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Cost-benefit analysis of commercial bipolar plates for PEMFC's

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Abstract

Identification of suitable materials for making high performance fuel cell stacks is of major importance, since the performance of a PEM fuel cell stack depends on the materials, especially in terms of their weight, cost, and corrosion stability. The weight of the fuel cell stack and thus the power density especially depends on the bipolar plates. In this paper we report the performance, heat generation, cost and weight analysis for a 1 kW PEM fuel cell stack system built with two types of commercial graphite plates. Cost benefit analysis has also been carried out using a design for manufacture and assembly technique (DMAT) by taking into consideration the fuel cell performance, stack configuration, repetitive units and fixed costs.

Keywords: PEMFC; Monopolar plates; Bipolar plates; Fuel cells

1. Introduction

In a fuel cell stack, the bipolar plate also known as the flow field or separator plate typically has four functions: distribution of fuel and oxidant within the cell, separation of the individual cells in the stack, facilitation of water and thermal management within the cell and current collection. Mehta and Cooper [1] note that plate topologies and materials facilitate these functions. Topologies include straight, serpentine or interdigitated flow fields, rigid or flexible plates, internal or external manifolding, internal or external humidification and integrated cooling. The requirements have been grouped into four categories: stack performance related design criteria system performance related design criteria, manufacturing related design criteria and environmental impact related design criteria. Cooper [2] analysed bipolar plate designs focusing on the requirements for stack and automotive performance with respect to design for manufacturing (DFM) and life cycle design (LCD), which can be used for as a qualitative guide.

There are several types of materials that are being used in bipolar plates. These include graphite, metallic plates with or without coating and a number of composite structures. Flexible graphite is a another material which has been used in fuel cell assemblies. Being based on natural graphite, purity and consistency of quality are real concerns for this material. Another drawback of graphite foil is the very limited formability and poor dimensional stability. Roser et al. [3] have recently reported on a low-cost graphite foil sheet for portable applications incorporating the gas diffusion media. The corrosion behaviour of sheet metals in the fuel cell environment has been studied by many groups [4–13].

One of the major cost components in manufacturing PEM fuel cells for various applications is the bipolar plate. Graphite plates are used as standards (especially with respect to the conductivity, porosity and corrosion resistance) in developing alternate bipolar materials. However, further requirements for bipolar plates include ease of manufacturability, thin and lightweight plates, which can yield a higher power density. Possibilities in achieving all of these characteristics lie with using composite materials or other conductive metals.

In the present study we have taken two types of commercial graphite plates with varying thickness, conductivity, cost, weight, etc. and analysed the performance in a PEMFC stack with respect to the above mentioned variables by keeping the operating conditions constant. The cost benefit analysis has been carried out using the design for manufacture assembly technique (DMAT), in order to identify a suitable bipo-

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lar plate with less cost, weight, low thermal output and high performance.

2. Experimental

Four electrode membrane assemblies (EMA) of 90 cm^2 were made by a proprietary process developed at our Centre for Fuel Cell Technology using carbon paper with a microporous layer as substrate, 20% Pt/C as electrocatalyst and Nafion 1135 as the electrolyte. Two types of graphite plates labeled as GPS1 and GPK1 from two different sources were procured and their characteristics are given in Table 1. The conductivity of these plates were measured by keeping the plates in a test rig consisting of current collectors and an end plate assembly. DC current was supplied to the plates using a DC power source and the voltage across the plates was measured with a multimeter. The compression force for the assembly was varied and the resistance was measured for various DC currents.

The EMA's were gasketed using fibre reinforced gaskets and fixed between the two flow field plates made from GPS1 and GPK1, using sealant. The fuel cell assembly consisted of repetitive units of monopolar plates for fuel and the oxidant as shown in Fig. 1. The plates were machined for fuel and oxidant passage with ribs and channels for current collection and gas flow, respectively. The whole assembly was kept between two current collector plates, reactant feed plates and the end plates. They were tightened with the help of bolts and nuts to prevent gas leaks and for uniform current collection. The fuel cell experiments were conducted using a test bench facility, fabricated in house which consists of Mass flow controllers for hydrogen and air, bubble type humidifiers, temperature controllers, thermocouples and water traps. The standard test methods were followed based on the USFCC test protocol [14].

