Studies on the Forming Process for the Bipolar Plate of Fuel Cells

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〈Abstract〉

Stamping process and rubber pad forming process were performed to manufacture the bipolar plate for fuel cells. For that, a vacuum die casting process and a semi-solid forming process wherein liquid-state materials were used were adopted. After preparing the blank with the stainless steel thin plate having a thickness of 0.1 mm, the bipolar plate channel was formed with the stamping process and rubber pad forming process. The depth of the bipolar plate channel prepared by the stamping method was 0.45 mm and the depth of the bipolar plate channel prepared by the rubber pad forming process was 0.41 mm. Meanwhile, with the vacuum die casting and semi solid forming, the bipolar plate having a channel depth of 0.3 mm, same as the size of the die, could be formed.

Keywords : Fuel Cell, Bipolar Plate, Stamping, Rubber forming, Die Casting, Semi-solid Forming

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1. Introduction

A fuel cell is a device that converts chemical energy into electric energy. The electric energy can be generated by reacting hydrogen with oxygen. Since the operation temperature of proton exchange membrane fuel cell (PEMFC) is low and it generates a high output density and quick responsivity, many researches about PEMFC are being conducted in the fields of power supply for automobiles and industrial small power generation. In case of the PEMFC stack which is used for power supply for automobiles, it occupies around 60-80% of the stack weight since 400-500 bipolar plates are stacked. In addition, the stacking is attributed 35-45% of the production cost. Among the components of the fuel cell stack, bipolar plate supplies the gas which is required for chemical reaction in the form of gas diffusion layer through channel and plays an important role by transferring the electric charge generated from the unit cell to the fuel cell, removing the heat in the stack, preventing the leakage of the reactants, and structurally supporting the components [1-3].

Since bipolar plate is used in the cathode and anode respectively, it occupies 50% of the stack weight and volume and is attributed around 40% of the production cost. Therefore, the bipolar plate should be light in weight with a shape of a thin plate and should be suitable for mass production [3-5]. While concentrated researches are carried out on the fuel cells worldwide, graphite series are banished as materials for the bipolar plates. Meanwhile, metal materials are replaced with bipolar plates. Aluminum, stainless steel, and titanium have been drawing the limelight as metal materials for the bipolar plates in recent years. There are stamping, rubber forming, hydroforming, vacuum die casting, and semi-solid forming processes as forming processes for the mass production of the bipolar plates. Kang and Jin have drawn an excellent research outcome by focusing the forming process for the forming of metal bipolar plates since 2009. They manufactured the aluminum bipolar plate using vacuum die casting and semi-solid forging processes [4-8]. They also manufactured aluminum, stainless steel, and titanium bipolar plates using stamping and rubber forming processes, and applied the bipolar plates on the fuel cells [6-9]. This paper introduces various processes that have been used to manufacture the bipolar plates for the fuel cell until today.

2. Experiment

2.1 Stamping process

Stamping is a process to form a product by plastic deforming the material upon inserting it into the upper and lower dies and imposing load on the upper die. Figure 1 shows the manufacturing process of the bipolar plate with the stamping to form the channel by compressing the metal blank. The austenitic series 304 stainless steel plate having a thickness of 0.1 mm was used as a material for the bipolar plate. 304 stainless steel can be used under a wide corrosion environment such as acid and alkali due to its low oxidizing properties under high temperature and excellent corrosion resistance. In addition, it has appropriate mechanical properties under high temperature or low temperature conditions, is strong against shock, and is well-processed with its excellent formability. Material testing system (MTS) was used for the forming of the bipolar plate channel. As the straight load condition, load 100 kN was applied for compressing the bipolar plates.

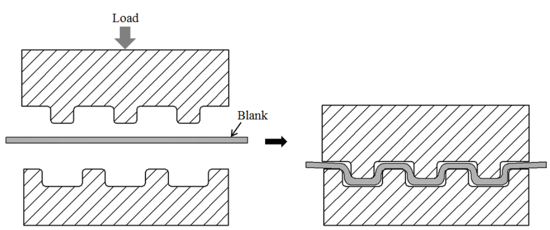

Fig. 1 Stamping process for manufacturing bipolar plate.

