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Short communication

Injection moulding of graphite composite bipolar plates

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Abstract

SGL Technologies GmbH has been developing different moulding technologies for graphite composite bipolar plates (BPP) for PEM fuel cells since 1997. Injection moulding of polypropylene (PP) and phenolic (PF) bonded graphite compounds have been identified as most promising and cost-effective production processes.

SGL Technologies has invested in injection moulding machines for moulding both thermoplastic and thermoset materials. In addition, materials and processes have been developed in order to mould highly filled compounds with a graphite filler content above 80 wt.% needed for the BPP application.

The PP bonded compound ®Sigracet PPG86 can be mould with complicated flow field structures and manifold through holes in a single process step. The material and process can be considered production ready for the low temperature ($T \leq 80\,^\circ$C) PEMFC application.

The PF bonded compound ®Sigracet BBP4 shows improved electrical conductivity and temperature stability over PPG86. It has been so far available as compression moulded plates only. However, our recent developments show that BBP4 can be injection moulded without major change of the attractive properties in comparison to the compression moulded plates. Anyhow, the injection moulded BBP4 will remain more expensive than PPG86 due to more complicated processing and a longer cycle time.

The pros and cons of the two materials and processes will be discussed in detail.
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Keywords: Bipolar plate; Graphite composite; Injection moulding

1. Introduction

Hydrogen fuelled polymer electrolyte membrane fuel cells (PEMFC) are commonly considered as attractive power sources for different stationary, mobile and portable applications, e.g. distributed heat and power generation. Despite recent technical advances in PEMFC development and production the systems still remain rather costly [1]. The main cost drivers are the perfluorosulphonated electrolyte membrane, the Pt catalyst and the BPPs [1,2]. The share of the BPP of the stack costs are expected to be from 3 to 37% depending on the manufacturing technology, and the target costs below 100 €/kW for stationary and below 15 €/kW for automotive applications respectively [1].

The BPPs are typically based on either graphitic materials or metals, e.g. stainless steel. The major advantage of graphite over metals is the excellent chemical and thermal stability leading to good corrosion resistance which is especially important in stationary applications where a long operational life of 40 000 h is expected [3]. As pure graphite is brittle and it is expensive to mill the complicated flow field structures needed for the BPPs, it is preferred to use mouldable graphite composite materials with polymer binders for cost effective production of the BPPs. Different thermoplastic, e.g. PVDF, PP, LCP, and thermoset, e.g. phenolic (PF) and epoxy resins (EP) as well as vinyl ester (VE), binders as well as different moulding processes including compression (CM), injection (IM), injection–compression (ICM), transfer (TM) and slurry moulding (SM) are covered by both scientific papers and patents [4–7], see [4] for a recent review.

Although injection moulding has been identified as the most promising technology for major cost reduction of graphite composite BPPs by many authors [1,4–7], compression moulding seems still to be the predominant production method for small and intermediate production series of BPPs. The obvious reasons for this are the difficulty of injection moulding of the highly filled graphite compounds needed for sufficient electrical conductivity as well as the fact that most stack manufacturers are still not prepared to compromise stack performance for the cost

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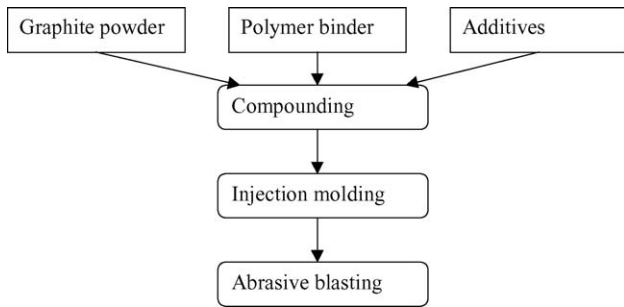[1] Present address: Dynamit Nobel Kunststoff GmbH, Jahnstrasse 18, D-91781 Weissenburg, Germany.

Fig. 1. The production process for the polypropylene bonded ®Sigracet PPG86 plates.

Fig. 2. The production process for the phenolic resin bonded ®Sigracet BBP4 plates.

reduction. Furthermore, the present BPP production volumes are not large enough in order to justify the high investment costs needed for dedicated injection moulding machines and moulds. Moreover, the electrical and mechanical properties of injection moulded BPPs have not been well documented previously [7–9].

SGL Technologies GmbH has IM machines readily available for moulding highly filled graphite polymer composites using both thermoplastic and thermoset binders. SGL has identified PP and PF as the most promising binders for the graphite composite BPPs. The economics of injection moulding of these compounds has been discussed in an excellent dissertation by Gebert [10].

