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Design and Analysis of Bipolar Plate of Polymer Electrolyte Membrane Fuel Cell Assembly used for Automotive Applications

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Abstract

A polymer electrolyte membrane fuel cell (PEMFC) is defined as a type of fuel cell used to generate voltage and current. A fuel cell produces very small amount of electrical energy about 0.7 volts. So, it is essential to stack the fuel cells in bipolar plate series connection for the production of the large amount of electrical energy to fulfil the requirement. However, it is required to stack them with uniform pressure distribution in order to minimize the chance of BPP, MEA and GDL damage, fuel leakage and contact resistance. The mechanical properties and geometrical attributes of PEMFC stack components were collected with the help of many journal papers and books for the sake of their design and simulation work. In this study, the finite element analysis (FEA) were employed to simulate the bipolar plates meant for the assessment of the uniform stress dissemination.

Keywords: *Polymer electrolyte membrane fuel cell; Bipolar plate; Membrane electrode assembly; Gas diffusion layer and Finite element analysis.*

1.0 Introduction

Research on fuel cells has been concentrated on the enhancement and improvement of various properties such as efficiency cell voltage, power density etc. Ample attention was also given towards scale-up of these proposed systems to make them ready for commercial application. Enormous work has been carried out on materials development of fuel cell components, component design, mathematical simulation, system design, and development [1-2]. The many research was conducted for the improvement of the fuel cell and eventually, fuel cell was used for a variety of applications. In

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the current situation, the prerequisite of fuel cells in automobiles have developed beyond the mandate. A battery is a device which is used to store the electrical energy from some other sources. However, the fuel cell is totally different than the conventional battery, directly generates the voltage by supplying the reactants with very fewer discharges. Therefore, the efficiency of fuel cell vehicles is higher in contrast to IC engines [3-4]. A fuel cell (FC) is a device like galvanic cell used for the transformation of the hydrogen (H_2) power into electrical power through the electrochemical process between the hydrogen fuel and oxygen. It consists of many components, but its main components are the anode, cathode, catalysts, electrolyte, and the electrical circuit etc. FC involves the continuous amount of the hydrogen (H_2) fuel and oxygen (O_2) to retain electrochemical process for generation of the electric power and they are totally different than batteries a battery uses the chemicals already present in it for generation of electric energy. Electric power can be produced continuously if the hydrogen fuel and the oxygen are maintained. The FC can be employed as a primary source and backing power in many fields such as commercial, industrial, residential buildings and rural areas [5]. Apart from the generation of electricity, it also produces water and heat simultaneously. It also produces a very small amount of NO_2 and other emissions. The fuel cell has generally 40-60% energy efficiency. However, if the heat waste is minimized, then the energy efficiencies can be obtained up to 85% [6-7]. A single PEMFC stack was simulated using the finite element analysis to calculate the pressure distribution and compliance on the membrane electrode assembly of a single cell stack. The experimental tests were conducted by inserting the pressure film between the BPP and MEA layer to verify the simulated results. The calibration of pressure film colour variation was done to find the pressure distribution [8]. The comparison of analysis data and the experimental data were completed with various trials applying different pressures. Therefore, these data help to determine the proper stacking parameters for proper operation of the fuel cell. Similarly, an experimental approach and FEM method were employed to assess the contact resistance and the pressure between the BPP and GDL providing a constitutive relation [9-10]. From the FEM simulation, it was found that there is same distribution of the contact pressure under different loading conditions. However, the flow channels are under more contact pressure due to the rib on both surfaces of BPP. Therefore, an experimental activity was accomplished to examine the effect of the compressive force (i.e., clamping force) on the performance of the PEMFC. This method also uses pressure film for the evaluation of results [11].As per this activity, the better cell performance was achieved by increasing the contact pressure on GDL of a stack. A stack consists of two regions i.e., ohmic and mass transport and the power of these regions were increased at 2 MNm^{-2} pressures with 9 and 18 $mWcm^{-2}$ respectively. However, when the pressure was increased above 5 MNm^{-2}, the power of both regions strongly reduced [12].

The present works is about design and assembly of a polymer electrolyte membrane (PEM) fuel-cell-stack assembly used for automotive applications by doing structural and modal analysis of PEM bi-polar plates using FEA analysis.

