Iranian Journal of Hydrogen & Fuel Cell 3(2017) 189-199

Iranian Journal of Hydrogen & Fuel Cell

IJHFC

Journal homepage://ijhfc.irost.ir

Design and investigation of honeycomb end plates for PEM fuel cells

Mostafa Habibnia [1,*], Peyman Ghasemi Tamami[2], Hossein Sang Davini[3]

[1]Department of Mechanical Engineering, Jouybar Branch, Islamic Azad University, Jouybar, Iran
[2]Department of Mechanical Engineering, Tarbiat Modares University, Tehran, Iran
[3]Department of Mechanical Engineering, Sari Branch, Islamic Azad University, Sari, Iran

Article Information

Article History:

Received:
02 Oct 2017
Received in revised form:
27 Nov 2017
Accepted:
09 Dec 2017

Keywords

PEM fuel cell
End plate
Honeycomb
Optimization

Abstract

In this article a new structure of PEM fuel cell end plate is presented. The new structure is known as a honeycomb sandwich panel. Several properties of the presented structure, such as mechanical and thermal behavior, as well as its advantages and disadvantages are introduced. The aim of this paper is to reduce the weight of the plates while maintaining a better compression force on the PEM fuel cell components. By considering a honeycomb sandwich panel, this structure has a lighter weight and more strength and flexibility. In this regard, some mechanical experiments and electrical simulations have been done on the honeycomb structure end plates to provide a comparison between this new structure and the old structure usually made of steel. These mechanical experiments include pressure and bending tests. The results were evaluated in two cases: with foam and no foam. After analyzing the experimental results, it has been concluded that the honeycomb sandwich panel structure for end plates has many advantages that makes it a good alternative to the old endplate structure.

1. Introduction

A fuel cell is a device that converts chemical energy from chemical reactions into useful electrical energy. Fuel cell function is not like a battery that stores energy, but instead turns one state of energy into another. In this conversion the material is not consumed in the fuel cell. All components of a PEM [1]

[*]Corresponding Author's Fax: 0098 1133298502
E-mail address: M.habibnia@jouybariau.ac.ir

[1]Proton Exchange Membrane

doi: 10.22104/ijhfc.2017.2501.1156

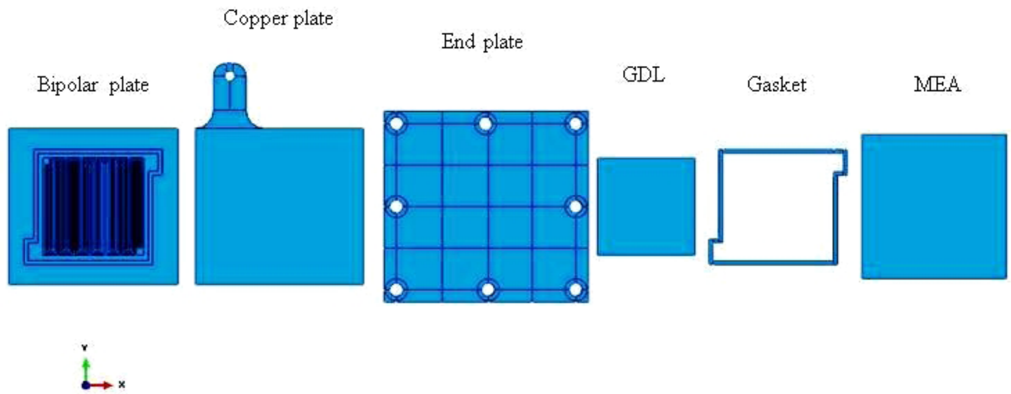

Fig. 1. Components of a one stack PEM fuel cell [1].

fuel cell are shown in Fig. 1 [1-3].

Components of a fuel cell, such as the MEA, GDL[1] and bipolar plate, should be put together with appropriate contact pressure to prevent leakage of the reactor and also to minimize the contact resistance of the cells. This goal is achieved by using two thick steel end plates to maintain proper distribution of pressure in the cells [4-5]. For this purpose, the end plate should have a high bending strength to last against high pressure on the corners. Clamping pressure is used to properly distribute contact pressure. A lower bending hardness of the end plate may result in the distribution of uneven pressure behind the cell. However, the weight of the end plate should be reduced to the extent possible for a variety of applications. For this purpose, composite sandwich panels can be used. Sandwich structures are a special type of lamina composite. Lamina composite is a combination of at least two different layers that are connected to each other. Sandwich structures include at least three elements that are shown in Figs. 2 and 3 [6].

