

BIPOLAR PLATES FOR PEM FUEL CELLS: ELECTRICAL PERFORMANCE AND COMPOSITE MATERIAL REUSABILITY

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Abstract:

This work aims to investigate composite materials used for the fabrication process of bipolar plates in proton exchange membrane fuel cells. At an applicative level, the through-plane electrical conductivity was measured for five commercial samples, potential candidates for bipolar plates. Among these, the highest results indicated 2236 S/m. This plate was milled in order to obtain gas flow channels, and the resulting powder was collected. The analysis of chemical elemental composition of this sample was carried out using the Energy-Dispersive X-ray Spectroscopy method. The content proved to be rich in carbon, and the absence of impurities indicated a possible reuse of the obtained powder for the manufacture of adhesives in order to assemble a bipolar plate. The other four samples, with known conductivity were assembled, using two adhesive proposals developed in the laboratory. The samples used resins as the polymeric matrix, and the obtained powder form the machined plate. Through-plane electrical conductivity of each assembly was then measured, before the addition of the adhesive, with the plates in direct contact, and after the addition of the adhesive. It was found that the first sample shows the best overall performance.

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1. INTRODUCTION

This paper aims to explore the electrical properties of composite materials for bipolar plates and highlight the possibility to make further use of the powder obtained from machining process of the flow field channels. Five commercial samples are measured in order to determine through-plane conductivity. Based on the powder obtained by machining

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the sample that presents the highest results, an elemental composition analysis is carried out by the Energy-Dispersive X-ray Spectroscopy method. Then, the powder is mixed with resins in order to obtain conductive composite binders. Then, two binded samples are proposed and measured in order to determine if the proposed materials can be suitable candidates for this type of application.

2. SHORT REVIEW

Several papers focusing on PEM fuel cells, mentioned various types of materials as bipolar plates candidates, and it was stated that, among them, graphite-based polymer composite materials are great candidates [Rzeczkowski et al. 2019]. Over the years, authors highlighted the efficiency regarding electrical properties of these composite materials [Kakatia et al. 2009; Lee et al., 2009]. A variety of polymers have been addressed such as epoxy and phenol resins, polypropylene and polyethylene [Shojaei et al. 2024, Antunes et al., 2011]. Different carbon materials have also been approached, such as activated carbon, carbon nanotubes, graphene, carbon fibers, expanded graphite, and carbon black [Kakatia et al. 2009; Antunes et al., 2011]. Some papers approach methods where, resin or carbon–resin mixture is added to carbon fabric in order to obtain a laminate composite materials [Kuan et al. 2021; Kim et al., 2013]. A variety of fabrication methods were studied during the development of PEM fuel cells, such as vacuum impregnation, hot press, injection of hot mixtures, and compression molding [Simaafrookhteh et al., 2020]. In some cases, room-temperature curing polymers can be compatible with the operating temperature of PEM fuel cell and offer chemical stability [Rong et al., 2024]. Some studies approach fabrication methods aimed for producing flat plates, not the bipolar plates overall. Usually, more complex geometries, such as flow channels, require additional processes, including milling [Simaafrookhteh et al., 2020]. The methods mentioned above were summarized in a diagram illustrating the fabrication process for carbon-based polymer matrix composites (Figure 1). Highly filled graphite composite materials have been investigated as alternatives for bonding and sealing fuel cell structures, as traditional solutions such as gaskets and O-rings are often rigid and prone to limitations [Rzeczkowski et al. 2019].

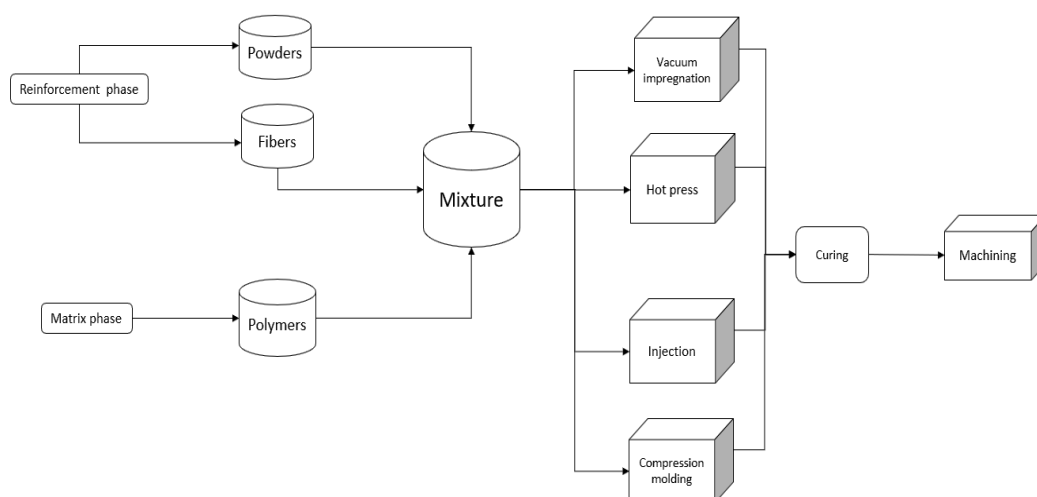


Figure 1. Fabrication process of carbon-polymer matrix composite

3. MATERIALS AND METHODS

Different authors address through-plane electrical conductivity [Warner and Graf, 2024; Cunningham et al., 2005]. Through-plane conductivity can be expressed as it follows (1).

$$\sigma = \frac{L}{R * A} \quad (1)$$

where R is the electrical resistance measured in ohms, A is the cross-section area of the conductor, measured in m² and L is the thickness of the conductor, measured in meters.

