Injection moulded composite bipolar plates for a portable hydrogen fuel cell charger

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Abstract. Fuel cells are electrochemical devices that convert the chemical energy of a reactants directly into electricity and heat with high efficiency. Proton Exchange Membrane or Polymer Electrolyte Membrane (PEM) fuel cells are one of the most common type of fuel cells. In a convection PEM fuel cell, the oxygen from air is introduced to the cathode and hydrogen is introduced to anode. Between the anode and cathode electrodes is sandwiched the polymer electrolyte membrane. The hydrogen molecules break apart into protons and electrons due to the reaction helped by catalysts. The protons travel through the membrane to the cathode and electrons travel to an external circuit. At cathode side the protons, electrons and oxygen molecules combine to form water. Research work was directed to the study of hydrogen fuel cell power systems for portable applications. Last decade the industry developed portable power systems based on hydrogen fuel cell, mobile telephone chargers, vehicles energy supply. In this paper are presented the experiments with a hydrogen fuel cell stack in which were assembled resin filled graphite bipolar plates and then injection moulded polymeric conductive composite bipolar plates and results were compared concluding that injection moulded bipolar plates could represent an attractive alternative in building efficient fuel cell portable power systems.

1. Introduction
Hydrogen, fuel cell technology. News about it are spread on scientific and popular media very often; Debate regarding the hydrogen production and storage advantages and disadvantages is faraway to a conclusion. Research activities are directed to the development of new materials, storage systems, cost reduction and to improve the efficiency. “Gheorghe Asachi” Technical University of Iasi announced and presented prototypes for an electrically bike and scooter powered by fuel cells with hydrogen stored in a capillary arrays system [1]. Pragma Industries of France announced a commercially available electrically bike with power supplied by a fuel cell system [2]. Several vehicle manufacturers launched hydrogen fuel cell powered cars, trucks and buses. A stack of five cells each measuring 6 cm x 6 cm x 1.975 mm, with an active area of 25 cm² using hydrogen and oxygen supplied an open voltage of 4.75V per stack, 0.95 V per cell. The bipolar plates were made in Aluminium alloy which was nickel and gold plated at a cost of 600 USD [3]. A ten fuel cells stack was developed as power supply device, with a 25cm² active area was producing a rated power of 15W and was able to operate a portable DVD for 3 hours. The bipolar plates were made of graphite plates in which were milled the gas flow circuits [4]. In 2010 Horizon Fuel Cell Technologies launched the MiniPak portable PEMFC charger which was supplying a 2 W USB output with hydrogen from metal hydride cartridges [5]. To a small Proton Exchange Membrane Fuel Cell (PEMFC) was added a boost converter, the system generated a voltage of 4.1 V. The bipolar plates were made in aluminium and gold plated [6]. The
Membrane Electrode Assembly (MEA) is the core component of a fuel cell where is produced the electrochemical reaction needed to separate electrons [7]. With about 80% of the total weight and 40% of the total cost the bipolar plate represents an important component of the fuel cells. The bipolar plates are made of stainless steel or aluminium and need special expensive surface treatments; are made of graphite and need special treatments to reduce the permeability; are made of carbon composites by compression moulding plates and then milling the gas circuits; are made by injection moulding of conductive polymeric composites. The polymeric conductive composites have a matrix in a thermoplastic or thermoset polymer and graphite, carbon black, carbon fibres or carbon nanotubes as fillers. The carbon black and carbon nanotubes help filling the gaps between the graphite particles and improve the conductivity. For a compression moulded Epoxy matrix polymer with fillers graphite 80% and carbon black 4.5% was obtained a conductivity of 150 S/cm and a flexural strength of 20 MPa [8]. For a metal-polymer composite made by over moulding on an aluminium plate a polypropylene matrix with 60% fillers graphite, carbon black and carbon fibres was attained a resistivity of 0.2 Ω-cm. For the polypphenylene sulphide matrix filled with graphite and carbon black was obtained a resistivity of 0.1 Ω-cm [9]. Experiments on a disc of 30 millimetres diameter and 2 mm thickness made by compression moulding a polymeric composite of graphite 87wt% in polypropylene with a secondary filler carbon black or carbon nanotubes evidenced an area specific resistance of 10mΩcm² [10].

2. Experimental

2.1. Injection moulding of the conductive polymeric composite bipolar plates

In figure 1 is presented the bipolar plate used for the experiments. The material chosen was a conductive polymer composite with a recipe as shown in table 1 and for which was measured an electrical resistivity of 0.001 Ω-m on a compression moulded sample [10].

| Material          | Type      | wt.%  |
|-------------------|-----------|-------|
| Polypropylene     | Matrix    | 13wt% |
| Graphite          | Filler    | 82wt% |
| Carbon Black      | Filler    | 5wt%  |

| Property          | Unit      | Value  |
|-------------------|-----------|--------|
| Flexural Strength | MPa       | 30     |
| Electrical Resistivity | Ω-m   | 0.001  |