Table 1
Physical properties of GPS1 and GPK1

Properties	GPS1	GPK1
Weight (g)	112.25	83.22
Thickness (mm)	4	2.7
Bulk density ($g\,cm^{-3}$)	1.99	1.98
Flexural strength (MPa)	40	71
Compressive strength (MPa)	50	57
Thermal conductivity ($W\,mK^{-1}$)	>50	
Cost (US$ m^{-2})	500	100
Specific electrical resistance ($\mu\Omega\,m$)		
XY	90	
Z	190	420

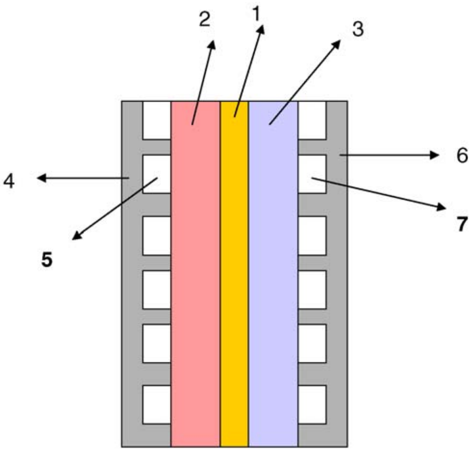


Fig. 1. Schematic of PEMFC: (1) polymer membrane; (2) anode electrode; (3) cathode electrode; (4) anode flow field plate; (5) fuel passage flow; (6) cathode flow field plate; (7) oxidant flow passage.

3. Results and discussion

3.1. Electrical conductivity and fuel cell performance

The properties of the two plates used in the present study are given in Table 1. The conductivity of the plates at two different compression forces viz., 20 lbf-ins and 40 lbf-ins are shown in Fig. 2. From the figure it can be seen that the conductivity of GPK1 is lower than GPS1 by about 7 S m^{-1} at 10 A DC, which increases to 10 S m^{-1} at 100 A DC. This shows that when high current is drawn from a fuel cell stack with GPK1 as the bipolar plate, electrical resistance will play a major role and the heat output will also greater. With increased compressive force, the conductivity does not seem to increase for the GPK1 and GPS1 plates indicating the interfacial resistance between the EMA and the flow filed plate is constant. The fuel cell stack performance for the GPS1 and GPK1 are shown in Fig. 3, where it can be clearly seen that the performance of the PEMFC with GPS1 plates is much higher than the GPK1 plates at all current densities. This is mainly due to the high conductivity of the GPS1 plates. The voltage drop due to the GPK1 plates from the GPS1 plates at various current densities are given in Table 2. This voltage difference at a particular current density leads to an increased thermal output for the GPK1 plates compared to GPS1. The fuel cell performance data can be extrapolated, assuming that the operating voltage is 0.55 V at 300 mA cm^{-2} current density, to get the thermal output for a 1 kW electrical output. The extrapolation to 1 kW can be done by calculating the number of cells and plates required with monopolar or bipolar repetitive units

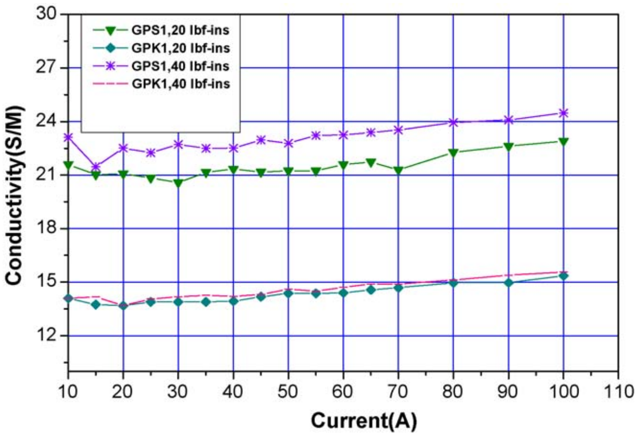


Fig. 2. Conductivity of GPS1 and GPK1 with respect to compression force.

