

Application of Novel Porous Metals with Felt-like Structures to AEM Water Electrolyzers

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Nickel Celmet, a product of Sumitomo Electric Toyama Co. Ltd., is a porous metal featuring a three-dimensional network structure. We have been investigating the application of Celmets as porous transport layers (PTLs) for anion exchange membrane (AEM) water electrolysis and have previously reported that it enables high cell performance. However, further studies have indicated that, depending on the cell configuration, performance can be improved by using PTLs with denser structures than Celmets. In this work, we developed a felt-type Celmet for use in such cells. The resulting material combines the advantages of both conventional Celmet and metallic felt, and its properties are reported here.

Keywords: AEM water electrolysis, Celmet, porous metal, porous transport layer (PTL), felt

1. Introduction

In line with growing deployment of renewable energy, Power-to-Gas, which uses surplus electricity for water electrolysis and utilizes the produced hydrogen for energy storage and transport, has attracted attention.⁽¹⁾ Among water electrolysis methods, anion exchange membrane (AEM) electrolysis is regarded as a promising method to achieve both low cost of alkaline water electrolysis and high performance of proton exchange membrane (PEM) electrolysis.^{(2),(3)} Meanwhile, many challenges remain for practical implementation. For the porous transport layer (PTL*) used in AEM water electrolyzers, several requirements must be satisfied, although they are often in trade-off relationships: (1) gas transport performance, (2) catalyst retainability, and (3) a framework structure that minimizes damage to the AEM. Efforts are underway to develop materials that meet these requirements.

Nickel (Ni) Celmet, which is a product of Sumitomo Electric Toyama Co., Ltd., is a porous metal with a three-dimensional network structure. It is a promising material for the PTL due to its high porosity. Previously, we reported the development of “layered Celmet,” which is fabricated by stacking small-pored and large-pored Celmet, and demonstrated its high cell performance by satisfying the requirements for PTLs.⁽⁴⁾ However, we subsequently found that some PTL structures can further improve the performance. For example, if the grooved bipolar plate on the back side of the PTL has high gas transport capability, the importance of (1) gas transport performance required of the PTL decreases in relative terms, while (2) catalyst retainability and (3) a structure that minimizes damage to the AEM become more important. Under such conditions, a more densely packed surface structure is required (Fig. 1).

In this paper, we developed a Ni Celmet with a felt-like structure to meet these design requirements. Evaluations were conducted on the obtained material, which was compared with conventional Celmet and a commercially available metallic felt to propose a new PTL option for AEM water electrolyzers.

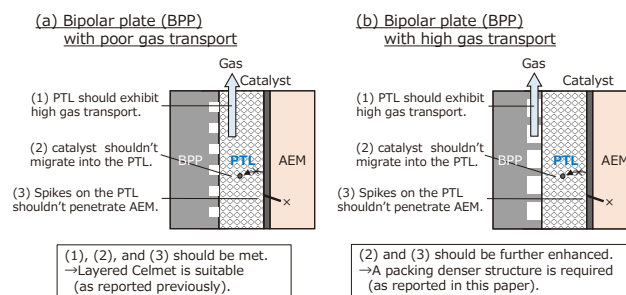


Fig. 1. Cell configuration and required properties

2. Experimental Method

2-1 Fabrication of felt-type Celmet

Celmet is manufactured by applying conductive treatment and electroplating to polyurethane foam as the substrate, followed by heat treatment to remove the polyurethane. Thus, porous metals of various shapes can be formed by altering the resin structure of the substrate (Fig. 2). We fabricated “felt-type Celmet” by using a resin felt substrate instead of polyurethane foam. When this material is used as the PTL, it can be roll-pressed*2 to a desired thickness. In this study, evaluations were conducted with felt-type Celmet roll-pressed to a thickness of 0.3 mm, which is the PTL thickness of our in-house evaluation cells. Scanning electron microscopy (SEM) was used for observation of the appearance and cross-sectional structure.

