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Modeling and experimental study on the sealing gasket of proton exchange membrane fuel cells

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Abstract

In this study, the cross section geometry and material of gaskets in proton exchange membrane (PEM) fuel cells have been investigated to achieve a fuel cell with more terms of energy efficiency. The role of gaskets in fuel cells is sealing and preventing combinations of gas flow channels. In a PEM stack, a gasket with approved geometry which suffers more stress has better sealing. For this investigation, experimental leakage tests have been done first and then gaskets manufacturing, stack assembly, and finally putting the setup under press and studying leakage values in terms of time and various pressures. The results showed that a sealing gasket with a width of 3mm and thickness of 0.4 mm in pressure of 2 MPa seals well according to standards. To obtain optimal results, the width of 3mm and thickness of 0.4 mm has been considered for numerical simulation. After the leakage test, some materials have been tested and results showed that a gasket with hyper elastic properties is the best choice for sealing. After the experimental tests six gasket shape cross section profiles in a fuel cell stack have been modeled in Abaqus software and the best material and profile shape for gaskets in a fuel cell has been selected. Results of simulations showed good uniform pressure distribution in the stack.

1. Introduction

One of the most important problems for human is finding a good way to convert fuel energy to useable energy. With thermodynamic science advances, better fuel cycles have been investigated. Although some options were not useable or had complex processing procedures, but current fuel cells have simple processing procedures and have been replaced as new energy sources. As a fuel cell does not follow the

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Carnot cycle and instead transfers chemical energy to electrical energy directly by using an electrochemical process, its efficiency is 80% for Hydrogen and 30% for Methane [1-2]. Sealing is essential in a PEM fuel cell stack and elastomeric gaskets are used in order to prevent leakage of reactant gases and cooling fluid from other cases and outside the stack [3]. There are several common methods used to produce sealing gaskets for usage in PEM fuel cells [4]. One of these methods is cutting the intended seal from silicone and rubber sheets. The second method is silicon molding of different profiles. Another common method is the injection of molten silicone into the stack through an injection runner which is works well after the baking process. In existing Iranian facilities only methods 1 and 2 are possible for the listed stacks; and the second method, which is more efficient but costs more cost, is generally used. Elastomeric gaskets work in harsh conditions such as in acidic, moist air and hydrogen and under mechanical compressive forces. In the event of any loss or destruction of the gaskets, reactant gases H_2 and O_2 have the ability to sit outside or mix with each other during the reaction or even when waiting. With attention to the cost and importance of the components listed, wider research has been done to reduce costs and improve quality and performance of these components. Less attentions and research has been done on the performance and durability of sealing and adhesive productswhich plays a smaller role in fuel cells, despite the fact that failure of any of these components could reduce the efficiency of the system. Obviously, the deterioration and destruction of seals not only reduce the overall efficiency of the fuel cell but also are very important in terms of safety [5]. An example of a sealing gasket is shown in Fig. 1. The sealing gaskets mechanism is commonly achieved by creating a specific field of tension on the contact surfaces, prevents fluid passing. So far, a lot of research has been conducted on the properties of polymeric materials and their resistance to destructive agents such as temperature, acid and some other parameters, but few studies in the field of polymeric materials sustainability as sealing in the PEM fuel cell performance environment have been done. The required properties for a PEM sealing gasket are shown in Table 1.

A sample of fuel cell and its components has been shown in Fig. 2.

The gasket mechanism usually works by creating a specific field of tension on the contact surfaces, prevents the fluid passing. The minimum value of tension depends on the gas type, pressure and gasket material. Value estimation requires complex experiments that cannot be done simply. That is why the strategy used in this criterion should carefully consider the available facilities for the construction and molding of gaskets.

Through time, gaskets become worn and the quality of its work decreases. This would result in gas and

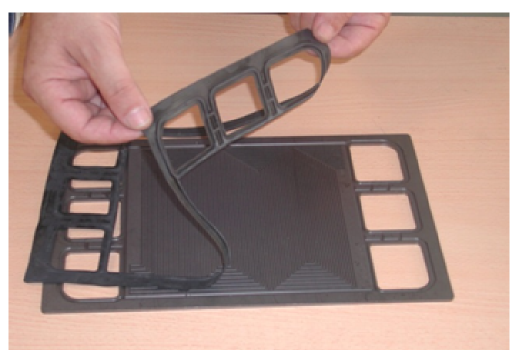

Fig. 1. A sample of a sealing gasket in fuel cells.