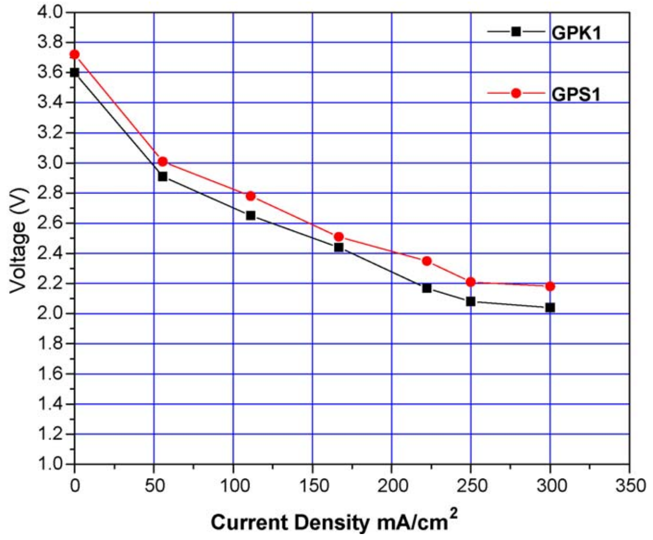


Fig. 3. Fuel cell performance of four cell assembly with GPS1 and GPK1 plates H2/air, temperature 60 °C, humidified H_2/air temperature 60/50 °C.

based on Eqs. (1) and (2), respectively:

$$N = 2P/IAV \tag{1}$$

$$N = 1.5P/IAV \tag{2}$$

where N is the number of plates, P the power in W, I the current density in mA cm^{-2}, A the area of the electrode in cm^2, and V is the voltage in volts. The thermal energy thus evaluated for 1 kW from the difference between theoretical voltage and the operating voltage for both the plates is shown in Fig. 4. From the figure one can see that the thermal output for the GPK1 plate is about 1400 W, whereas it is 1300 W for GPS1 plates. The thermal output from a stack is not only due to the bipolar plates but to the electrode membrane assemblies, contact resistance between the other components, etc. Although the electrical conductivity of the plates may differ by 50% (Fig. 2) the thermal output does not differ much. This may be due to the high thermal conductivity of the GPK1 plates compared to the GPS1 plates, as can be seen from the temperature rise at a particular current density. Hence, the GPK1 plates dissipate the heat efficiently, thereby not giving higher ohmic resistance for thermal output. The difference in thermal output between the two sets of plates can further be reduced if the operating voltage is increased to 0.6 V. Table 3 lists the requirement for 1 kW electrical output with respect to the number of cells, the number of monopolar plates, bipolar plates and the cost estimation.

Table 2
PEMFC performance at various current densities for GPS1 and GPK1 plates

Current density	Voltage (V)		
(mA cm^{-2})	GPS1	GPK1	Voltage difference
50	3.1	3	0.1
100	2.85	2.7	0.15
150	2.6	2.52	0.08
200	2.405	2.28	0.125
250	2.2	2.1	0.1
300	2.2	2.05	0.15

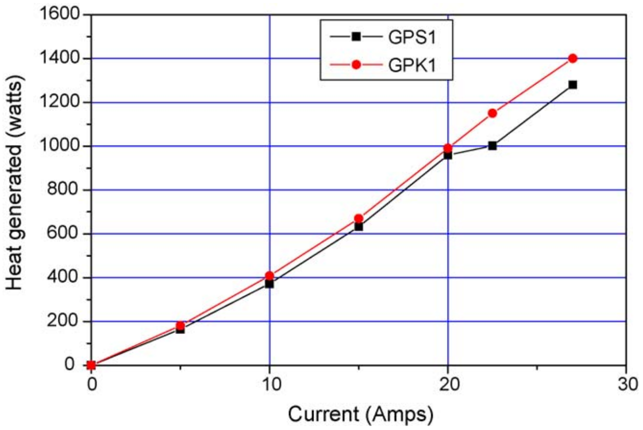


Fig. 4. Heat generated due to bipolar plates GPS1 and GPK1.

