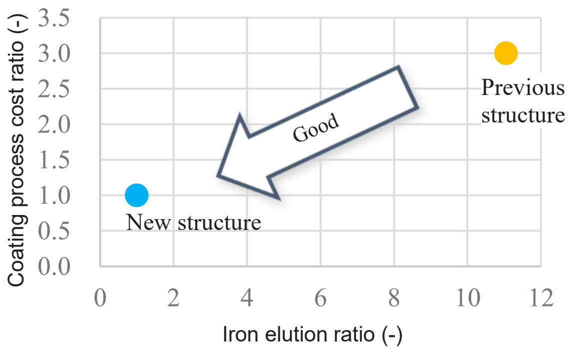

Fig. 4 Iron elution of BPP

2.3. Suppression of catalyst degradation by regulating BPP contact angle

It is necessary to suppress the decrease in the Pt surface area effective for power generation due to the reduction of the Pt amount. To prevent the degradation of the electrode catalyst, it is essential to stabilize the cell voltage.

The mechanism of electrode catalyst degradation is shown in Fig. 5. In the power generation range of a fuel cell (0.6 to 0.8 V), the Pt surface is oxidized or reduced due to voltage fluctuations caused by load changes, and the Pt surface area decreases due to Ostwald growth, in which Pt repeatedly elutes and precipitates. When the voltage exceeds 0.85 V during startup or when power is being generated close to the open-circuit voltage, the amount of elution due to Pt oxidation increases. Furthermore, it is known that the presence of oxygen at the anode electrode during startup raises the cathode potential to about 1.5 V, which increases the Pt particle size and in addition degrades the carbon carrier[7].

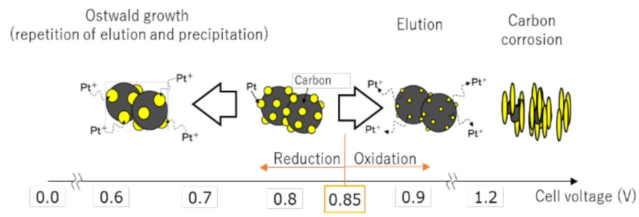

Fig. 5 Mechanism of electrode catalyst degradation

However, in the new fuel cell stack, the input gas supply is reduced by up to 17% compared to the previous model to increase system efficiency. In this case, when the water generated in the Unitized Electrode Assembly (UEA) cannot be sufficiently discharged into the flow path of the BPP, leading to an increased possibility of unstable power generation due to insufficient gas supply to the UEA. To mitigate this issue in the new fuel cell stack, it is necessary to increase the surface energy of the BPP, making it easier for the BPP to receive generated water from the UEA. Therefore, power generation stability was achieved by specifying the surface energy of the BPP as the contact angle.

Fig. 6 shows the results of evaluating cell voltage instability and contact angle of BPP. It was confirmed that power generation becomes stable when the contact angle of BPP is reduced to a certain value, so the contact angle of BPP was set to this value to ensure stable power generation.

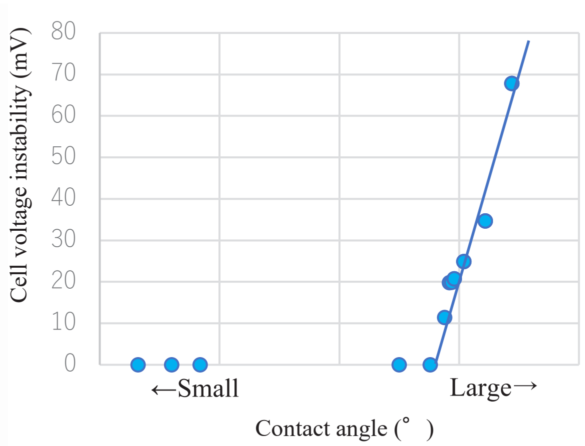

Fig. 6 Correlation between cell voltage instability and contact angle of BPP

3. REDUCING FUEL CELL STACK COST

Fig. 7 shows the cost comparison between previous and new-structure fuel cell stacks. For cell costs, which account for the majority of fuel cell stack costs, we maintained the same net power as previous fuel cell systems while reducing the number of cell stacks by 15% compared to previous stacks. This was achieved through improved IV performance due to adoption of a Pt alloy catalyst with high catalytic activity and reducing the power consumption of auxiliary equipment to supplement stack power generation.

Additionally, the cost of the cell unit structure and the stack structure responsible for fastening and protecting the cell unit (Fig. 8) has been reduced, resulting in the cost of the new-structure fuel cell stack being reduced to one-third of that of the previous stack.