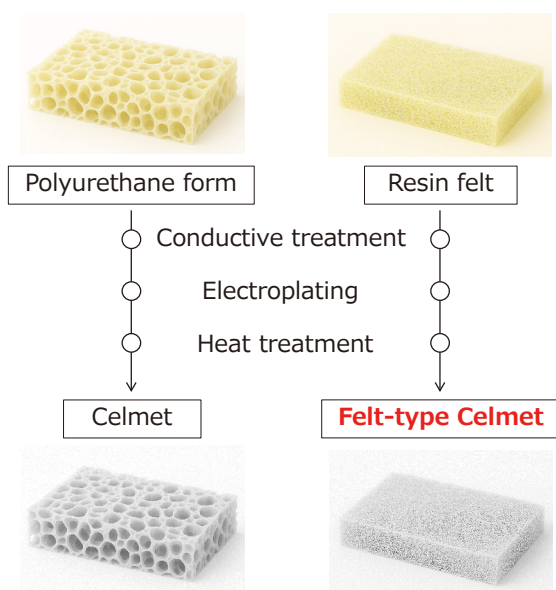


Fig. 2. Manufacturing process of felt-type Celmet

2-2 Measurement method for catalyst retainability

Because the catalyst is located at the PTL–AEM interface, a large contact area between the PTL and the AEM is considered to enhance catalyst retainability. To quantify this characteristic, the PTL surface was observed using a laser microscope (VK-X100, Keyence). In each 1.0×1.5 mm field of view, we measured the area where the surface height was within $1 \mu\text{m}$ of the highest point on the PTL surface. The fraction of this area relative to the total field-of-view area was defined as the “percentage of the catalyst retention area”. The evaluation was conducted at 10 points, and the mean value was defined as the percentage of the catalyst retention area of the material.

2-3 Measurement method for short-circuit pressure

To assess the risk of mechanical damage to the AEM, the short-circuit pressure was measured. As shown in Fig. 3, an insulating sheet used as a substitute for the AEM was stacked with the PTL, and the stack was sandwiched between metal plates and subjected to a compressive load. Initially, the metal plates are insulated from the PTL. However, when a load is applied, the insulating sheet is damaged by the spikes on the PTL surface, resulting in a short circuit between the upper metal plate and the PTL. The pressure that causes a short circuit is referred to as the short-circuit pressure. A higher short-circuit pressure indicates a lower likelihood of damage to the insulating sheet.

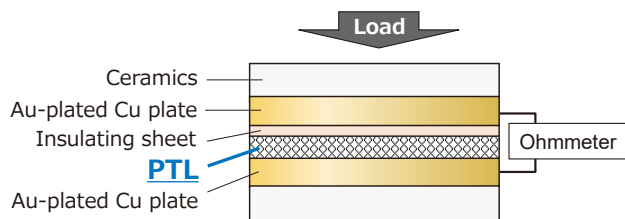


Fig. 3. Jig for measuring the short-circuit pressure

The short-circuit pressure serves as an index of potential damage to the AEM. In this measurement, a 0.025 mm-thick PTFE^{*3} sheet with mechanical properties similar to those of the AEM including puncture resistance was used. The evaluation was conducted five times, and the mean value was defined as the short-circuit pressure of the PTL.

2-4 Measurement method for pressure loss^{*4}

Pressure loss was measured to evaluate the gas transport performance of the PTL. A custom-built jig was used to feed air at a certain flow rate from the PTL surface via an air supply pipe and allow the air to pass through the PTL and exit from the back side. The pressure when air is fed with and without the PTL arranged on the jig was measured, and the difference was defined as pressure loss. The air flow rate was set to 0.5 L/min.

2-5 Evaluation method for water electrolysis

The cell performance of an AEM water electrolyzer using felt-type Celmet as the anode PTL was evaluated using an in-house setup. The bipolar plate featured straight flow channels to enhance gas transport. Carbon paper^{*5} was used for the cathode PTL, and felt-type Celmet was used for the anode PTL. Regarding the catalysts, a platinum catalyst was loaded at 1 mg/cm^2 for the cathode, and an iridium oxide catalyst was loaded at 1 mg/cm^2 for the anode. The catalysts were applied on the PTL (CCS^{*6}). Before electrolysis, the cell was conditioned^{*7} under constant-current operation for a certain period. For the electrolysis, the cell voltage after holding for three minutes at each current density was plotted. In addition, electrochemical impedance was measured to extract the reaction resistance at each current density, and equivalent-circuit fitting was performed based on the obtained Nyquist plot.

3. Result and Discussion

3-1 Observation of felt-type Celmet

Figure 4 shows the SEM image of the felt-type Celmet surface, and Fig. 5 shows the cross-sectional SEM image. For comparison, SEM images of the previously reported layered Celmet and a metallic felt are also shown.