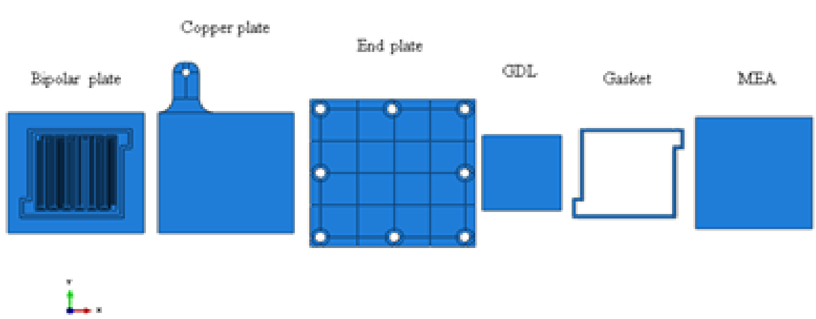

Fig. 2. Fuel cell components.

Table 1. Overall comparison between organic fuel cells in terms of efficiency and operating temperature and power production [6]

Usage	Power (KW)	Efficiency (%)	Working temperature (°C)	Electrolyte	Parameters
Alkaline fuel cell	Potassium hydroxide	60-90	40-60	To 20	Submarines and space
Methanol fuel cell	Membrane	60-130	40	Less 10	Portable applications
Molten carbonate fuel cell	Fixed liquid molten Carbonate	650	45-60	More 1	Power plant
Phosphoric acid fuel cell	Fixed phosphoric acid	200	35-40	More 50	Power plant
PEM fuel cell	Proton exchange membrane	80	40-60	To 250	Small power plant vehicles
Solid oxide fuel cell	Ceramics	1000	50-65	More 200	Power plant

liquid leakage from the fuel cell or a chamber stack and creates dysfunction. This phenomenon affects all fuel cell operation and reduces its efficiency. Thus, gasket chemical and mechanical resistance and its stability not only focus on sealing but also the effect on electrochemical performance of the fuel cell. So far, a lot of research has been done on the properties of polymeric materials and their resistance to spoiling agents like temperature, acid, etc. But there has been little research on polymeric material stability as a sealing gasket in the PEM fuel cell environment. Isabel et al. studied the material and the manufacturing process of gaskets and bipolar plates (BPP) and their impact on fuel cell (the columns are mixed up. This is the end of the sentence from the previous page!)efficiency. They investigated and showed the electrical and thermal properties of different materials [7]. Mark et al. studied the gasket producing process and sealing gasket role in PEM fuel cells, and they concluded that gasket production methods must be different based on the type of fuel cell performance [8]. S. Asgheri et al. designed and produced a 5.3 KW fuel cell stack and optimized the gasket geometry to achieve minimum leakage in a PEM fuel cell [9]. G. Tan et al. investigated silicone rubber viscoelastic material changes under load and no-load in the simulation environment. Results of the experiments showed that the decline in viscoelastic material increases with load and temperature increases [10-11].

2.Experimental

In this study, leakage tests were been first done in order to study the leakage rate of fuel cell fluids from the gasket and then the required dimensions for proper sealing in fuel cell have been selected. For these tests reactive gases Oxygen and Nitrogen entered the flow channels. Because of the risk of Hydrogen explosion, Nitrogen has been used instead. After the gases enter into the channels pressing force has been applied to the setup. After setup pressing the channel pressure was read and the leakage value calculated. The laboratory equipment used to perform these tests is described in the following sections.

2.1.Press machine

A 20 Ton hydraulic press machine, see Fig. 3, has been used to put pressure on the stack and perform experiments related to sealing gasket leakage.

2.2.Roughness machine

Roughness machine has been used for searching surface roughness and used machine is shown in Fig. 4.