2.2 Rubber Pad Forming process

Rubber forming is a forming method to create a product by pressing the material with a rubber pad. The rubber pad is fixed on the ram of the press, and the materials are placed on the form block. Forming is executed according to the outer shape of the form block and almost constant pressure is imposed throughout the surface of the material. This process has merits of simple device, easy replacement of die, and low device cost. It is a forming method wherein a blank is placed on the rubber pad, and blank and rubber pad are simultaneously pressed by die unlike the existing forming wherein rubber pad compresses blank. With this process, force from the upper die that compresses the blank and repulsive force by the elasticity deformation of the rubber pad are uniformly imposed on the entire surface of the blank. Figure 2 shows the manufacturing process of the bipolar plate with the rubber pad forming method. The 304 stainless steel plate having a thickness of 0.1 mm was used for the forming process. The thickness of the rubber pad used for compression was 60 mm, and its hardness was Shore A 20. The pressure and speed of the punch compression in the blank and rubber pad were 55 MPa and 30 mm/s, respectively.

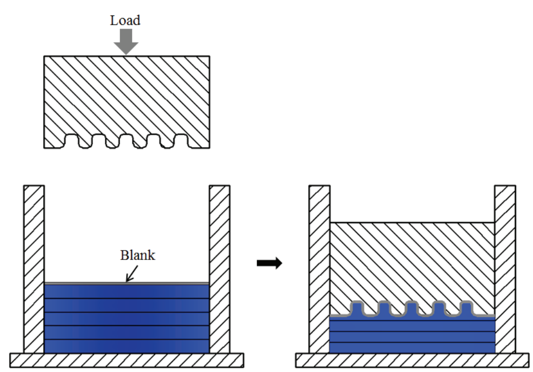

Fig. 2 Rubber forming process for manufacturing bipolar plate.

2.3 Vacuum Die Casting process

There is a liquid process as a process that can resolve the forming limit generated during the forming of liquid material. Die casting is a casting process with a die that can manufacture a complicated product at once and exhibits a high productivity as a mass production system which ultimately reduces manufacturing cost. Vacuum die casting improves stiffness and the mechanical properties of the surface of the products by reducing enclosed gas inside the product and producing thin products.

The dimension corresponding to the area of the bipolar plate was 200 mm in length as well as width, and 0.8 mm in thickness. The width and depth of the channel were set to 1 mm and 0.3 mm, respectively, and the thickness was set to 1.1 mm. The device used for forming was 660 tons of capacity cold chamber die casting machine. The material used for the die casting was Silafont 36 alloy which had an excellent castability. The temperature of the injected molten metal was set to 730 ℃, and the shot velocity to 0.3 m/s in the low-speed zone and 2.5 m/s in the high-speed zone, respectively. Figure 3 presents the forming process for the bipolar plate with a vacuum die casting.

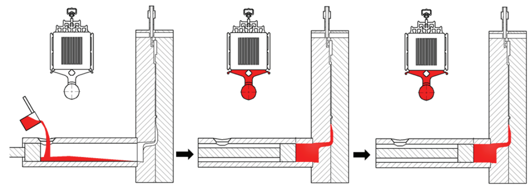

Fig. 3 Vacuum die casting process for manufacturing bipolar plate.

2.4 Semi Solid Forming process

Semi solid forming is a complex forming method of aluminum alloy using the merits of die casting and forging and uses partially solidified slurry in which solid phase and liquid phase are mixed. Since the viscosity of the partially solidified material is higher than that of the liquid state, flow is not developed to a turbulence during the charging of materials into the die cavity, reducing the defect caused by gas or air pore inside the product. The forming temperature is low which shortens the time to get a completely solidified product, thereby productivity can be increased by 20-30%. Complicatedly shaped parts and thin parts are produced at once, which reduces the thermal fatigue of die and energy.

Semi solid slurry process in which grains are controlled was executed to make liquid material semi solid as in the Rheo method. In the Rheo process, the A356 molten metal was stirred in the electronic mixing system at 620 ℃ and cooled till 590 ℃ (f_s: 45%). The area of the cavity corresponding to the thin plate was 150 mm x 150 mm and the thickness was 1.2 mm. The total length of the channel was 70 mm in length and 70 mm in width, and the depth of groove on the rough surface was 0.3 mm. Figure 4 shows the forming process of the bipolar plate with the semi solid forming process. The semi-solid slurry that was prepared by the electronic mixing system was charged into the die, compressed for five seconds, and the formed part was ejected. The compression speed and pressure imposed on the semi solid slurry were 0.3 m/s and 150 MPa respectively.

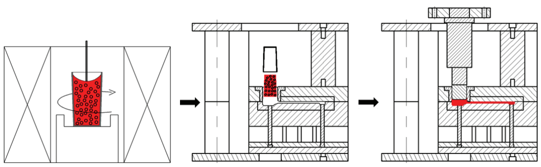

Fig. 4 Semi solid forming process for manufacturing bipolar plate.