1. Gas Diffusion Layer

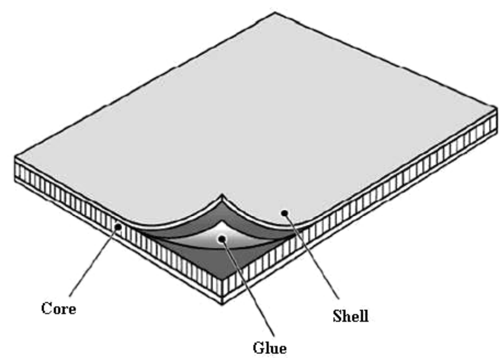

Fig. 2. Sandwich panel structure [7].

In addition to being lightweight, the cores must be strong enough to perform the following tasks[7-9]:

• Bearing loads perpendicular to the panel surface and fixing the gap between the top and bottom of the panel.

• Bearing of shear loads that slip surfaces relative to each other.

• Sustained maintenance of thin plates against topical buckling.

The cores are categorized as follows:

• Wood and its derivatives

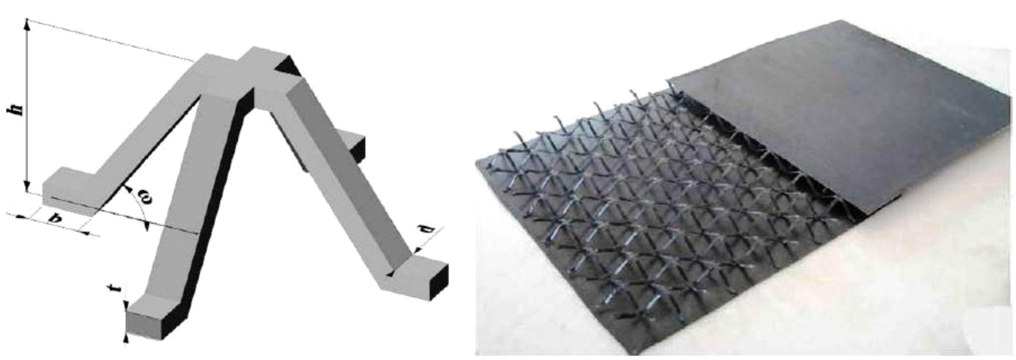

Fig.3. Sandwich panel configuration [7].

• Honeycomb
• Foam

The best kind of core in terms of strength and lightweight is a type of honeycomb. Honeycomb types are commonly used in products that are made from resin-impregnated, various aluminum alloys, aramid paper, and reinforced plastics of glass fiber or carbon in a number of fabric textures and resin systems. Titanium hexagonal honeycomb, stainless steel and other types are used in smaller quantities and quantities. Most honeycomb cores are made by bonding the viscous materials between thin materials and bonding them together. Honeycomb cores are made in two ways [10-12]:

• Expansion
• Splicing

A view of the core construction method is shown in Fig. 4.

All steps of honeycomb sandwich panel of PEM end plate construction and a sample are shown in Fig. 5. Physical and chemical properties of honeycomb core material are strongly influenced by the properties of the materials used to make them. Honeycomb aluminum panels have the following benefits:

• Lightness
• High compressive and shear strength
• Corrosion and fire resistance
• Recovery capability
• High strentgh to weight ratio

In general, the specifications of honeycomb material are summarized in Table 1.

In this article, the purpose of using honeycomb cores is to reduce weight and increase the rigidity of the composite panel. These cores are widely used in primary and secondary structures in the aerospace industry due to their high strength and rigidity and the superiority of some properties to metals. The finished form of end plate with a sandwich panel structure is shown in Fig. 6.

2.Experimental

The mechanical tests, bending and flattering pressure tests, performed on the samples are presented in the following sections. After testing on foamed and non-foamed specimens the results of bending and pressure tests are compared and then used to make endplates for fuel cell. To allow for comparison bending tests were also carried out on conventional end plate steel samples.