As follows, four flat samples of graphite-based composite bipolar plates procured from Schunk Group, presented in this paper as SCP1, SCP2, SCP3, SCP4, SPC5, were measured in order to evaluate their through-plane conductivity. The abbreviation used in this paper, SCP, comes from *Sample Commercial Probe* and the number is for further identification as four of the samples will be assembled together two by two in order to make the adhesive samples. The equipment used for the measurements is a CATI Benchtop TUC/RUC Tester (Figure 2).



Figure 2. CATI Benchtop TUC/RUC Tester equipment

The samples were placed between the two electrodes and measured. At a given current, the equipment measured each sample voltage. Using Ohm's Law in order to determine the electrical resistance R and using (1), electrical conductivity of each sample was calculated. Each sample must exhibit adequate flatness to ensure uniform contact on the electrode surface. The samples, were machined to address issues related to flatness deviations. The resulting thicknesses are presented in Table 1.

Table 1. Samples thicknesses

Sample	SCP1	SCP2	SCP3	SCP4	SPC5
Thickness[mm]	4.7	4.7	4.7	4.7	5

The sample that exhibited the highest value, as it will be presented in chapter 4, was machined in order to obtain the flow field channels geometry using a CNC milling machine (Figure 3). After the machining process, the obtained powder was collected. Energy-

Dispersive X-ray Spectroscopy analysis was made for this sample in order to determine elemental chemical composition.

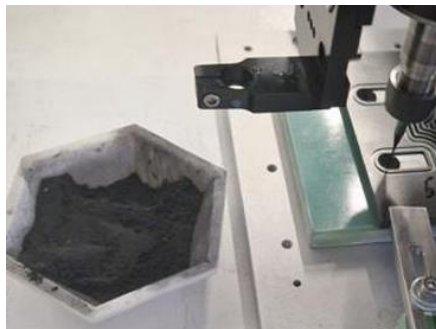


Figure 3. Milling process and powder collected from the sample with highest electrical conductivity

In a small container, 2.4 g of powder obtained from SCP1 and 4.8 g of clear casting epoxy resin, WWA, procured from Resoltech (Figure 4), were mixed using a spatula. The quantities were measured using a balance. After homogenization, the curing agent also procured from the same company, was added, and the mixing process was continued until a homogeneous mixture was obtained. The SCP1 and SCP2 samples were prepared for the adhesive application. They were machined into smaller samples with dimensions of $37 \times 57 \text{ mm}^2$.



Figure 4. Epoxy resin and curing agent from Resoltech

Also, before adding the adhesive in the assembly, the two samples were positioned one on top of the other, in direct contact and the through-plane electrical conductivity was measured. The obtained mixture was then applied to the surface of SCP1. The second commercial flat sample, SCP2, was placed over the adhesive and fixed by pressing. The composite cured at ambient temperature for 24 hours. The obtained assembly was named in this paper SCP1/2 (Figure 5), as the SCP1 and SCP2 samples were used and the number one sample, SCP1, was placed on top of the second, SCP2. The electrical conductivity of SCP1/2 was then measured.



Figure 5. Sample SCP 1/2 after the addition of adhesive mixture

For the second assembly, the same procedure was followed as previously described, however a different commercial binder was used. In this case, samples SCP3 and SCP4 were prepared, measured, and assembled to form the SCP3/4 sample. The adhesive was prepared by mixing 1 g of powder obtained from SCP1 with 3 g of Araldite, and 0.2 g of curing agent, both supplied by ROTH (Figure 6). Araldite can represent a good candidate for this purpose as this type of resin adhere very well to carbon due to its low curing shrinkage and good wetting of microscopic surface roughness. The mixture was then applied to the surface of SCP3. The other commercial sample, SCP4, was then placed on top of the adhesive layer. The assembly was pressed and allowed to cure for 24 hours at room temperature. Subsequently, the electrical properties regarding conductivity of SCP3/4 (Figure 7) assembly were measured.



Figure 6. Araldite and curing agent procured from ROTH used for sample SCP3/4.

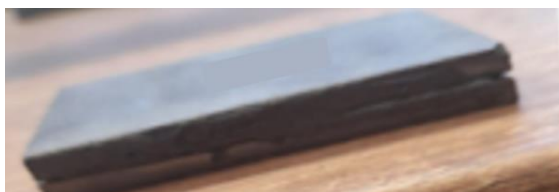


Figure 7. Sample SCP 3/4 after the addition of adhesive mixture.