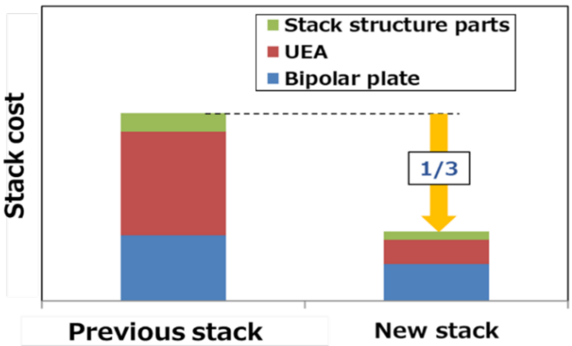

Fig. 7 Fuel cell stack cost

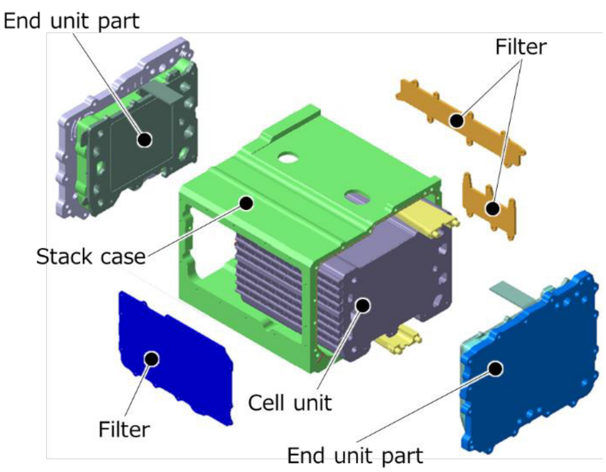

Fig. 8 New stack structure

3.1. Structural simplification and material review of BPP

As shown in Fig. 9, to reduce the cost of BPP, the coating on the surface of the base metal was changed, the sealing structure between cells was modified, and the outer rubber-coated structure was eliminated. The new structure simplifies the BPP by adopting a sealing structure with metal beads and micro-seals, achieved by welding two base metal plates together.

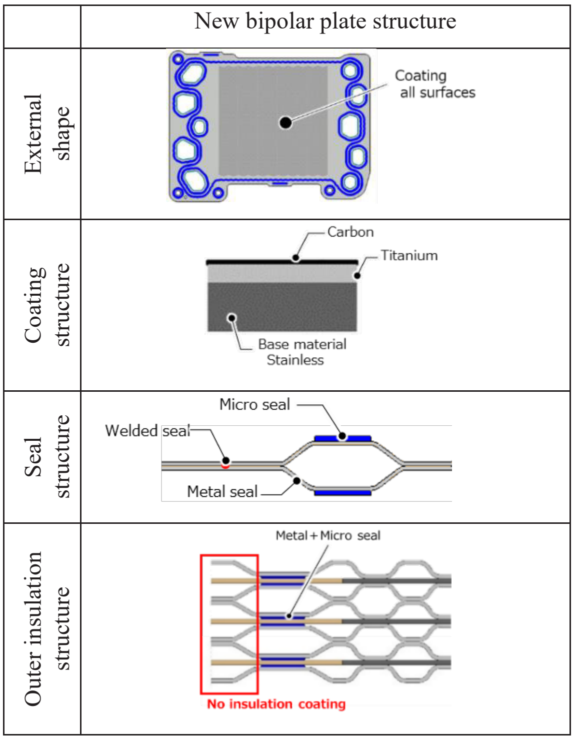

Fig. 9 New BPP structures

3.2. UEA material and structure changes

New UEA has a structure as shown in Fig. 10 and uses a highly active Pt alloy catalyst in the electrode layer, reducing the amount of Pt used to one-fifth of that in previous UEA.

Additionally, while a membrane product (single film) from a cooperating supplier was used in the past, a unique coating process has been adopted, reducing the thickness of the electrolyte membrane to three-fifth and lowering the cost of the UEA.

By improving the activity of the catalyst and reducing resistance through the thinner electrolyte film, the performance degradation caused by the reduction in platinum was compensated, resulting in output performance equal to or better than that of previous UEA.

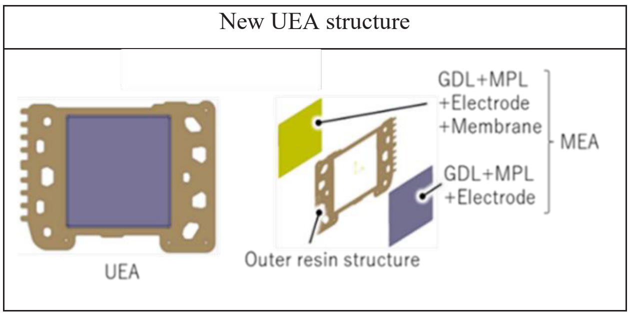

Fig. 10 UEA cost reduction structure

4. CONCLUSIONS

The features of the newly introduced technologies for the fuel cell stack are summarized below.

(1) Durability was improved by introducing the following technologies.

- By reviewing the coating material of BPP, we reduced not only costs, but also reduced iron elution to less than one-tenth of previous material.
- By optimally controlling temperature and humidity, the durability of the electrolyte membrane has been enhanced.
- The stability of power generation was ensured by specifying the contact angle of the BPP.

(2) The following technologies were used to reduce costs.

- By improving IV performance due to adoption of a Pt alloy catalyst with high catalytic activity and reducing the power consumption of auxiliary equipment, we managed to reduce the amount of precious metals used to one-fifth and decrease the number of cell layers by 15% compared to the previous fuel cell stack with the same output.
- By adopting a new shape of BPP and UEA, the structure has been simplified while ensuring performance.

As a result, the newly developed fuel cell stack has more than doubled the durability and reduced the cost to one-third of that of previous fuel cell stacks while maintaining the same net power.

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