2.1.Three points bending test

This test was performed according to the ASTM C393-00 standard. As shown in Fig. 7, the bending test jaws are closed on the machine. In this test, the distance between the two lower supports is 200 mm

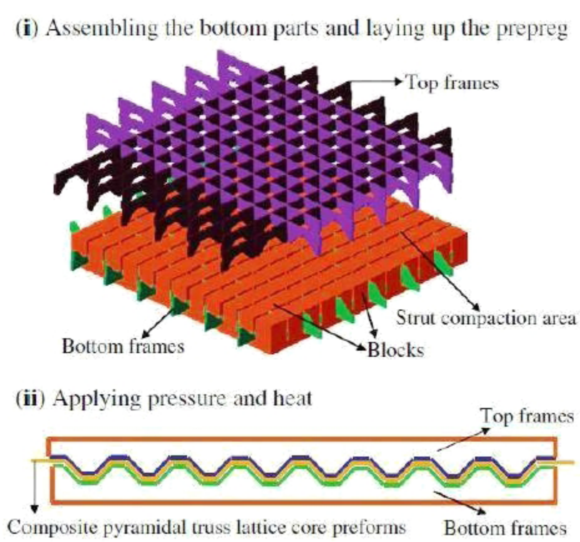

Fig.4. Core construction method [7].

Fig. 5. Sandwich panel end plate construction processes.

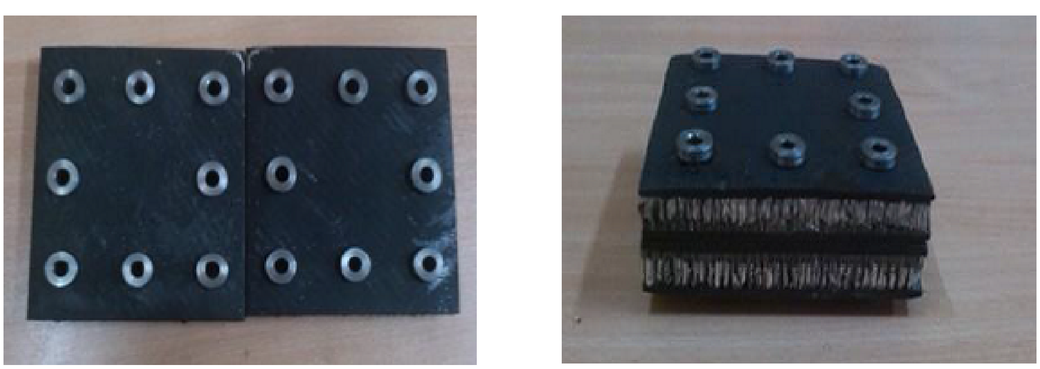

Fig. 6. Final structure of honeycomb end plate.

Table 1. Honeycomb material specifications [7].

Honeycomb core material	**Aluminum**	**Aramid**	**Glass fiber**	**Carbon fiber**	**Polyurethane**
Properties	Low cost	Ability to delay the fire	Thermal formability	Dimensional stability	Resistant to moisture
	Energy absorbent	Low dielectric properties	Multi-directional strength	Top shear modulus	Resistant to fatigue
	High strong to weight ratio	Shape ability capability	Insulation		
	Thin wall, Heat transfer conductor, Electric Shield, Machining capability	Ability to choose cell size, density and rigidity more than others	Low dielectric properties	Stability and maintain high strength and high performance	Ability to choose colors

mm and the upper jaw applies forces exactly in the middle of these two rebounds. The diameter of the support cylinders is 12 mm and the lower mandibular velocity for applying force was selected at 5 mm per minute. Also, the dimensions of the tested pieces in terms of length and width were nominally 250 × 25 mm and approximately equal in thickness. A view of this experiment is shown in Fig. 7.

First, the test was carried out for a non-foam sample, ktest results are presented in Fig. 8.

After testing on non-foam samples, the test was performed on samples that were filled with a foam honeycomb core. To perform this test, as in the non-foam bending test, three samples were tested, results are shown in Fig. 9.