2. Production methods

Compounding and injection moulding of the PP based compound ®Sigracet PPG86 is a three step process, Fig. 1. The graphite filler, the PP binder and possible additives, e.g. an internal release agent or flow promotor, are continuously compounded and granulated in a twin screw extruder. The granules can be fed into an IM machine without further processing. BPPs with desired flow field structures and manifold through holes are injection moulded using a fully automated moulding process. Finally, a polymer rich skin on the plate surfaces is broken by abrasive blasting [11] in order to decrease the contact resistance of the plate to the adjacent stack components.

The production process of the PF based compound ®Sigracet BBP4 is somewhat more complicated than that of PPG86, Fig. 2. After compounding the material has to be "conditioned" using a proprietary process before it can be moulded. Furthermore, the plates are post cured after moulding in order to guarantee sufficient thermal and chemical stability.

In order to show the technical feasibility of the different processes SGL has moulded blank plates and structured plates using internal designs. ®Sigracet PPG86 has been moulded using a "Demonstrator Plate" design with non-optimized gas and coolant flow fields and manifolds, Fig. 3. Combination of two of these plates brings one a fully functional BPP with internal coolant channels. ®Sigracet BBP4 has been moulded using an older "Show and Tell" design with a flow field but without manifold through holes, Fig. 4.
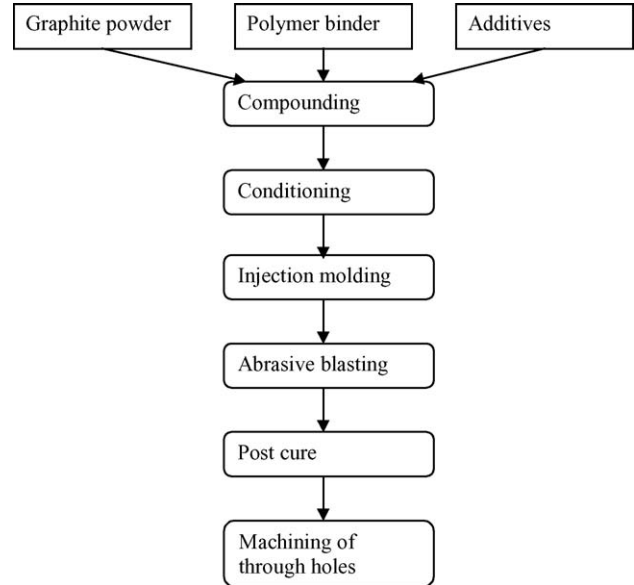

Fig. 3. Injection moulded ®Sigracet PPG86 "Demonstrator Plates".

Fig. 4. Injection moulded ®Sigracet BBP4 "Show and Tell Plates".

Table 1
Comparison of graphite composite bipolar plate materials (⊥: through plane, ||: in plane)

Property	Supplier						
	SGL PPG86[a]	SGL BBP4[a]	Schunk [12] FU 4369[a]	Morgan fuel cell [13] EF 150[a]	Nedstack [14] CP LT[a]	BMCI [15] 940-8649[a]	Plug power [16] Specification[a]
Process	IM	IM	CM			CM	
Density (g cm^{-3})	1.85	1.98	1.90	1.80	1.80	1.82	
Electrical resistivity (μΩ m, ⊥)	500	210	500	150	81	200	500
Electrical resistivity (μΩ m, ||)	180	80	90	50	50	100	180
Flexural strength (MPa)	40	50	40	35	30	40	40
Operation temperature (°C)	85	180	180		100		

[a] Type.

3. Material properties

3.1. Electrical and mechanical properties

The electrical and mechanical properties of the two ®Sigracet composites are compared against competing materials and customer specifications based on injection moulded PPG86 and BBP4 blank plates in Table 1. Although some competing materials show slightly lower resistivities than the ®Sigracet composites, the PPG86 and BBP4 plates are within the typical customer specifications. Moreover, direct comparison of the through plane electrical resistivities is not straightforward for the measuring technique is not well established. The resistivity of the ®Sigracet materials have been measured at 3.0 MPa compaction pressure and 1.0 A cm^{-2} current density using ®Sigracet GDL-30AA graphite paper to improve the electrical contact between the specimen and the measurement gold electrodes.

3.2. Chemical stability

Leachate analyses of injection moulded PPG86 and compression moulded BBP4 plates has been carried out in dilute sulfuric acid (pH 4.5) at 85 °C for 2000 h. An amount of 50 g of the composite material was stored in 250 ml of the acid in PP bottles in a heat chamber. No swelling of the specimens could be observed. The weight gain or loss remained below 1.0 wt.% for both materials. Practically no loss of flexural strength or change of Young's modulus could be observed, Fig. 5.

The leachate of any metallic impurities remained below 1 ppm from the PPG86 plates, Fig. 6 . The organic impurities measured as total organic carbon (TOC) could hardly be distinguished from reference PP bottles without any composite material. The TOC concentration remained below 40 ppm. Some Na (76 ppm) and organics (63 ppm) leached out of BBP4 plates. The exact nature of these organics could not be identified. No other metals leached out of BBP4.