4. RESULTS AND DISCUSSIONS

The results for samples SCP1, SCP2, SCP3, SCP4, SCP5 are presented in Table 2. SCP5 sample exhibits the highest through-plane electrical conductivity, reaching 2236 S/m. Consequently, it represents the most suitable option for reuse, due to its highest capacity to conduct electricity of all measured samples.

SCP5 flat plate was machined using a CNC milling process, and the resulting powder was collected and analyzed to determine its elemental composition by Energy-Dispersive X-ray Spectroscopy (EDX). Results indicated a total carbon content of approximately 95wt%, with oxygen accounting for about 5wt% (Figure 8.), confirming the predominantly carbon nature. High chemical purity of the material is also observed, as no additional elements were detected within the sensitivity limits of the technique.

Table 2. Electrical conductivity of commercial samples

Sample	Thickness [mm]	Electrical Rezistance [Ω]	Electrode diameter [mm]	Electrical resistivity [Ωm]	Electrical conductivity [S/m]
SCP1	4.7	$32 * 10^{-4}$	35	$6.6 * 10^{-4}$	1503
SCP2	4.7	$35 * 10^{-4}$	35	$7.3 * 10^{-4}$	1376
SCP3	4.7	$22 * 10^{-4}$	35	$4.5 * 10^{-4}$	2200
SCP4	4.7	$45 * 10^{-4}$	35	$5.8 * 10^{-4}$	1078
SCP5	5	$23 * 10^{-4}$	35	$4.5 * 10^{-4}$	2236

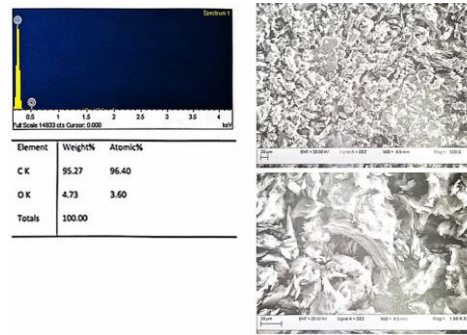


Figure 8. Energy-Dispersive X-ray Spectroscopy results for SCP5 sample

The measurements from SCP1, SCP2 placed on top of each other in direct contact, without adhesive, and SCP1/2 bonded with adhesive are presented in Table3. It also includes, the conductivity measurements of SCP3 and SCP4 placed on top of each other in direct contact without adhesive and assembly SCP3/4 bonded.

Table 3. Results of electrical conductivity

Sample	Thickness [mm]	Electrical Rezistance [Ω]	Electrode diameter [mm]	Electrical resistivity [Ωm]	Electrical conductivity [S/m]
SCP1/2 direct contact	9.4	$76 * 10^{-4}$	35	$7.7 * 10^{-4}$	1293
SCP1/2 assembly	9.5	$72 * 10^{-4}$	35	$7.3 * 10^{-4}$	1371
SCP3/4 direct contact	9.3	$56 * 10^{-4}$	35	$5.8 * 10^{-4}$	1730
SCP3/4 assembly	9.4	$69 * 10^{-4}$	35	$7.1 * 10^{-4}$	1418

In Table 2, SCP1 exhibited 1503 S/m and SCP2 1376 S/m. Sample SCP1/2, positioned in direct contact without adhesive, exhibited a lower value than the samples themselves due to the appearance of resistive losses. However, the bonded SCP1/2 assembly exhibited a higher value of 1371 S/m. The fact that the value is closer to the ones of the measured commercial plates indicates that the laboratory obtained composite offers electrical conductivity.

SCP3 and SCP4 exhibited values of 2200 S/m and 1078 S/m. It is noticeable that SCP3/4, placed in direct contact, exhibited a higher value than the SCP3/4 bonded assembly. These values indicate that SCP3/4 bonded with the laboratory obtained adhesive imposes a higher contact resistance than the direct contact of the plates and it can introduce resistive losses in the fuel cell performance.

This work also highlights the possibility of reusing materials collected after machining the geometries of different bipolar plates, if they do not contain impurities and if the carbon content is high. This also requires validation through measurements related to the electrical conductivity of the material. It is important that the mixture exhibits high conductive properties since the polymer percentage in the overall mixture will later increase through mixing with polymer resins.

5. CONCLUSIONS

The samples, proposed in laboratory, indicated acceptable performance in terms of electrical conductivity. Among them, the SCP1/2 bonded sample, with a conductivity of 1371 S/m, stood out in that the assembly in which, the adhesive mixture is included, exhibits electrical conductivity close to the values of each plate.

A future direction consists in using this type of mixture for further development in making samples containing more flat plates assembled. This kind of assembly can be used in order to determine the electrical properties in stack with more cells. However, additional considerations related to stack applications are necessary when designing its overall dimensions, including thickness, and the number of cells.

This paper highlights that the appropriate selection of composite materials and conductive adhesives is essential in order to obtain an optimal electrical performance of PEM fuel cells.

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Conflict of Interest Statement: The authors declare that they have no conflicts of interest.

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