By observing Figs. 7 and 9, we observe that first the force and the elastic region increases almost linearly with the displacement to a maximum value. Upon reaching this amount of force the plastic zone starts and the force begins to decrease as the device moves. The first part of the diagram, the elastic region, is important for engineering design. It insures that all calculations and designs in the structure, such as force and bending stress, do not exceed the bending strength. The second part of the graph is the plastic region. It should be noted that in general the behavior

Fig. 7. A view of bending test.

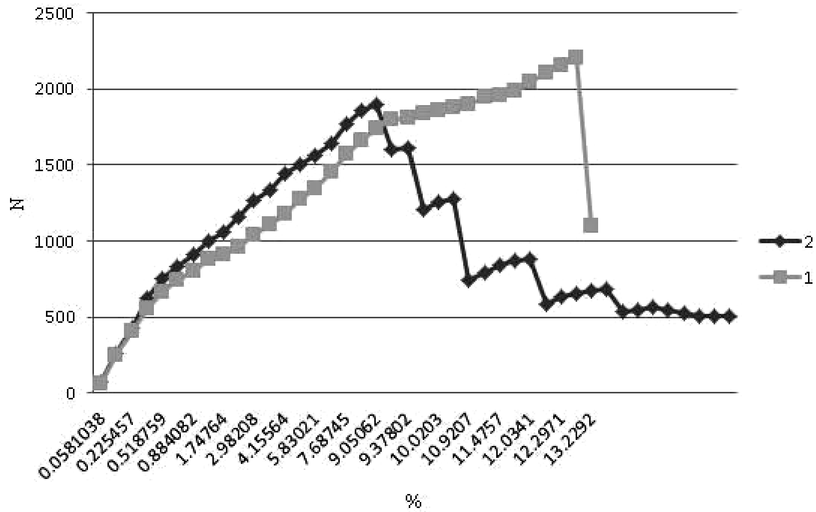

Fig. 8. Bending test curve, without foam test sample.

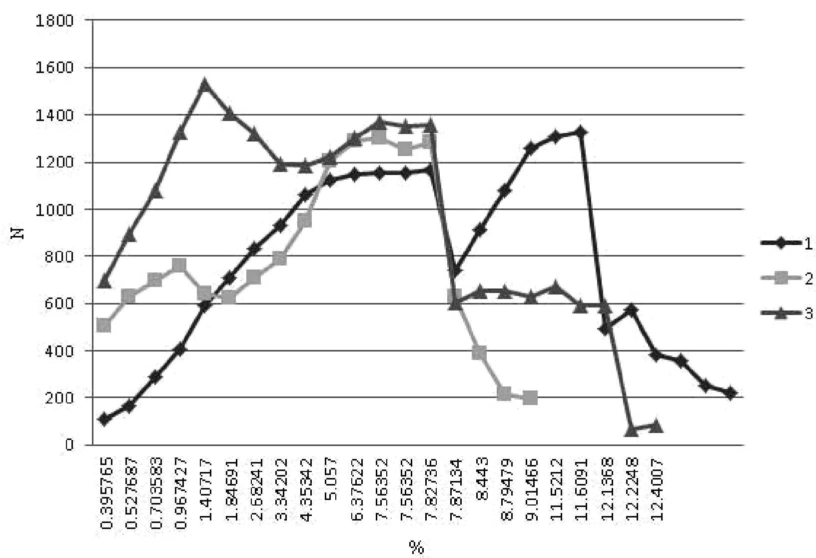

Fig. 9. Bending test curve, with foam test sample.

of the graph in both experiments is almost identical. The differences observed are due to the various defects in the samples, the accuracy of cutting the test samples or orientation of the core honeycomb network, and the amount of cell collapse in hexagonal shapes. To better compare the mechanical properties of the panels, these properties should be quantitatively extracted. To achieve this objective the bending properties of the pieces are calculated according to the ASTM D393-00 standard for the following relationships [7].