![Figure 1. The bipolar plate: (a) anode circuit (hydrogen); (b) cathode channels (oxygen).](image-url)
The polymer composite bipolar plate has an active area of the gas flow of 100mm² with the double flow channels on the anode side with a section of about 0.8 mm x 0.5 mm, at anode side with a section of 1.5 mm x 0.6 mm and total size of 55 mm x 55 mm x 4 mm. (the flow channels of the milled resin graphite bipolar plate at anode side are 2mm x 1 mm section and cover same active gas discharge surface of 100mm²). It was tested the melt flow index and was recorded no flow, at 300ºC temperature, 15 kg weight and on 2mm diameter of the die opening (300ºC/15.0 kg – EN ISO 1133-1:2012). The injection moulding was performed on a 350kN clamping force machine with the mould cavities electrically heated at 90ºC, temperature of the barrel 300ºC, injection speed 100 mm/s and hydraulic (ram) injection pressure of 11MPa. The mould cavities presented in figure 2 were made in aluminium EN7075 by micro-milling the gas flow circuits with an end-mill of 0.5mm diameter at a feed speed of 250 mm/min and 24.000 RPM. Tests evidenced that heating the mould and generous openings of the mould and injection unit nozzles are influencing the manufacturing process the most.

![Figure 2. Aluminium Injection Mould Details: (a) Anode side; (b) Cathode side](image)

2.2. The bipolar plates made of compression moulded resin graphite composite
The standard fuel cell stack, brand Fuel Cell Store [11] was assembled with the bipolar plates machined in resin graphite composite and measured performances, then, the stack was assembled with the bipolar plates made by injection moulding in conductive polymeric composite and measured the performances. In table 2 are presented the specifications of the compression moulded resin graphite composite plate, grade FC-GR347B as indicated by manufacturer [12].

| Property               | Unit             | Value  |
|-----------------------|------------------|--------|
| Polymer Matrix        | Thermoset Resin |        |
| Density               | g/cm³            | 1.99   |
| Particle size         | mm               | 0.0254 |
| Flexural Strength     | MPa              | 65     |
| Porosity              | %vol             | 0      |
| Electrical resistivity| Ω·m              | 0.0012 |

Into the plates of the resin graphite composite have been milled the gas circuits for anode and cathode as can be seen in figure 5 and figure 6.
2.3. First tests with the polymeric composite bipolar plates in a one cell assembly
First tests with the injection moulded polymeric conductive composite bipolar plates were done in an assembly with a single cell fuel cell stack, with a polymer electrolyte membrane with 0.4% mg/cm² Pt loading, graphite paper gas diffusion layer with PTFE porous layer, gaskets made of rubber foil and it was obtained a voltage of 0.85 to 0.9 volt with hydrogen / oxygen and 0.75 Volt with hydrogen / oxygen (forced air), the hydrogen and oxygen from an electrolyser with a capacity of about 20 ml Hydrogen/minute, respectively 10 ml Oxygen/minute. Measurements were done with multimeters and using a screw travel potentiometer 4.8kΩ on a stroke of 450 millimetres, with which were obtained different load values and there were noted voltage and current accordingly. Based on the mentioned experimental measurements were obtained the polarization curve presented in figure 3.

![Figure 3. Polarization Curve of a fuel cell stack with one cell, injection moulded polymeric composite bipolar plates.](image)

2.4. Fuel cell system configuration
The system was designed to test the performance of the injection polymeric composite bipolar plates versus the ones machined in resin graphite plates (compression moulding, thermoset resin matrix, graphite 0.0254 mm particle size, bulk density 1.99 g/cm³). The configuration and the predicted output are presented in table 3 and the lay out is shown on figure 4.

![Figure 4. Schematic lay out of the experimental system.](image)

With the goal to obtain a power of 0.350 W, enough for charging a mobile telephone battery for example, the system was configured as a stack of 5 cells hydrogen/air connected in series.
Table 3. Hydrogen – Air Fuel Cell System Configuration and Predicted Performance.

| Input                        | Units  |
|------------------------------|--------|
| Power Needed                 | 0.350 W |
| Active Area                  | 10 cm² |
| Current Density              | 0.01 A/cm² |

| Output per one stack of five cells | Series connected |
|-----------------------------------|------------------|
| Volts/cell                        | 0.75 V |
| Power/cell                        | 0.075 W/cell |
| Total Current                     | 0.1 A |
| Total Voltage                     | 3.75 V |
| Total Power                       | 0.375 Watt |
| Estimated Hydrogen Consumption a  | 0.0035 LPM |

*a* Calculated at a rate of 0.007 LPM / cm² and not considering losses.

2.5. Materials

The standard fuel cell stack was assembled with the bipolar plates machined in resin graphite composite and measured performances, then, the stack was assembled with the bipolar plates made by injection moulding in conductive polymeric composite and measured the performances. The bipolar plates used in the experiment are presented in figure 5 and figure 6 and the materials of the stack in table 4.