2.0 Work Flowchart

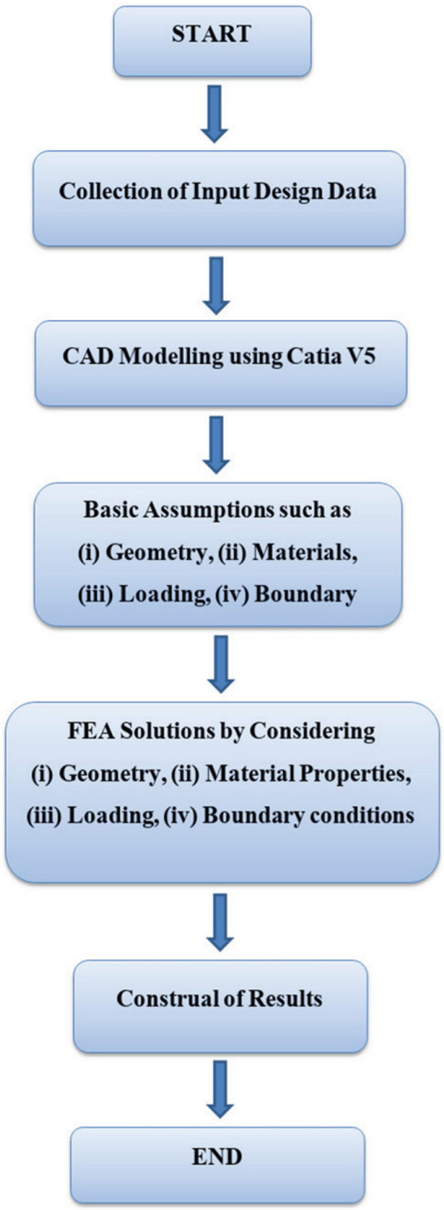

Figure 1: Methodology Flowchart

3.0 Design of Bipolar Plates

Bipolar plates are used to provide the strength of the stack. it is essential to produce plates with allowable thickness. It includes more than sixty percentage of the weight and thirty percentage of the total cost in a fuel cell stack. Therefore, a proper design of a bipolar plate is required to reduce the weight, volume, and cost of the fuel cell stack. The bipolar plates also act as separator plates which can use for a larger capacity fuel cell in series for its cooling purpose. In some design, it helps to minimize the waste heat generated in the cell and along with gaskets keep the fuel and oxidant separated keeping them from blending each other for the better execution of a fuel cell. The design of a bipolar plate can be carried out by considering the different properties of materials such as metals, and graphite [13].

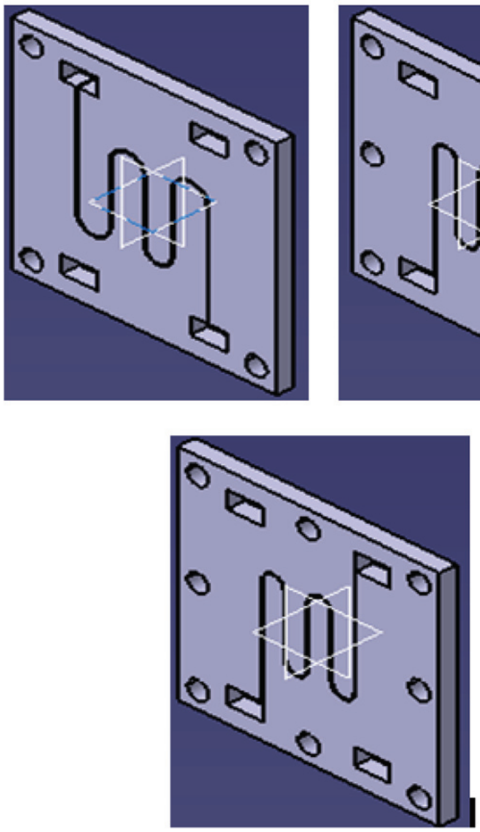

Figure 2: Bi-Polar plate with 4, 6, 8 bolts configuration

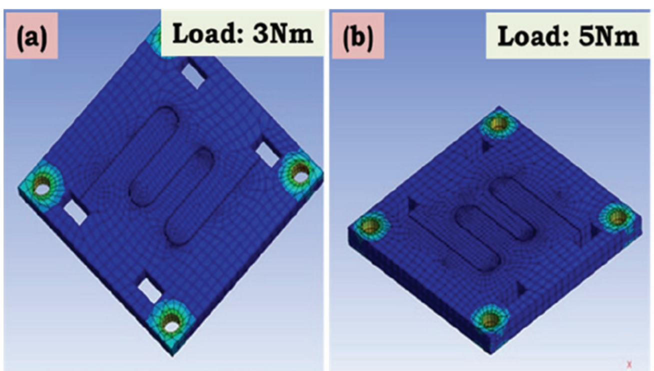

Figure 3: Structural Analysis (Equivalent Von-Mises) on Bi-Polar plate with four bolts configuration at (a) 3Nm and (b) 5 Nm Load