Where P is force (N), d is the sandwich thickness (mm), c is the core thickness (mm) and b is the sandwich width (mm), Eq. (1) is used to calculate core shear stress:

$$\tau = \frac{P}{(d+c)b} \tag{1}$$

Where t is the shell thickness (mm) and L is the distance between two supports (mm), Eq. (2) is used to calculate shell bending stress:

$$\sigma = \frac{PL}{2t(d+c)b} \tag{2}$$

Where E is the shell elastic modulus (MPa), Eq. (3) is used to calculate panel bending stiffness.

$$D = \frac{E(d^3 - c^3)}{12} \tag{3}$$

Eq. (4) is used to calculate panel shear rigidity.

$$U = \frac{G(d+c)^2 b}{4C} \tag{4}$$

With respect to the initial gradient of the graph, the maximum force tolerated by the samples and the physical information of the samples. The dimensions and bending properties of each panel are shown in Tables 2 and 3.

2.2.Flat pressure test

In this test, which is also known as the off-plate pressure test, a piece of the panel is placed between the two jaws as, seen in Fig. 10, and the surface of the panel shell is pressurized. This test measures the strength and modulus of the core compression. This test is carried out in accordance with the ASTM C365-03 standard, and according to this standard the jaw speeds should be 0.5 mm per minute. Due to the time limit for the laboratory and to complete testing of all the samples, the samples were done at a speed of 3 mm/min. This test examines the properties of the core. A flat-panel pressure test is shown in Fig. 10.

This test is carried out in the same way as a three-point bending test in two types of foamed and non-foamed specimens. The experiment was first performed on non-foamed specimens. Three samples have been taken for this experiment. The results of the experiments on these samples are shown in Fig. 11.

After testing on non-foam samples, the experiment was performed on samples filled with the foam honeycomb core. To perform this test, as in the non-foam bending test, three samples were tested and the results are shown in Fig. 12.

As in the bending test, the diagram has two parts representing the elastic region and the plastic region. This means that in the first part of the force, the force increases almost linearly with the displacement to a maximum value. Upon reaching this amount of force, the plastic zone starts and the force begins to decrease as the device moves. For panel engineering designs, the first part of the diagram, i.e., the elastic region, is important and must be considered, so that all calculations and designs should be such that the structure of the force and compressive stress does not exceed its compressive strength. In the case of the second part of the graph, the plastic region, it should be noted that in general the behavior of the graph is similar in all experiments. But there are some minor differences that are due to the various defects in the

Table 2. Bending properties of sandwich panels made of foam

Sample	Panel length (mm)	Panel width (mm)	Panel thickness (mm)	Shell bending stress (MPa)	Core shear stress (MPa)	Panel bending stiffness (N-m^2)	Panel shear rigidity (KN)
Number 1 with foam	250	25.14	20.4	1.74	34.94	125.52	56.92
Number 2 with foam	250	25.22	19.4	1.8	36.03	1145.23	53.4
Number 3 with foam	250	25.12	19.86	2.04	40.91	1144.32	54.87

Table 3. Bending properties of sandwich panels made without foam

Sample	Panel length (mm)	Panel width (mm)	Panel thickness (mm)	Shell bending stress (MPa)	Core shear stress (MPa)	Panel bending stiffness (N-m^2)	Panel shear rigidity (KN)
Number 1 without foam	250	24.78	17.78	3.15	62.84	1763.35	168.56
Number 2 without foam	250	24.8	16.3	2.89	57.82	1550.68	159.98

Fig. 10. Flat pressure test.

