Appropriate Stamping Conditions of Metallic Polar Plate For Proton Exchange Membrane Fuel Cell

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ABSTRACT

In the present, the fuel cell is an alternative energy which can be renewable and environmental friendly. In general the fuel cell equipment is costly and bulky which obstruct the implementation of this device in automobiles and portable device industries. Therefore, various researchers have been investigating and developing many parts of the fuel cell assembly, such as the critical component-the polar plate, in order to reduce the arising issues.

Accordingly this study aims to investigate an appropriate method of polar plate fabrication using a stamping technique. Then, an experimental design based on Central Composite Design (CCD) method is implemented to statistically evaluate the effect of stamping conditions: stamping pressure and dwell time on the performance of the stamped polar plate. The responses measured from the stamping process are based on plate curvature, depth and wrinkle. The specimen used for this research were 0.127 mm thick 316 SS with 40x40 mm. active area. The results show that appropriate stamping conditions are 79 kgf/cm^2 and 6 second of dwell time. The responses at these conditions are 0.818 mm. channel depth with 1.539 mm. of plate curvature and 80% of wrinkle area. Then, the polar plates were installed in the fuel cell and the electrical test through polarization showed characteristics of the current density at 125.7 mA/cm^2 and the power density at 67.63 mW/cm^2.

Keywords: Metallic polar plate, stamping, fuel cell, central composite design

INTRODUCTION

Polymer Electrolyte Membrane or Proton Exchange Membrane Fuel Cells (PEMFCs) are devices that convert the chemical energy into the electrical energy. Therefore those fuels have been anticipated as an energy source due to high power density performance at low temperature (70-90°C) (Gottesfeld and Zawodzinski, T., 1991) as shown in Figure 1. Unlike the internal combustion engine, there is no burning of the fuel and therefore no generation of pollutions during operation period. Since a single cell of PEMFC can only generate an output voltage around 0.5-0.7 V, the cells are stacked together in series, to yield enough voltage to power any specific electrical device. The polar plates are a multifunctional component in PEMFC as they collect and conduct the current from cell to cell, they separate the gases and the flow channels in the plates, and also deliver the reacting gases to the fuel cell electrodes (Metha and Cooper, 2003). In a typical fuel cell stack, the bipolar plate facilitates heat and water management, as well. The most widely used bipolar plate materials are the graphite-based materials, which are ideal in terms of corrosion resistance and conductivity. Nevertheless, their high cost and the need for machining to form the flow channels limit these materials for applications involving high volume manufacturing. In addition, graphite is lack of mechanical strength and has a natural brittleness; therefore the graphite polar plate is bulky to avoid cracking during the stack cell assembly and usage (Metha et al., 2008).

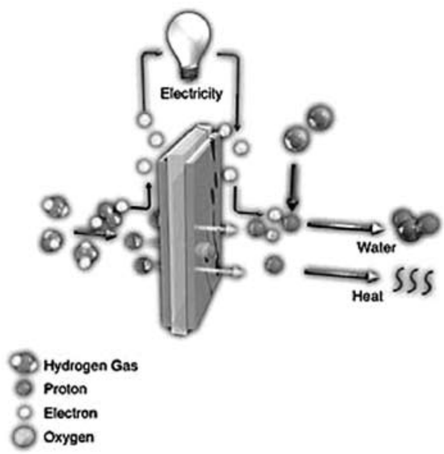

Figure 1. Schematic of PEMFC.