2.3.Pressure regulator

Basically regulators are used to regulate tank

Fig. 3. The press machine used in the experiments.


Fig. 4. Used roughness measuring device.

tank pressure. In these tests, regulator is used to regulate tank pressure too. The regulator used is shown in Fig. 5.
A view from designed stack for measuring the value of leakage is shown In Fig. 6.
The leakage values have been calculated after putting the stack under a press machine and applying pressure. After leakage calculation it was found that a gasket with a width of 3mm and thickness of 0.4mm at a pressure of 2 MPa seals completely. Using the same dimensions (the columns are mixed up. This is the end of the sentence from the previous page!)the gasket has been modeled. Results of the leakage test are shown in Table 2.

Table 2. Tank pressureat different times for stress of 1.95 MPa on the gasket.

Time(Min)	Pressure(Bar)
0	3
12	2.9
19	2.8
26	2.7

The Leakage test has been done at other different pressures, results are shown in Fig. 7.

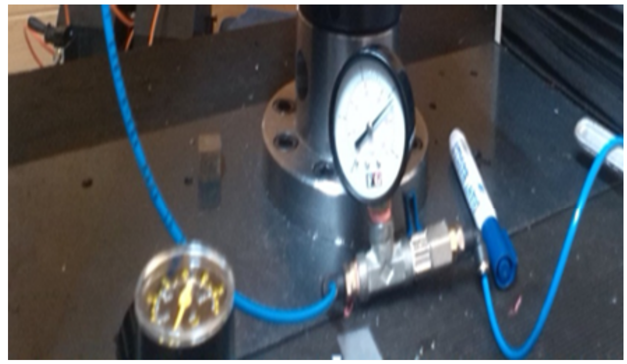
Fig. 5. Used regulator.


Fig. 6. The stack designed for the leakage test.

3. FEM geometrical model

According to the experimental tests a width of 3mm and thickness of 0.4mm at pressure of 2 MPa gasket seals the fuel cell well. Thus, numerical simulations have been done according to these values. In the numerical modeling, six profiles with different geometries have been modeled in software. These profiles shapes are using in the industry [2]. Considering proper conditions, each profile with the most stress has been selected and modeled. Fig. 8 shows the profiles geometries.
FEM modeling has been done in Abaqus software. This simulation has been modeled in a dynamics/ explicit step and all property and interaction modules are mechanical. Mechanical loads and boundary conditions are applied on components in the load module. Hex/Structured elements have been used in the mesh module, and in the final step the model has been analyzed. The simulation model has been

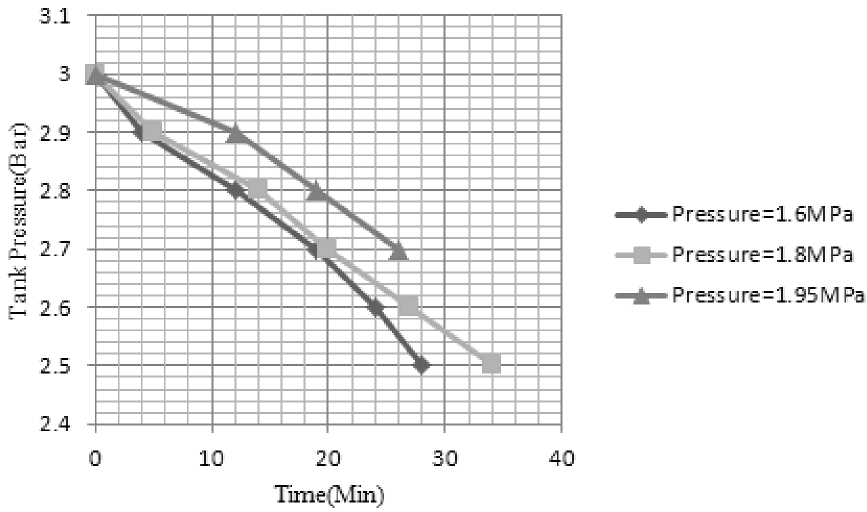

Fig. 7. Tank pressure in terms of time spent in the leakage test.

has been analyzed. The simulation model has been created from three geometrical components. The first component is a part of the bipolar plate containing the silicone gasket. The second component is the silicone gasket and the third component is the rigid plate that plays a holding role. Fig. 9 shows a sample of the components package and their positions, and as Fig. 9 shows, a section of BPP and Gasket has been modeled. In the following section, the various parameters involved in modeling and the results of tests will be explained. The main component of modeling is the specific model used to simulate the behavior of silicone rubber in PEM fuel cells.