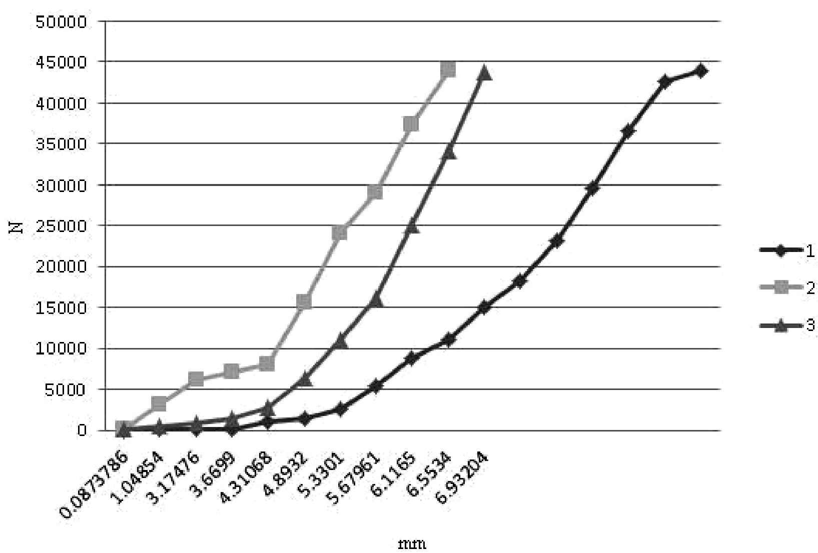

Fig. 11. Pressure test curve, without foam test sample.

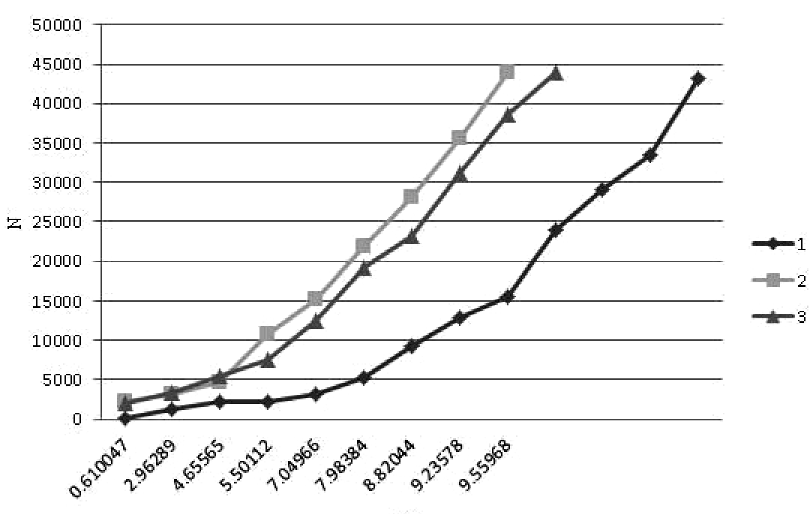

Fig. 12. Pressure test curve, with foam test sample.

samples, the precision in cutting the test samples or the degree of collision of the hexagonal cells. By examining the graphs and the amount of forces taken from the test, it has been found that foam-free specimens have a higher resistance than foam specimens. The compressive strength of the panel with the dimensions of the pieces is given in Table 4. Tocompare the strength of the honeycomb sandwich panel and steel, a bending test of a steel specimen was done. The bending strength of the steel sample is shown in Fig. 13.

A PEM fuel cell without a foam end plate was simulated in Abaqus finite element software to investigate the electrical resistance and electrical current., this fuel cell model. The condition for the Electrical-Mechanical analysis of this fuel cell in FEM software is shown in Fig. 14 [1].

The electrical resistance and electrical current of

Table 4. Specifications of sandwich panels made of foam.

Sample	Panel length (mm)	Panel width (mm)	Panel thickness (mm)	Panel compressive strength (MPa)
Number 1 with foam	25.12	24.87	20.22	86.54
Number 2 with foam	25.24	25.62	20.58	83.69
Number 3 with foam	24.08	24.85	20.77	85.49

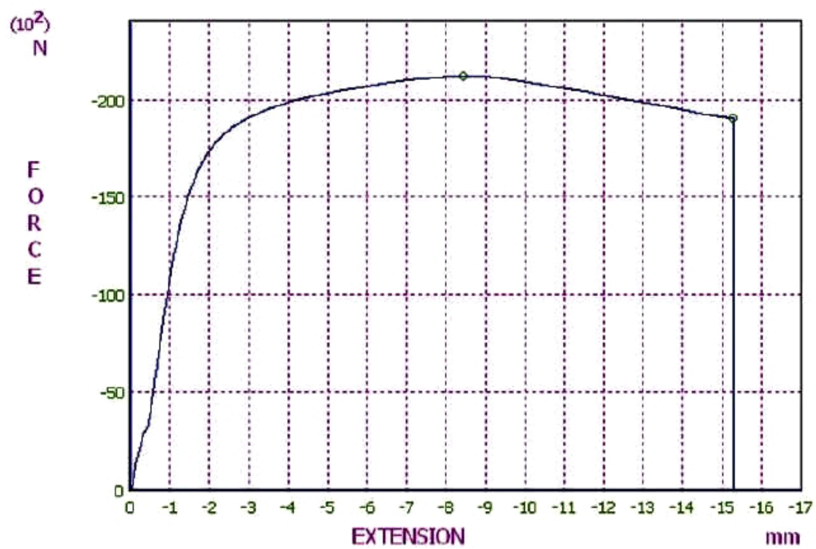

Fig. 13. Steel specimen bending test.