Alternative material for bipolar plate fabrication includes metal. Metallic sheet, such as stainless steel, has high potential for bipolar plate formation due to its high mechanical strength and stability, electric conductivity and thermal conductivity (Hsieh et al., 2008). Metal also has better machinability. Many manufacturing techniques can be implemented to form metallic bipolar plate. In general, for cost effective production, sheet metal stamping is the proper technique to fabricate the bipolar plate for PEMFC. In addition, stamped quality of metallic sheet was effect by many process parameters such as the tool and die geometry, the draw-bead restraining force, the blank shape, as well as the friction (Bae et al., 2007). The stamping force was major factor to directly depend on the shape of the sheet metal forming. However, the shape of sheet metal forming has been determined with expert engineer's experiences or trial-and-error procedures. A proper tool design incorporated with appropriate stamping conditions is necessary prior to the tryout stage of press working in order to reduce the development cost and time of a product efficiently. In order to statistically identify appropriate conditions for metallic stamping, Design of Experiment (DoE) technique should be implemented. A Central Composite Design (CCD) is one of the DoE that can be used to elucidate the effect of these stamping conditions on the optimized production. The design involves the estimation of linear relationship as well as quadratic relationship by two-level factorial designs as well as star and center point experiments, as shown in Figure 2 (Duan et al., 2006). Table 1 shows the two independent variables investigated in this study and their levels of experiment.

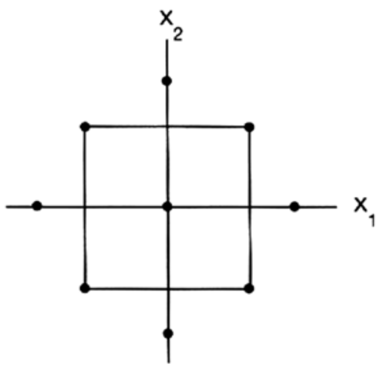

Figure 2. Central composite design model.

Table 1. Factor level in CCD.

Factor	Factor level in coded form				
	-√2	**-1**	**0**	**1**	**√2**
X_1	18	30	57	85	96
X_2	0	0	10	20	24

*X_1 is the pressure (Kgf/cm^2), X_2 is the dwell time.

The experimental design is used to optimize the stamping conditions of a metallic sheet for polar plate. The CCD method is implemented in this study to statistically evaluate the effect of stamping conditions: stamping pressure and dwell time, on the performance of the stamped polar plate. The responses of the stamping process are measured based on channel depth, plate curvature, and wrinkle. Regression model of appropriate conditions is drawn from the optimal conditions of these responses.

METHODOLOGY

First of all, the stamping mold for the polar plate forming was designed by the Computer-Aided Design (CAD), as shown in Figure 3. Then the CNC machining center was implemented to fabricate both punch and die set for this stamping mold (Figure 4).

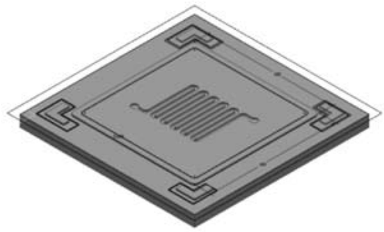

Figure 3. Mold Design.

Figure 4. Mold machining.

Then, the CCD method was implemented to study the independent variables: stamping pressure and dwell time, on the quality of the stamped plate. Based on CCD, the total number of experimental run was 26 (including 1 replication). The responses of the experiment were channel depth, plate curvature, and wrinkle area. The first response was evaluated by a dial gauge, as shown in Figure 5. The plate curvature was measured by a coordinate measuring machine, as shown in Figure 6. Last, the visual inspection is implemented for wrinkle area evaluation. All responses information were then input into the CCD data sheet, to further statistical analyze the relation between stamping conditions and the response, as well as to draw the regression models of the finding. Furthermore, the electrical performance of single cell based on stamped metallic bipolar plate was tested afterward, to evaluate the potential of the system under normal operating situation.

Figure 5. Channel depth measurement.

RESULTS AND DISCUSSIONS

The result of the experiment is shown in Table 2. MiniTAB v.15 software was implemented in this study to generate and analyze the experimental result based on CCD technique. In statistically, analysis of Variance (ANOVA) has been used for identify the level of significant of all main factors, the second-order, as well as their interactions. Furthermore, both R-squared and adjusted R-squared statistic were calculated to indicate how the fitted models can explain to what percentage of the variability of the results.