Layered Celmet is characterized by high surface smoothness because hollow skeletons, which are characteristic of Celmet due to its manufacturing method, collapse during roll pressing. However, its packing density is low due to the three-dimensional network structure. In contrast, the metallic felt has a high packing density because stacked fibers form a dense structure, but its surface is less smooth because the framework doesn't collapse during pressing. Felt-type Celmet combines the high packing density of the metallic felt with the surface smoothness of layered Celmet. This combination is expected to improve catalyst retainability. For layered Celmet, spikes are exposed on the surface, serving as the origin of damage to the AEM. By contrast, felt-type Celmet doesn't have such exposed spike, and which is expected to be advantageous in reducing damage to the AEM. As shown in Fig. 5, the cross sections of the layered Celmet have sharp edges, whereas those of the felt-type Celmet are free of sharp edges. This difference is also expected to reduce mechanical damage to the AEM.

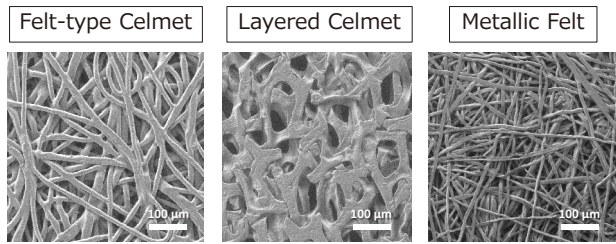


Fig. 4. Surface SEM image

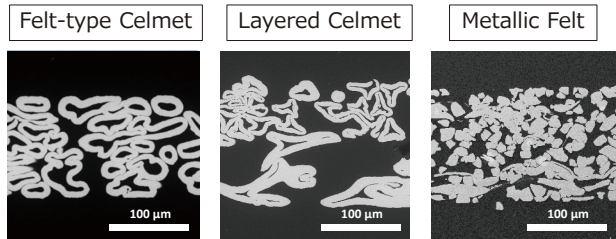


Fig. 5. Cross-sectional SEM image

3-2 Catalyst retainability

Figure 6 shows the results for the catalyst retention area percentage. Felt-type Celmet exhibited a higher value than the other two samples. This improvement is likely due to its densely packed and smooth surface, as discussed in Section 3-1.

3-3 Short-circuit pressure

Figure 7 shows the evaluation results of the short-circuit pressure. Felt-type Celmet exhibited a much higher short-circuit pressure than the other two samples. This improvement is likely due to its smooth surface and the absence of exposed spikes on its surface, as discussed in Section 3-1.

3-4 Pressure loss

The evaluation results of pressure loss are shown in Fig. 8. Because felt-type Celmet has higher packing density than layered Celmet, its pressure loss is not higher than that of layered Celmet, but is lower than that of the metallic felt. This result is consistent with our design assumption that, when the bipolar plate has sufficient gas transport, a low-pressure loss isn't critical. Its impact on the cell performance is discussed in 3-5. For the metallic felt, it is difficult to pack fibers loosely due to the manufacturing method, resulting in high pressure loss. By contrast, felt-type Celmet uses a resin felt, which allows the fibers to be packed more loosely. This provides flexibility in tailoring the structure, enabling the pressure loss to be reduced to the level targeted in the present design.

3-5 Water electrolysis

Finally, the cell voltage measurement results are presented in Fig. 9. The cell voltage of felt-type Celmet is lower than that of the other two PTLs at all current densities. The superior cell performance of felt-type Celmet was confirmed. The lower voltage of felt-type Celmet is attributed to high catalyst retainability and low pressure loss. High catalyst retainability is considered to reduce the resistance of oxygen evolution reaction (OER), while lower