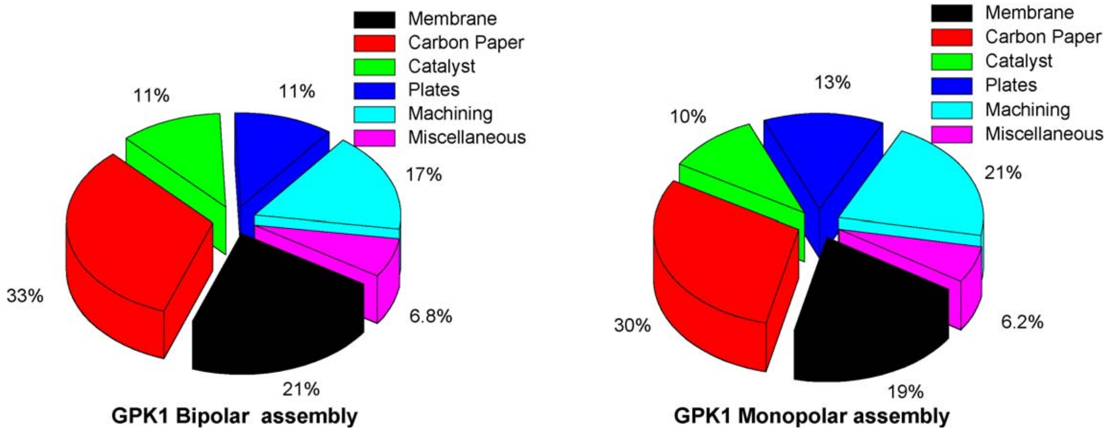
Table 3
Requirement of bipolar plates for 1 kW with different cell assembly and cost estimation

Graphite plate type	Cells required	Plates required	Cost (US$)
GPK1	72	108, bipolar 144, monopolar	324 432
GPS1	56	84, bipolar 102, monopolar	1176 1568
GPK1	74	111, bipolar 148, monopolar	333 444
GPS1	62	93, bipolar 124, monopolar	1302 1736

From Table 3, one can see that cost benefits will be more using GPK1 plates compared to GPS1 plates, at an operating current density of 300 mA cm^{-2} for 1 kW. However, if the area of the electrode is increased to draw a current of 100 A, the thermal output will be much higher for the GPK1 plates compared to the GPS1 plates, due to the large difference (10 S m^{-1}) in the conductivity of the plates at high currents. The cost of the GPK1 plates was ~100 \$ m^{-2} while the GPS1 plates cost ~500 \$ m^{-2}.

4. Cost benefit analysis

One of the major cost components in PEMFC stack development is the bipolar plate. The cost factor basically arises from the production volume and the operating conditions in terms of its rated output. For example, in the case of stationary power generation, it is advantageous to choose fuel cell operation at atmospheric pressure as it demands 5–10 year component lifetimes and is not weight sensitive. The low pressure systems also have lower parasitic loads and as the membrane performance improves, the cost impact between pressurized and non-pressurized operation becomes less important. However, in the case of transportation applications, the main challenge lies in identifying light weight components for the fuel cell stack and