Properties of components modeled in software are shown in Table 3.

Utilizing the results of the experimental tests on the sealing gaskets, the material for the gaskets has been selected with hyper elastic properties as shown in Fig. 10.

Simulation has been done in a 2D state and displacement type loading on the Graphite plate moves as it approaches the flat surface of the gasket.

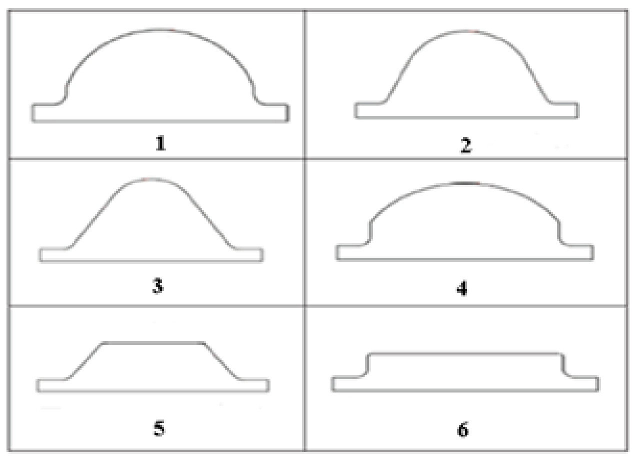

Fig. 8. Profile shapes for sealing gaskets.

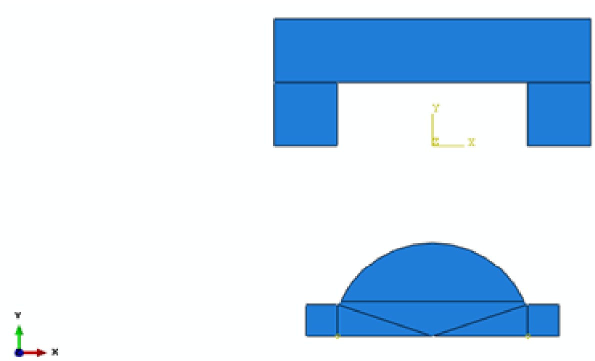

Fig. 9. components modeled in software.

Table 3. PEM components mechanical properties [12]

Part	Material	Mechanical behavior	Yong's module(GPa)	Poisson's ratio	Density(Kg/m^3)
Bipolar plate	Graphite	Elastic	0.12	0.25	2000
Gasket	Polymer	Hyper elastic	-	-	2330

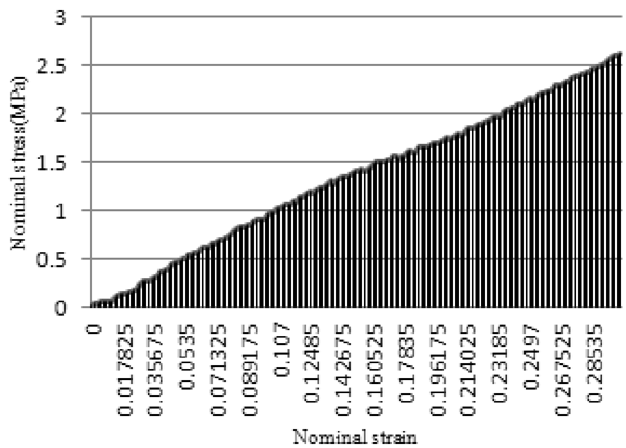

Fig. 10. Hyper elastic properties of sealing gaskets.

The parameter that shows the best profile model is created stress. Hex/Structured type Meshing was done and the analyzed models have been compared together.