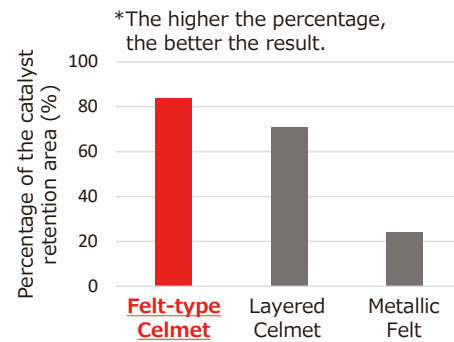


Fig. 6. Catalyst retainability

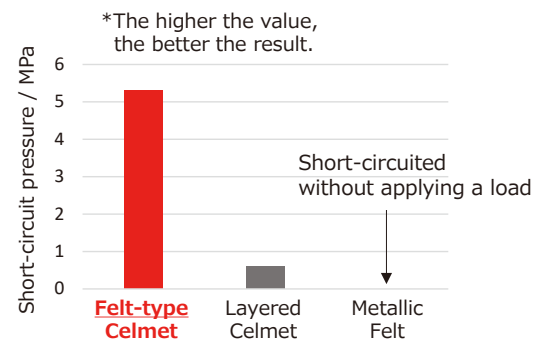


Fig. 7. Short-circuit pressure

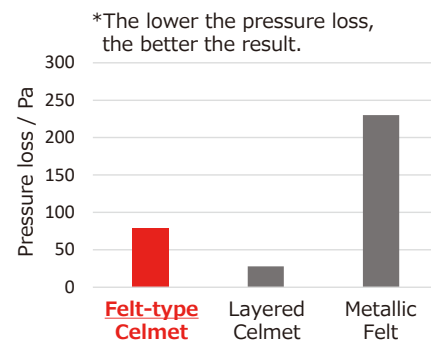


Fig. 8. Pressure loss

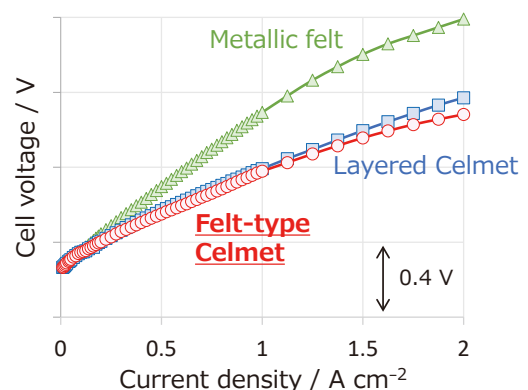


Fig. 9. Cell voltage

pressure loss is considered to reduce the mass transport resistance. To verify this hypothesis, equivalent circuit fitting was performed based on the electrochemical impedance spectroscopy (EIS) data. The reaction resistance values of hydrogen evolution, oxygen evolution, and mass transport at low current density (0.1 A/cm²) and high current density (2.0 A/cm²) were tabulated (Table 1). By comparing the three PTLs, the reactions showing lower resistance for felt-type Celmet were identified as those contributing to its superior cell performance. These reactions were then identified from Table 1. Reactions associated with superior electrolysis characteristics of felt-type Celmet were found to be oxygen evolution in the low current density and oxygen evolution and mass transport in the high current density. These results support the above hypothesis.

Table 1. Reaction resistance values

Current density	Reaction resistance	PTL type		
		Metallic felt	Layered Celmet	Felt-type Celmet
0.1 A/cm ²	Hydrogen	0.06	0.06	0.06
	Oxygen	0.19	0.22	0.17
	Mass transfer	0.05	0.05	0.05
2.0 A/cm ²	Hydrogen	0.03	0.03	0.03
	Oxygen	0.07	0.13	0.07
	Mass transfer	0.11	0.08	0.08

(unit: Ω cm²)

4. Conclusion

In this paper, we developed felt-type Celmet for the PTL of AEM water electrolyzers. In a cell structure with high gas transport performance of the bipolar plate, felt-type Celmet exhibited superior cell performance. Felt-type Celmet is also highly effective in reducing damage to the AEM.

Felt-type Celmet is expected to provide a new PTL option for water electrolyzers and to enhance customer value through improved electrolyzer performance. We will continue to develop PTLs optimized for our customers' cell designs.

• Celmet is a trademark or registered trademark of Sumitomo Electric Industries, Ltd.

Technical Terms

- *1 Porous transport layer (PTL): A porous material in which water electrolysis reaction occurs in water electrolyzers.
- *2 Roll pressing: A processing method in which a material is compressed by rollers. It is used to attain uniform thickness and density.
- *3 PTFE: Polytetrafluoroethylene. A fluororesin characterized by high insulation and low-friction properties.
- *4 Pressure loss: A phenomenon in which the fluid pressure decreases due to resistance generated when a fluid flows in a pipe. The lower the value, the higher the gas transport performance.
- *5 Carbon paper: A paper-like conductive material made from carbon fibers.
- *6 CCS: An abbreviation for “Catalyst Coated Substrate.” In this method, a catalyst is coated on the PTL side. It is distinguished from the Catalyst Coated Membrane (CCM), in which a catalyst is coated on a membrane.
- *7 Conditioning: An initial operation process used to stabilize the electrode, catalyst, and membrane and to enhance performance and durability in water electrolysis.

References

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