GPK1 Bipolar assembly

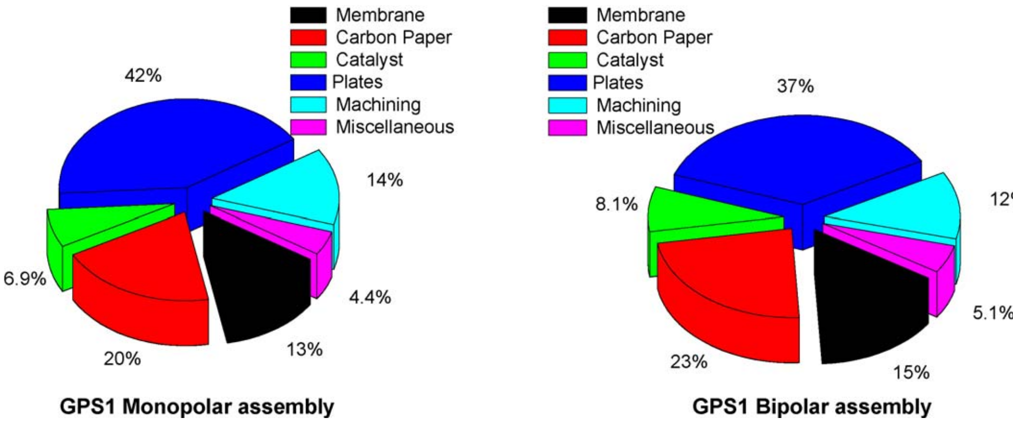
GPK1 Monopolar assembly

Fig. 5. Cost estimation using GPK1 plates with bipolar and monopolar configuration.

the expected life time is around 5000 h [15]. The fuel cell system cost as a function of the membrane area, which can be converted to the cost as a function of output power can be estimated according to James et al. [16]. Based on the above analysis, we have used the design for manufacture and assembly technique (DFMA) in this cost benefit analysis. The estimated cost of the fuel cell stack comprises of two cost parameters *A* and *B*, where *A* is a cost parameter that depends on the fuel cell platinum loading for both electrodes (mg cm^{-2}), cost of platinum, substrate cost, electrolyte cost, bipolar plate cost, fuel cell gross DC peak power (W), the fuel cell power density (W cm^{-2}), etc., and *B* is the fixed cost of the stack. The fuel cell stack cost depends on the two cost parameters (*A*, *B*) which in turn can be developed for various production volumes. The "*A*" parameter is the power-dependent term and the "*B*" parameter is the fixed cost for the fuel cell stack. This analysis was done for an output level of 1 kW without considering the operating conditions of the stack which takes in to account the parasitic power required to run the fuel cell system such as a compressor for the fuel cell cathode or a blower. The cost estimation has been carried out based on the following equation:

$$C = N(C_\mathrm{e} + C_\mathrm{s} + C_\mathrm{c} + C_\mathrm{p} + XC_\mathrm{m}) + YC_\mathrm{fc}(y_\mathrm{g} + y_\mathrm{e} + y_\mathrm{b+n}) \quad (3)$$

where *N* is the number of cells, C_e corresponds to the electrolyte cost, C_s the cost of substrate layer, C_c corresponds to catalyst loading, C_p the cost of bipolar plates, *X* the number of sides for machining, C_m the cost of machining, and C_fc is the fixed cost includes y_g gas feed plate, y_e endplates, $y_\mathrm{b+n}$ bolts and nuts. Figs. 5 and 6 show the cost estimation for 1 kW by taking into consideration both the terms *A* and *B* for the monopolar and bipolar repetitive units of the two sets of graphite plates. In cases where moulded plates are used, machining cost will be replaced by a die cost. The calculations are based on a current density of 300 mA cm^{-2} at 0.6 V. From the figures it can be inferred that the GPK1 plate contribution to the stack is ranging from 13 to 17% depending on the cell assembly configuration, while the GPS1 plate contribution is 37–42%. This very clearly reveals that the PEMFC stack cost can be considerably reduced by about 25% when GPK1 plates are used, in spite of the increased number of cells and plates. In order examine the weight benefits between the two types of plates, an analysis has been carried out to find the major weight components in a fuel cell stack and their contribution in terms of percentage was evaluated. It was observed that the major weight component is due to the bipolar plates constituting about 53–60% for the GPK1 plates in monopolar and bipolar arrangement, respectively as shown in Fig. 7, while the GPS1 plates contributed 55–62%. In either type of assembly,



GPS1 Monopolar assembly

GPS1 Bipolar assembly

Fig. 6. Cost estimation using GPS1 plates with monopolar and bipolar configuration.