4.0 Results and Discussions

4.1 Structural Analysis of Four Bolts Configuration (Bipolar Plate) with different Loads

Figure 3 depicts the structural analysis (equivalent Von-Mises) on bipolar plate with four bolts configuration at 3Nm and 5Nm load respectively. From the Figs we can observe the flow field channels are designed perpendicular to each other to flow the fuel and oxygen separately. The fuel and oxygen reach the MEA layers through this flow channels for the operation of a fuel cell stack [14]. Therefore, a comparison process was carried out by applying two different values of torque i.e., 3 and 5 Nm on bolts to find out this clear imprint. From this comparison process, it was concluded that the clear perpendicular imprints were found at 5Nm torque compared to that of 3Nm in structural, dynamic analysis (Modal) on bipolar plate with four bolts.

4.2 Structural Analysis of Six Bolts Configuration (Bipolar Plate) with different Loads

Figure 4 depicts the structural analysis (equivalent Von-Mises) on bipolar plate with six bolts configuration at 3 Nm and 5 Nm load respectively. Like Figure 4 and 5 also shows

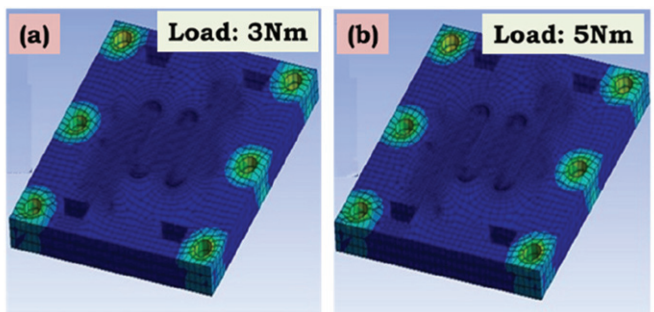

Figure 4: Structural Analysis (Equivalent Von-Mises) on Bi-Polar plate with four bolts configuration at (a) 3Nm and (b) 5 Nm Load

flow field channels are designed perpendicular to each other to flow the fuel and oxygen separately [15]. Therefore, a comparison process was carried out by applying two different values of torque i.e., 3 and 5 Nm on bolts to find out this clear imprint. From this comparison process, it was concluded that the clear perpendicular imprints were found at 5 Nm torque compared to that of 3Nm in structural, dynamic analysis (Modal) on bipolar plate with six bolts.

4.3 Structural Analysis of Eight Bolts Configuration (Bipolar Plate) with different Loads

Figure 5 depicts the structural analysis (equivalent Von-Mises) on bipolar plate with eight bolts configuration at 3 Nm and 5 Nm load respectively. Like Figures 4 and 5 also show flow field channels are designed perpendicular to each other to flow the fuel and oxygen separately [15]. Therefore, a comparison process was carried out by applying two different values of torque i.e., 3 and 5 Nm on bolts to find out this clear imprint. From this comparison process, it was concluded that the clear perpendicular imprints were found at 5 Nm torque compared to that of 3Nm in structural, dynamic analysis (Modal) on bipolar plate with eight bolts.

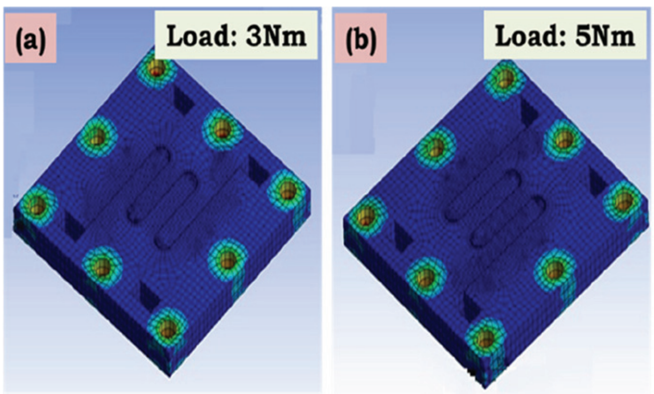

Figure 5: Structural Analysis (Equivalent Von-Mises) on Bi-Polar plate with four bolts configuration at (a) 3Nm and (b) 5 Nm Load