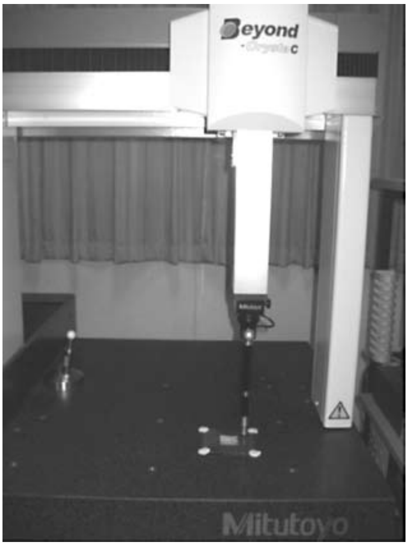

Figure 6. Plate curvature measurement.

Table 2. Experimental design data sheet.

Run No.	Factors		Responses		
	Pressure Kgf/cm^2	Dwell time (s)	Depth (mm)	Curvature (mm)	Wrinkle (scored)
1	30	0	0.501	0.501	2.33
2	30	20	0.541	0.541	2.33
3	57	10	0.739	0.739	3.00
4	57	10	0.740	0.740	3.00
5	96	10	1.101	1.101	3.33
6	57	10	0.739	0.739	3.00
7	57	10	0.741	0.741	3.00
8	57	0	0.562	0.562	3.00
9	85	0	1.031	1.031	3.33
10	19	10	0.312	0.312	1.67
11	57	24	0.757	0.757	3.00
12	57	10	0.740	0.740	3.00
13	85	20	1.054	1.054	3.33
14	30	0	0.562	0.562	2.00
15	30	20	0.513	0.513	2.33
16	57	10	0.542	0.542	3.00
17	57	10	0.541	0.541	3.00
18	96	10	0.655	0.655	3.33
19	57	10	0.556	0.556	3.00
20	57	10	0.555	0.555	3.00
21	57	0	0.562	0.562	3.00
22	85	0	0.821	0.821	3.33
23	19	10	0.411	0.411	2.00
24	57	24	0.694	0.694	3.00
25	57	10	0.556	0.556	3.00
26	85	20	0.798	0.798	3.33

The result of the analysis included the significant of each stamping condition on each response of the test. Furthermore, the contour and surface plots can be drawn to identify the optimal conditions of the experimental boundary. From the study, channel depth and the wrinkle area of the stamped plated was effected by only the stamping pressure, while the plate curvature was impacted by both pressure and dwell time. The prediction model of these responses cooperated with R-square and adjusted R-squared are presented in Table 3, Figure 7 and Figure 8 show the surface and contour plot of the curvature versus the pressure and dwell time.

Table 3. Prediction models with r-square.

Response	Prediction model	R-square	adjusted R-squared
Channel depth	y1=0.6686+0.1924(pressure)	63.98%	62.48%
Plate curvature	y2=1.6632-0.4406(pressure)+ 0.4381(Dwell time)+ 0.5049(pressure)^2+0.5727(Dwell time)^2	88.07%	85.80%
Wrinkle area	y3=2.9710+0.7494 (pressure)	87.51%	86.99%

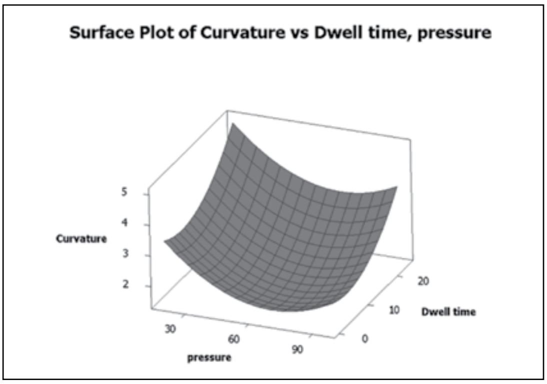

Figure 7. Response surface of curvature of polar plate.

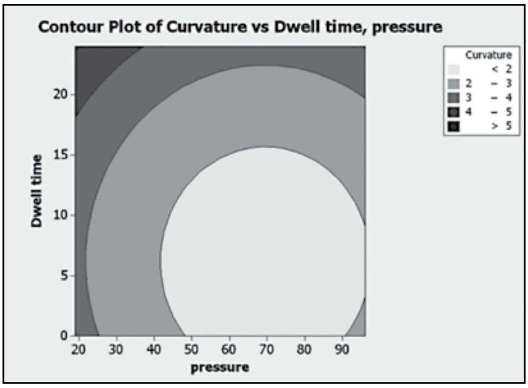

Figure 8. Contour plot of curvature of polar plate.