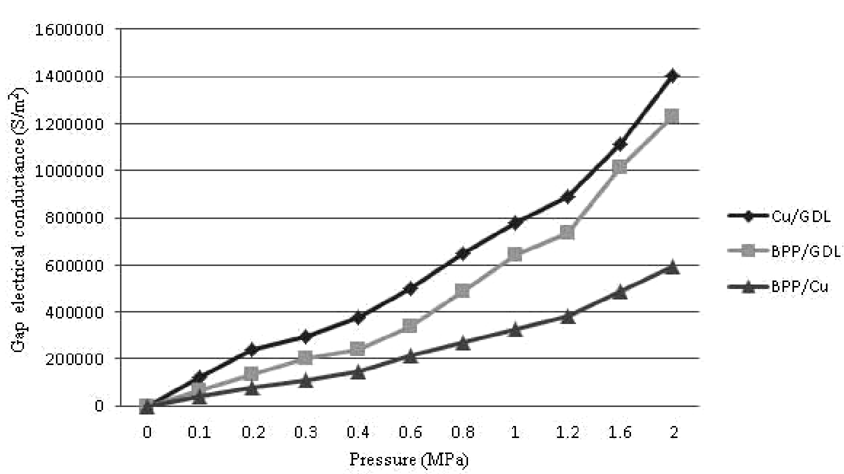

Fig. 14. Gap electrical conductance dependent on pressure between components [1].

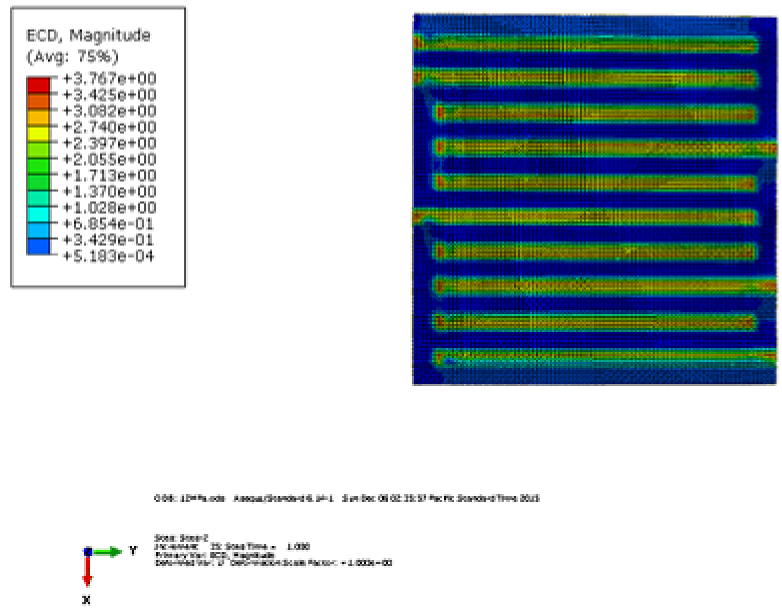

Fig. 15. Electrical current per unit area contour in GDL.