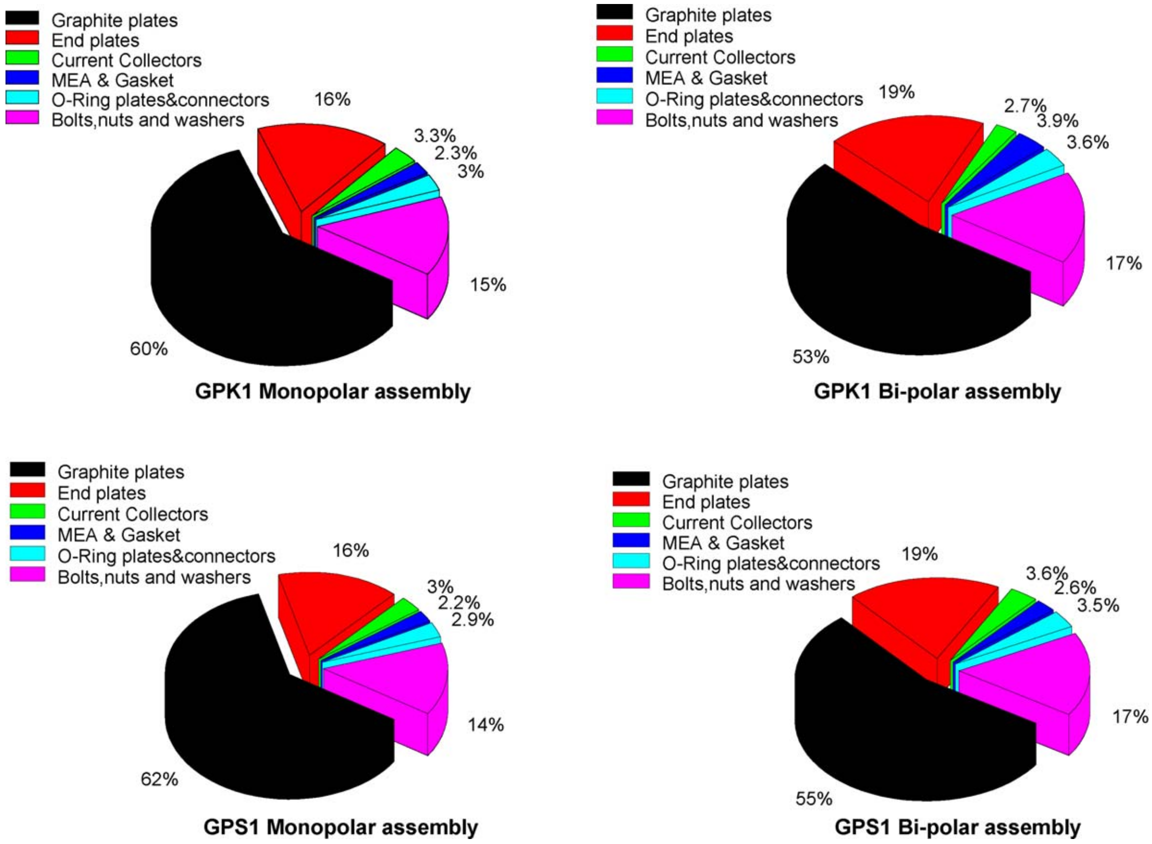


Fig. 7. Weight analysis of GPK1 and GPS1 plates in 1 kW fuel cell stack with both monopolar and bipolar arrangements.

the GPK1 plates reduced the weight of the stack by 2% only. However, the size of the stack can be reduced by about 25%, because of the lower thickness of the GPK1 plates compared to the GPS1 plates.

5. Conclusion

In the present paper we have analysed two types of commercial bipolar plates for their fuel cell performance. This analysis was carried out by fixing the design parameters with respect to fuel cell performance, and other materials, and components using the DMAT method. The GPK1 plates showed a lower fuel cell performance by about 10% which was mainly attributed to the conductivity of the plates of about 15 S m^{-1}. The thermal heat generated for a 1 kW PEMFC system at an operating voltage of 0.6 V was found to be 100 W higher for the GPK1 plates than for the GPS1 plates. Although the GPK1 plate shows a lower fuel cell performance and higher thermal output compared to GPS1, the benefits associated with the GPK1 plates are low cost by about 30%, in spite of the compensation made for an increased number of cells and consequently number of plates. However, with respect to weight, there were no appreciable benefits, since the plates had almost of same density. Reduction in size could be achieved by about 25% in the length of the stack. It is concluded that these benefits such as cost and volume can be valuable in transport applications.

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