Afterward, the stamped metallic plates were assembly with membrane and clamped in a fixture to investigate the electrical performance on the fuel cell test station, as shown in Figure 9 and 10. The results from electrical polarization show that the current density of this single cell at 0.6 volt was 112.5 mA/cm^2 and 67.36 mW/cm^2 of maximum power as shown in Figure 11.

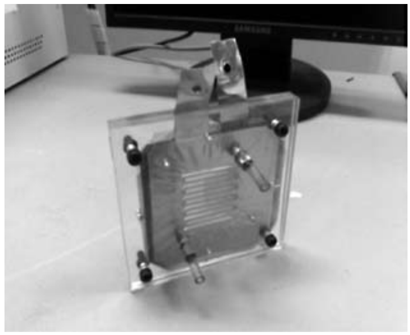

Figure 9. The single cell assembly.

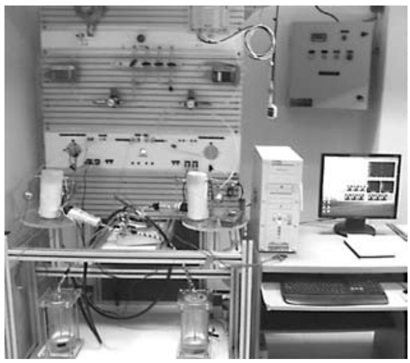

Figure 10. Fuel Cell test station.

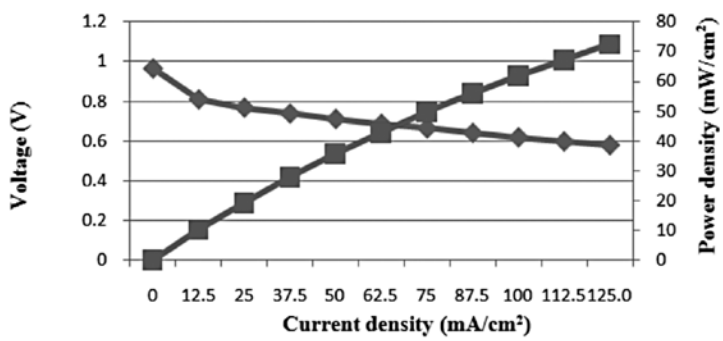

Figure 11. The single cell polarization test.

CONCLUSION

An investigation on the optimization of metallic polar plate stamping conditions was carried out in order to identify the proper stamping conditions which yield the better dimensional accuracy and uniformity of the stamped plate. The specimen used for this study were 0.127 mm thick 316 SS with 40x40 mm. active area. Response surface method based on Central composite design (CCD) is the experimental design used in the optimization process. The results show that the channel dimension, plate curvature and wrinkle area are significantly related to stamping force. Furthermore, plate curvature is also effect by dwell time. This could relate to the spring back behavior of the metal sheet after stamping. According to this study, appropriate stamping conditions were found at 79 kgf/cm^2 stamping force with 6 second dwell time, which contribute to 0.818 mm. of channel depth, 1.539 mm. of plate curvature and 80% of wrinkle area. As can be seen from this result those plate curvature and wrinkle areas of the stamped part were still high. These problems could result from improper stamping speed and plate handling during stamping period. Further study should be included the impact of stamping speed as well as the development of appropriate clamping fixture during the forming process. Moreover, the performance improvement of metallic plate should be performed to support the adaptation of metallic polar plate for the commercial scale production. In addition, the implementation of this experiment on the larger scale of plate is currently pursued due to the demand for larger amount of electrical generation of the system. Possible implementation of metallic polar plate will focus on the portable equipment which light weight and compact are the majority reason of the system development. The better the accuracy of metallic polar plate, the higher the potential of portable PEM electronic-based system will be more possible and affordable to the consumer.

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