4.Results

As has been explained in t hfirst section, six profiles have been studied with a width of 3mm and thickness of 0.4 mm. As these profiles have non compressible behavior and their surfaces cannot be greater than the Graphite hole, an upper limit of 3 mm^2 has been selected for surface area of these profiles. One sample of the stress contours is shown in Fig. 11 which illustrates that more stress produces better sealing and mechanical behavior. After the preliminary steps in the software, profiles models have been analyzed and according to the stress to gasket, a geometry and material for the gasket with higher energy efficiency has been selected. Path module has been used to compare stresses to gasket elements in the software. According to the path module contact route between the gasket and BPP has been selected for the gasket and the stresses of this route have been calculated. Because a sealing gasket has a symmetric shape, half of this line has been selected as shown in Fig. 12.

This procedure has been repeated for all sealing gasket geometries in that same line and the results have been compared together. Total results have been shown in the diagram in Fig. 13. For stresses comparison in gaskets with different geometries, the bipolar plate has been moved equal to the distance

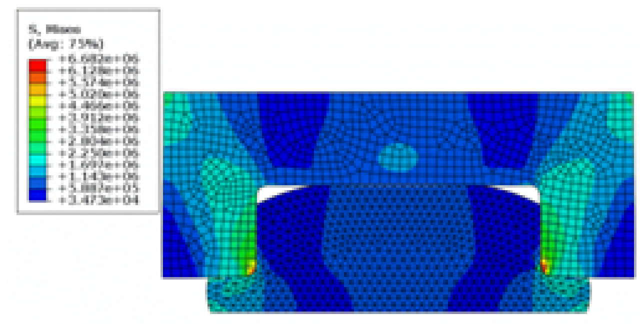

Fig. 11. Profile simulated (4) in the software.

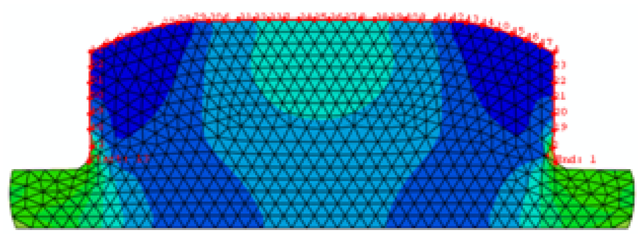

Fig. 12. Selected path on the sealing gasket for stress calculating.

with the gasket and then pressed. The stresses in the different profiles are shown in Fig. 13. Element stresses of the six gasket profiles are shown in Fig. 13, where the vertical axis is stress and the horizontal axis is true distance from first point in path. After calculation and comparison of the stress in various profiles, these steps have been repeated for strains as shown in Fig. 14.

In Fig. 14 the elements strains for the six profiles are shown, where the vertical axis is strain and the horizontal axis is the true distance from the first point. The contact width between gasket and BPP in software simulation after pressing is shown in Fig. 15.

5. Conclusion

With attention to Figs. 13 and 14 we can conclude that sealing gasket geometry has an effective on stress and strain fo the gasket, and a profile with sharper geometry has more stress and strain and better sealing in gasket elements. From the six profiles,

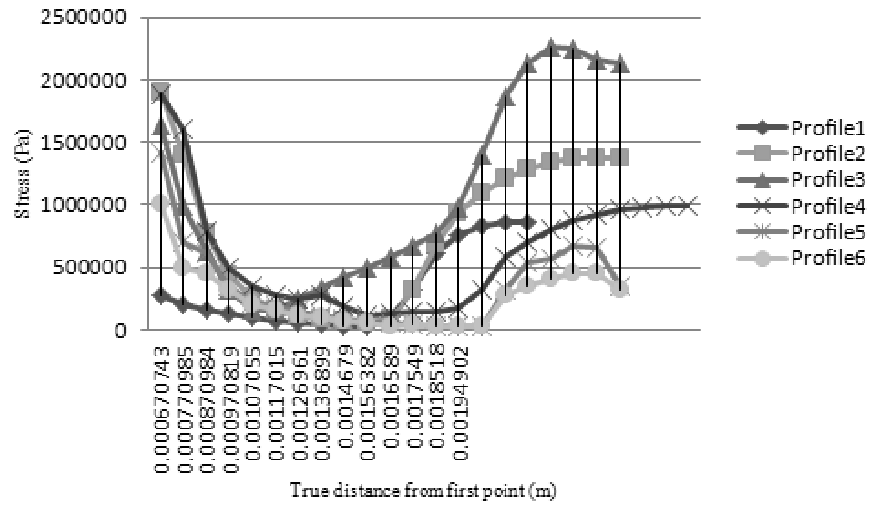

Fig. 13. Comparisons of stresses on the sealing gasket in same path.

