Optimization of characteristics and construction of composite bipolar plates of polymer fuel cells

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ABSTRACT

This study investigates the construction of polymer/graphic composite bipolar plates via hot compression molding for use in polymer fuel cells and the optimization of characteristics by experimental test design. For this purpose, the Minitab software is used. Besides, this study was examined the physical, mechanical, and electrical characteristics of the constructed bipolar plates through performing the tests of water absorption, calculation of density, the test bending strength, interfacial contact resistance, electrical conductance. The pressure and the curing time were considered as the input parameters of the optimization, and the goal is to optimize the flexural strength and interfacial contact resistance to achieve the U.S Department of Energy's 2020 target for the bipolar plates of polymer fuel cells. The results show that with a pressure of 79.499 MPa and the curing time under pressure was 70s, the parameters of flexural strength and optimum interfacial contact resistance are 53.91 MPa and 10.57 mΩ.cm2, respectively. The properties also include water absorption and electrical conductivity in the through-plane (TP) direction 0.36 percent and 27.22 (S/m) respectively, which is in line with the goals of the US Department of Energy.

KEYWORDS

Compression molding, Polymer Fuel Cell, Composite Bipolar Plates, Optimization.

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1. Introduction

A fuel cell is an electrochemical device that converts the chemical energy of a fuel into electrical energy without combustion. Bipolar plates are the main components of polymer membrane fuel cells that have several functions. Poor mechanical properties of graphite, corrosion problems in metal plates and high cost of coating have attracted the attention of many manufacturers and researchers to composite bipolar plates.

In this study, composite bipolar plates were investigated and used bulk molding compound/composite for the construction of bipolar plates, called BMC. The samples were fabricated based on the experimental design by Minitab software. Then the experimental results of the physical, mechanical and electrical properties of the bipolar plates made of polymer/ graphite composite were discussed. Finally, by optimizing the results of flexural strength and interfacial contact resistance (ICR) and aiming to reach the standards of the US department of energy in 2020 (DOE), the ideal parameters for the construction of composite bipolar plates were obtained.

2. Materials and composite preparation

At this stage, according to the range proposed by the powder company for molding bipolar plates [1], the range of main parameters was determined. Then, the conditions for making composite bipolar plates were investigated by designing a central composite experiment in the face center at 5 levels in the period between 5.68-70 seconds and a pressure of 48.7-91.2 MPa, and 13 composite bipolar plates were molded. Finally, the tests required to evaluate properties of the plates were determined in accordance with the optimal target of the US Department of Energy 2020 (DOE) [2]. Water absorption percentage was obtained by means of Eq. (1) according to ASTM D570 standard [3].

$$\text{Water absorption } \% = \left(\frac{W-D}{D}\right)\times 100 \quad (1)$$

Flexural strength in accordance with the standard ASTM D790 by Eq. (2) done [4].

$$\sigma_f = \frac{3PL}{2bd^2} \quad (2)$$

In this study, electrical conductivity was measured only in the Through-plane according to Eq. (3) and (4).

$$\rho = \frac{R}{L}A \quad (3)$$

$$\sigma = 1/\rho \quad (4)$$

Interfacial contact resistance test between two layers of gas diffusion layer and two copper plates with gold coating and the contact resistance between the levels will be calculated by the following Eq. (5) to (8) [5].

$$R_1 = 2R_{GDL} + 2R_{cu} + R_{BP} + 2R_{GDL/BP} + 2R_{GDL/cu} \quad (5)$$

$$R_{GDL/BP} = \frac{1}{2}(R_1 - 2R_{GDL} - 2R_{cu} - R_{BP} - 2R_{GDL/cu}) \quad (6)$$

$$R_2 = 2R_{cu} + R_{GDL} + 2R_{GDL/cu} \quad (7)$$

$$R_{GDL/BP} = \frac{1}{2}(R_1 - R_2) \quad (8)$$

3. Results and Discussion

The densities obtained in some samples were slightly lower than the densities provided by the material manufacturer. Part of this difference was due to the difference in the density of the uncured powder and the curing material. Water absorption amount in sample number 12 was 0.36%, which compared to other samples indicates better curing conditions and quality of this sample in terms of this physical property. The optimal amount of water absorption in the energy department for composite bipolar plates is reported to be less than 0.1%.