![Figure 5. Fuel Cell Components a) Cathode Side injection moulded bipolar plate b) Polymer Electrolyte Membrane c) Electrode d) Cathode Side Milled Resin Graphite Composite Bipolar plate.](image)

The stack components were the same: MEA, gaskets, O-rings, clamping plates, collectors, screws, only the bipolar plates were exchanged. Results are presented in chapter 3. The materials used for building the fuel cell stack are presented in table 4. A PEM fuel cell consists of a negatively charged electrode (anode), a positively charged electrode (cathode) and the electrolyte membrane; the hydrogen is oxidized on the anode and oxygen reduced on the cathode, protons are transported through the MEA to cathode and the electrons are carried to an external load; at cathode oxygen reacts with protons forming water and heat, as presented in figure 7 [7].
Figure 6. Fuel Cell Components a) Anode Side injection moulded bipolar plate b) Gasket PTFE c) Electrode Graphite Cloth d) Anode Side Milled Resin Graphite Bipolar plate.

Table 4. Materials for the fuel cell stack.

| Component          | Material                        | Remarks               |
|--------------------|---------------------------------|-----------------------|
| Bipolar Plates (I) | Resin Graphite Composite Plate  | Made by milling       |
| Bipolar Plates (II)| Polymeric Conductive Composite  | Made by injection moulding |
| MEA                | Membrane Electrode Assembly     |                       |
| Gaskets            | PTFE foil 0.25, Rubber O-rings  |                       |
| Clamping Plates    | Polycarbonate                   | Milling, Drilling     |
| Fixing             | Stainless steel nuts and screws |                       |

Figure 7. Fuel (one) cell sandwich components: Bipolar Plate Anode Side, Gasket, Membrane Electrolyte Assembly, Gasket, Bipolar Plate Cathode Side.

2.6. Hydrogen and Oxygen Supply
For the tests was choose a Proton Exchange Membrane Electrolyser with a capacity of about 30 ml/minute of Hydrogen. The Oxygen has been obtained from air and measurements were done with forced air by help of a 1.4W fan.
3. Results

Were measured the voltage with no load, the voltage and current during charging the battery 10 minutes, the voltage of the battery after 10 minutes of operation. Results are presented in table 5 and 10 minutes charging the mobile telephone battery measurements are presented in figure 8.

|                                | Injection Moulded Polymer Composite Bipolar Plates | Milled Resin Graphite Bipolar Plates |
|--------------------------------|---------------------------------------------------|--------------------------------------|
| Voltage Fuel Cell [V]          | 3.92                                              | 4.20                                 |
| Voltage in operation [V] air forced | 3.45                                          | 3.44                                 |
| Current in operation [A] air forced | 0.100                                           | 0.089                                |
| Voltage of the battery /10 min. [V]   | 3.45                                           | 3.44                                 |
| Power supplied [W]              | 0.345                                            | 0.306                                |
| Hydrogen Pressure [MPa]         | 0                                                 | 0                                    |
| Resistance through plane [Ω]    | 1.5                                               | 1.5                                  |

Figure 8. Voltage and Current Measured during a period of 10 minutes charging a Lithium-Ion battery model BL-5CB5 – 800mAh 3.7 V 3.0Wh.

The measurements indicated a better performance for the voltage with no load for the fuel cell equipped with the machined graphite bipolar plates versus the injection moulded in polymer composite ones, 4.10 V against 3.92 V, but during operation the fuel cell equipped with injection moulded polymeric composite bipolar plates supplied higher power 0.345 W versus 0.306 W supplied by the fuel stack equipped with the resin graphite composite bipolar plates. Was confirmed that the higher content of graphite positively influences the performance of the fuel cell as similar results have been found for both bipolar plates due to same electrical conductivity. The measurements of the experimental model of a supplied power of 375mW, 3.92V(3.45V in operation) at 0.1A confirmed the predicted power of 375mW, 3.75V at 0.1A.
4. Conclusions

The performance of a fuel cell depends on the hydrogen supply, pressure, flow, sealing, depends on the electrical conductivity of the bipolar plates, on MEA quality. During tests, was observed that a better flow of oxygen (or air) can improve the power. The experiments presented in this paper demonstrate the fuel cell built with injection moulded polymer composite bipolar plates charged a mobile telephone battery up to 3.5 Volts and that a commercial portable hydrogen fuel cell charger could be built with injection moulded bipolar plates using a hydrogen 10L metal hydride cartridge or with hydrogen stored in a capillary arrays system. Hydrogen storage system represents the most important issue for portable applications. The lower production costs of the polymer composite bipolar plates could be considered as an important advantage, an attractive alternative to the traditional bipolar plates made in stainless steel or noble metals or graphite which need additional expensive treatments. For injection moulding of conductive polymeric composites was observed that generous openings of the mould and machine nozzles and controlled tempering the mould cavities help the most the processing. Will be planned future experiments for analyse the influence of the injection pressure on the packing of the bipolar plates and as a consequence on the electrical conductivity. Future works will be directed to the research for improvement the performances by optimize the design of gas flow channels and analyse the influence of surface of the bipolar plate’s roughness on the gas flow.

5. References

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Acknowledgments

LS Inteh srl, Bucharest, kindly provided the materials and the necessary equipment for manufacturing the mould and for the experiments.