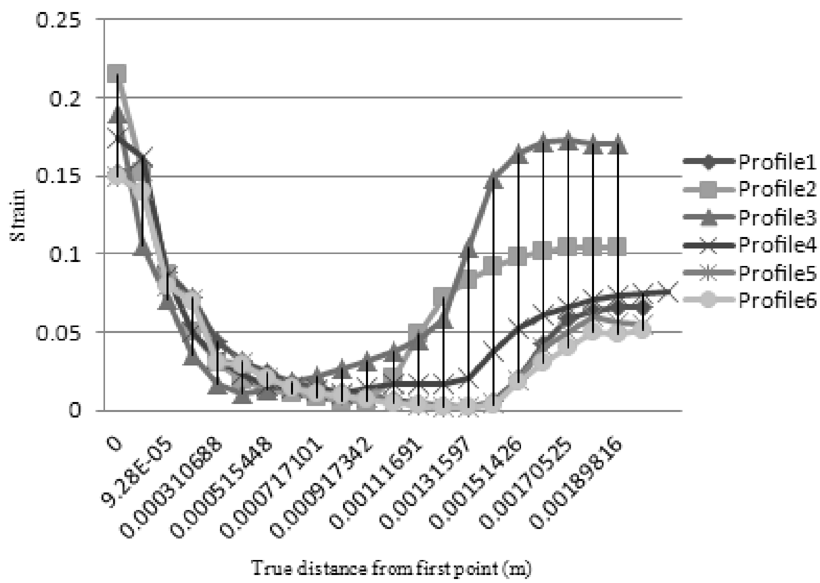

Fig. 14. Comparisons of strains on the sealing gasket in the same path.

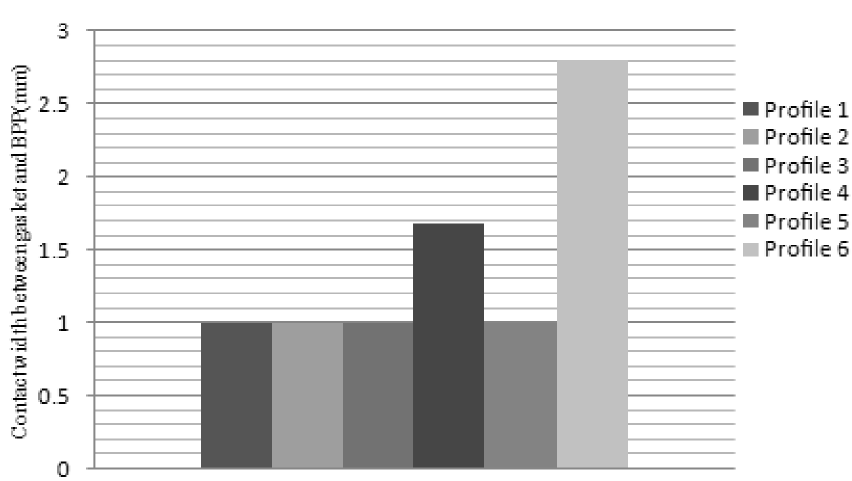

Fig. 15. Contact width between sealing gasket and BPP after loading.

the profile geometry of number 3 has better sealing but less contact width between the gasket and BPP after loading, see Fig. 15, due to some problems such as lack of fit of gasket with BPP and deviation probability in assembly step while the profile geometry of number 4 has more contact width between gasket and BPP. Hyper elastic material has been selected as the best material for gaskets after the results of tests shown in Fig. 10. Our results suggest that selected parameters for fuel cells with higher energy efficiency should be middle and optimized. Results of this research can be widely use in industry and economy and be used in any field.

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