Table 1. Test results for fabricated samples

Samples	ICR (mΩ.cm2)	Flexural strength (MPa)	Density (gr/cm^3)	Water absorption **(%)**
1	11.85	52.05	1.91	0.68
2	9.87	53.42	1.88	0.72
3	15.17	43.20	1.67	0.63
4	11.96	42.27	1.74	0.63
5	15.84	38.32	1.59	0.57
6	10.36	50.82	1.92	0.78
7	11.34	47.55	1.66	0.61
8	14.37	44.82	1.89	0.49
9	11.37	48.82	1.90	0.59
10	11.87	48.47	1.80	0.41
11	11.80	47.92	1.69	0.53
12	10.57	53.91	1.86	0.36
13	12.96	43.55	1.63	0.59

The value of flexural strength according to DOE 2020 should be more than 25 MPa. The results were obtained for the samples prepared in the same range and the flexural strength of sample 12 was 53.91. The electrical conductivity was obtained in the direction of through-plane of sample 12, 27.22 (S /m), which is in the acceptable range. ICR between the surfaces of bipolar plates and gas diffusion layer is one of the most important features of bipolar plates and even more important than the electrical conductivity of plates. For this purpose, the interfacial contact resistance behavior of the plates was investigated. Most specimens correspond to DOE 2020 optimal targeting that the ICR of the specimens should be at a pressure of 1.38 less than 10 mΩ.cm^2 and the ICR of the specimens is approximately close to this range. Even sample 2 was less than this value. The ICR of sample 12 at pressures of 1.38 MPa was 10.57 (mΩ.cm2), respectively, indicating a favorable bond between conductive particles. The electrical conductivity in the direction of through- plane in sample 12 was 27.27 (S/m).

In this part of the article, the results were optimized in Minitab software. As mentioned in the design of the experiment, in order to extract a better model and find the maximum effect, the response level method was used. One of the main conditions to prove the good quality of the model or the accuracy of the model is that the P-Value[2] is less than 0.05 [6], which is less than 0.05 in this design as the first output of the design Experiment is obtained. As in the Versus-Fits diagram, the residual changes do not follow a specific trend, which proves that the variances are constant, and this is the first assumption for the adequacy of the model. In the histogram, the residual changes are Gaussian distribution, indicating that the data came from a normal population, which is the second assumption for model adequacy. The third assumption for model adequacy is the assumption of data independence and time independence, which is evident in the Versus Order diagram. The fourth assumption for the adequacy of the model is to check the quadratic power of the answers, which all tends to 1 or 100%. Finally, by examining the results of ICR and flexural strength in Minitab software, according to the range of pressure and time changes, the best state and the most optimal state were obtained at a pressure of 79.499 MPa in a time of 70 seconds.

4. Conclusion

In this research, the design and fabrication of polymer/graphite composite bipolar plates by hot compression molding for use in polymer membrane fuel cells and optimization of results or Minitab software were investigated. The physical, mechanical and electrical properties of the composite bipolar plates were investigated by performing tests of water absorption, density calculation, flexural strength test, ICR and electrical conductivity. Examining the properties of the fabricated samples, sample No. 12 showed the best properties. In this sample, a density of 1.86 g/c^3 was obtained, which was very close to the density presented, the percentage of Water adsorption was 0.36, which was acceptable. In the flexural strength test, the flexural strength of the existing specimens was in the appropriate range and all specimens were more than 25 MPa. Flexural strength was obtained in sample 12, 53.91 MPa. The electrical conductivity test was measured using silver glue and copper wires in the direction of through- plane. The electrical conductivity obtained in sample 12 was 27.27 Siemens per meter and ICR at a pressure of 1.38 MPa equal to 10.57 mΩ. cm^2 was measured, which is closer to the DOE 2020 for polymer/graphite composite bipolar plates than other models made. Finally, by optimizing the results and manufacturing conditions, the ideal state for making composite bipolar plates, under pressure of 79.499 MPa, curing time of 70 seconds, working temperature of 200°C and weighing 37.5 gr of raw material Was obtained. According to the results obtained in this paper, the samples made were in an acceptable range and by making a suitable mold, the construction of plates with the following channels can be used. Validation of the results was performed using various experiments to achieve the desired and optimal state. After reaching the desired sample using the test design and Minitab software, the optimized sample (sample 12) was rebuilt using the obtained conditions and tests of its mechanical, electrical and physical properties were performed. No changes in properties such as ICR, flexural strength, and water absorption indicate the validity of the results.

5. References

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