3. Results

Figure 5 (a) shows the bipolar plate formed with the stamping process. The channel was formed through the compression process with the straight load of 100 kN. As can be seen in the photo of the plain figure of the bipolar plate, there was a crushing phenomenon at the edge of the channel, and flatness was not even due to the distortion of the entire plate. The depth of the formed 304 stainless steel was 0.45 mm. Figure 5 (b) presents the bipolar plate with formed channel by the rubber pad forming method. There was no single wrinkle created near the channel, and the flat bipolar plate was formed without bending. The formed channel depth was 0.41 mm for the 304 stainless steel.

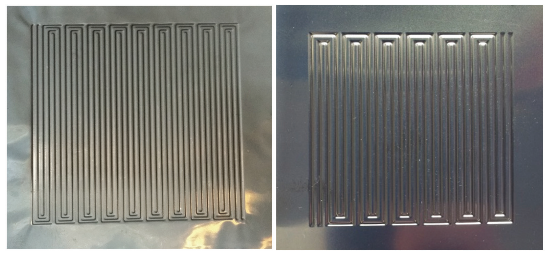

Fig. 5 Fabricated bipolar plates by solid material process: (a) Stamping and (b) Rubber pad forming.

Figure 6 (a) shows the bipolar plate prepared by the vacuum die casting process. Though there were little flow marks on the surface of the product, no other defects were found (even air pore or distortion) except flow mark. A depth of 0.3 mm for the bipolar plate could be achieved in the same dimension of the designed die. Figure 6 (b) shows the bipolar plate prepared by the semi solid forming process. Flow mark was largely created, making the surface somewhat rough. Still, there were no defects of air pore and distortion. The depth of the bipolar plate channel was 0.290 mm which was a little smaller than the designed die. With both the vacuum die casting and semi solid forming processes, bipolar plates with accurate dimensions were produced.

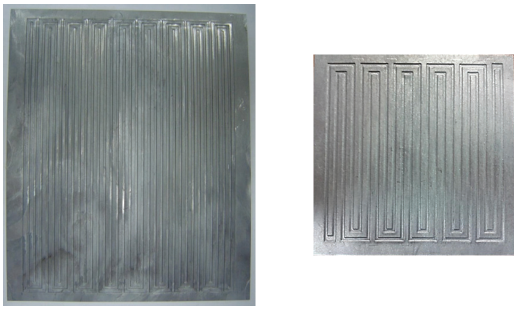

Fig. 6 Fabricated bipolar plates by liquid material process: (a) Vacuum die casting and (b) Semi solid forming.

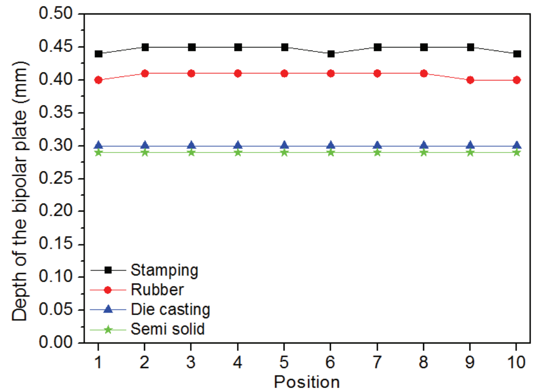

Fig. 7 Channel depth of the bipolar plate manufactured by different fabrication process.

The depths from ten places arbitrarily selected from the channel were measured to investigate if the channel depth of the bipolar plates prepared with the four process methods were uniform overall. Figure 7 shows the channel depths of the ten places from the bipolar plates produced with the four different forming methods. In case of the stamping, the difference between the deepest and the shallowest depth was 0.02 mm. It was 0.01 mm in the channel produced by the rubber pad forming. However, there was no difference in the depth for the channels produced by the vacuum die casting and semi solid forming.

4. Conclusions

As for the manufacturing processes for the bipolar plate, stamping and rubber forming using solid state materials, and vacuum die casting process and semi solid forming process using liquid state materials were introduced.

(1) A channel depth deeper than 0.4 mm could be formed with the stamping and rubber forming. However, there was a problem of forming limit that cannot produce a part similar to the die cavity shape.

(2) With the vacuum die casting and semi-solid forming methods, it was difficult to produce a bipolar plate with a thickness thinner than 0.8 mm and channel depth deeper than 0.3 mm. However, a bipolar plate having size accuracy and stiffness could be formed.

Acknowlegement

This work was supported by the National Research Foundation of Korea (NRF) Grant funded by the Korea Government (No.2017-017242).

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(Manuscript received May 22, 2018; revised June 30, 2018; accepted July 9, 2018.)