5.0 Conclusions

The following conclusions can be drawn based on the current structural analysis of bipolar plates which is as follows:

The bipolar plate was designed and analysed with the different bolts configuration. The suitable materials and dimensions were collected for the components of cells stack. These materials were graphite, aluminium and stainless steel for the bipolar plates, end plates and bolts/nuts respectively. The 4, 6 and 8 bolts configuration plates were separately simulated by FEA method with proper boundary and loading conditions. From this simulation, it was concluded that eight bolts configuration provides uniform pressure distribution within the stack under 5 Nm torque. Also, there is no buckling of the endplates using eight bolts configuration. From this simulation process, we can get better fuel cell stack which can prevent reactants leakage and cracking of bipolar plates.

References

[1] Andrew LD. PEM fuel cells: Applications. Reference Module in Earth Systems and Environmental Sciences; 2020.

[2] Zhao J, Li XG. A review of polymer electrolyte membrane fuel cell durability for vehicular applications: degradation modes and experimental techniques. Energy Convers Manage 2019; 119:112022.

[3] Song YX, Zhang CZ, Ling CY, Han M, Yong RY, Sun D, et al. Review on current research of materials, fabrication, and application for bipolar plate in proton exchange membrane fuel cell. *Int J Hydrogen Energy* 2020; 45:29832–47.

[4] Zhang GB, Jiao K. Multi-phase models for water and thermal management of proton exchange membrane fuel cell: a review. J Power Sources 2018;391: 120–33.

[5] Toghyani S, Afshari E, Baniasadi E. Three-dimensional computational fluid dynamics modeling of proton exchange membrane electrolyser with new flow field pattern. *J Therm Anal Calorim* 2019; 135:1911–9.

[6] Taherian R. A review of composite and metallic bipolar plates in proton exchange membrane fuel cell: materials, fabrication, and material selection. *J Power Sources* 2014; 265:370–90.

[7] Jahnke T, Futter G, Latz A, Malkow T, Papakonstantinou G, Tsotridis G, et al. Performance and degradation of proton exchange membrane fuel cells: state of the art in modeling from atomistic to system scale. *J Power Sources* 2016;304: 207–33.

[8] Lin KJ, Li XY, Dong HS, Du SF, Lu YX, Ji XC, et al. Surface modification of 316 stainless steel with platinum for the application of bipolar plates in high performance proton exchange membrane fuel cells. Int *J Hydrogen Energy* 2017; 42:2338–48.

[9] Rajaei V, Rashtchi H, Raeissi K, Shamanian M. The study of Ni-based nanocrystalline and amorphous alloy coatings on AISI 304 stainless steel for PEM fuel cell bipolar plate application. *Int J Hydrogen Energy* 2017; 42:14264–78.

[10] Manso AP, Marzo FF, Garican X, Alegre C. Corrosion behaviour of tantalum coatings on AISI 316L stainless

steel substrate for bipolar plates of PEM fuel cells. Int *J Hydrogen Energy* 2020; 45:20679–91.

[11] Orsi A, Kongstein OE, Hamilton PJ, Oedegaard A, Svenum IH, Cooke K. An investigation of the typical corrosion parameters used to test polymer electrolyte fuel cell bipolar plate coatings, with titanium nitride coated stainless steel as a case study. *J Power Sources* 2015; 285:530–7.

[12] Zhong D, Lin R, Liu DC, Cai X. Structure optimization of anode parallel flow field for local starvation of proton exchange membrane fuel cell. *J Power Sources* 2018; 403:1–10.

[13] Liu HC, Yang WM, Cheng LS, Tan J. Numerical analysis of different multiserpentine flow fields for proton exchange membrane fuel cells. *Fuel Cells* 2018; 18:173–80.

[14] Yin Y, Wang XF, Xiang SG, Zhang JF, Qin YZ. Numerical investigation on the characteristics of mass transport and performance of PEMFC with baffle plates installed in the flow channel. *Int J Hydrogen Energy* 2018; 43:8048–62.

[15] Wang YL, Wang SX, Wang GZ, Yue LK. Numerical study of a new cathode flow field design with a sub-channel for a parallel flow-field polymer electrolyte membrane fuel cell. *Int J Hydrogen Energy* 2018; 43:2359–68.