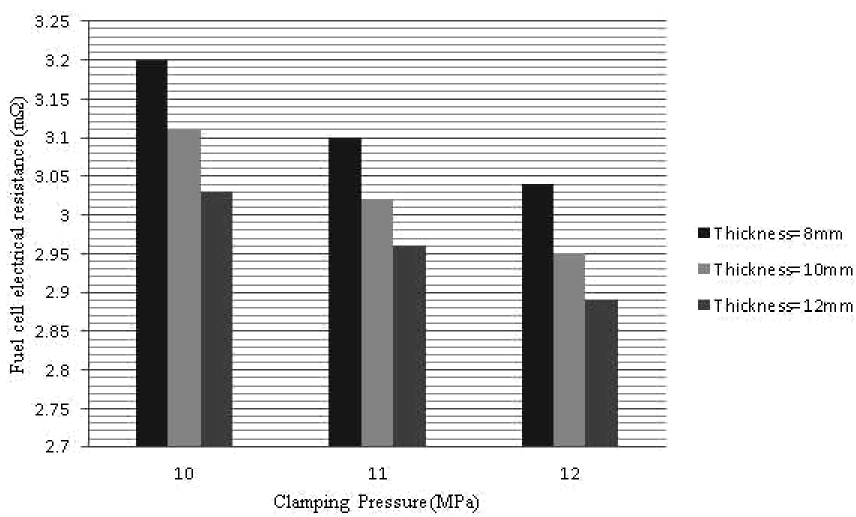

Fig.16. Relationship between clamping pressure and electrical resistance of PEM without foam fuel cell and different thicknesses.

this fuel cell has been evaluated based on different thicknesses and clamping pressures. The results of the analysis are shown in Figs. 15 and 16.

3.Conclusion

Analysis and prediction of mechanical behavior and fuel cell dilatations made with aluminum honeycomb were completed and compared with steel end plates. Using the results of the experiments shown in Figs. 8 to 13, two samples of foamed and non-foamed specimens were identified, and the panels made of a non-foam type were found to have a better bending strength than those with foam. The use of foam in the honeycomb core resulted in less weight for the sheets but also less bending strength than the foamless specimen. Results of electrical-mechanical analysis of the fuel cell showed that increasing clamping pressure in fuel cells with the honey comb structure can improve electrical efficiency and decrease electrical resistance and energy losses. Clamping pressure of end plate should be increased as much as possible to a level that decreases electrical resistance, but it should be noted that too much clamping pressure damages the fuel cell honey comb structure. As Fig. 16 shows, end plates thickness increases will reduce electrical resistance and this matter has been investigated in different thicknesses of 8, 10 and 12 mm.

References

[1] Habibnia M. et al., "Investigation and optimization of a PEM fuel cell's electrical and mechanical behavior." Iranian Journal of Hydrogen & Fuel Cell, 2016, 3.1, 1: 10.

[2] Fili Mohammad Hossein. et al., "Modeling and experimental study on the sealing gasket of proton exchange membrane fuel cells." Iranian Journal of Hydrogen & Fuel Cell, 2017, 3.3, 213: 220.

[3] Habibnia M. et al., "Determination of the effective parameters on the fuel cell effciency, based on sealing behavior of the system." Int. J. Hydrogen Energy, 2016, 41.40, 18147: 18156.

[4] Technical Fabrics Handbook-Reinforcements for composites. Hexcel corporation: USA, 2010.

[5] ASTM E290-14, Standard Test Methods for Bend Testing of Material for Ductility, ASTM International, West Conshohocken, PA, 2014.

[6] HexWeb Honeycomb Attributes and Properties, Hexcell, Editor. 2013, Hexcell company: USA.

[7] Habibnia Mostafa. et al., "Design and Investigation of Honeycombs", Master Thesis, Islamic Azad University, Sari Branch, 2017.

[8] Redux Bonding Technology, Hexcell, Editor, Hexcell Company, 2014.

[9] Xiong J. et al., "Shear and bending performance of carbon fiber composite sandwich panels with pyramidal truss cores." Acta Materialia, 2012, 60.4, 1455: 1466.

[10] ASTM E290-14, Standard Test Methods for Bend Testing of Material for Ductility, ASTM International, West Conshohocken, PA, 2014.

[11] Ha Na Yu. et al., "Axiomatic design of the sandwich composite end plate for PEMFC in fuel cell vehicles." Composite Structures, 2010, 92.6, 1504: 1511.

[12] Siegel Ch. et al., "Approaches for the Modeling of PBI/ H3PO4 Based HT-PEM Fuel Cells." High Temperature Polymer Electrolyte Membrane Fuel Cells, Springer International Publishing, 2016, 18: 387.