Both materials have shown a stable stack performance well beyond 2000 h at different customers which is an indication that Na from the BBP4 plates is washed out of the cell with the product or coolant water instead of being accumulated in the electrolyte membrane.

A further stability analysis of compression moulded BBP4 plates was carried out in mineral oil and in concentrated (98 wt.%) phosphoric acid at 200 °C for 2000 h. Once more, no loss of flexural strength or change of Young's modulus could be observed, Fig. 7 . Neither Na or TOC could be found in H_3PO_4.
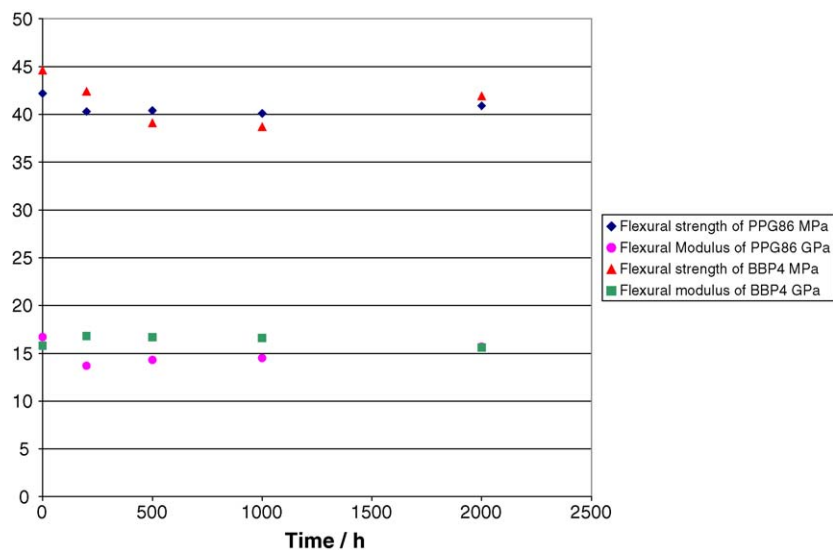

Fig. 5. Flexural strength and Young's modulus of injection moulded ®Sigracet PPG86 and compression moulded ®Sigracet BBP4 plates after storage in dilute H_2SO_4 (pH 4.5) at 85 °C for 2000 h.
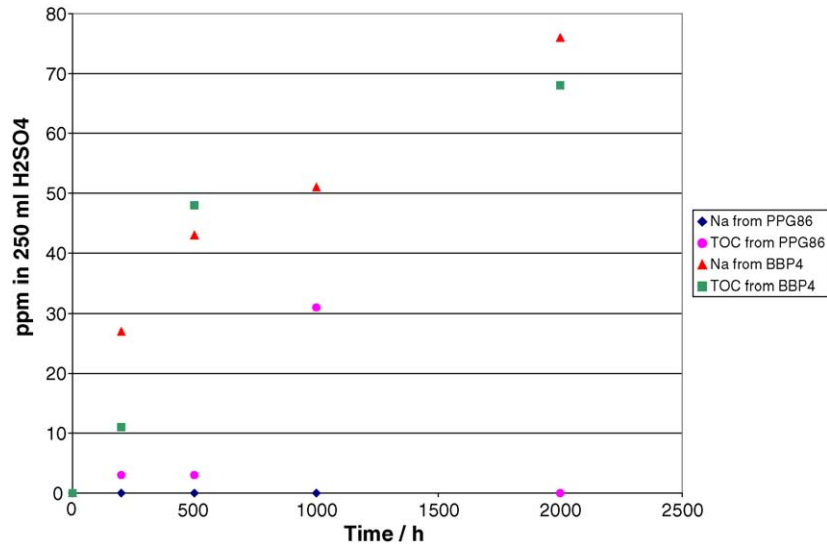
Fig. 6. Leachate of Na and total organic carbon (TOC) from injection moulded ®Sigracet PPG86 and compression moulded ®Sigracet BBP4 plates in dilute H_2SO_4 (pH 4.5) at 85 °C for 2000 h. About 50 g composite in 250 ml acid.

Injection moulded BBP4 plates are expected to be chemically as stable as the compression moulded ones for the material has not been changed.

4. Manufacturing experience

4.1. Plate dimensions and tolerances

The PPG86 demonstrator plate shown in Fig. 3 has outer dimensions of 150 mm × 150 mm × 3 mm and an active flow field area of 160 cm². The parallelity of the plate is below 0.05 mm and the channel depths and widths are within ±0.05 mm. Larger plate dimensions of up to 200 mm × 200 mm × 2.5 mm are feasible using the state-of-the-art PPG86 compound and process. Furthermore, the anode and cathode plates

could be moulded simultaneously using a two cavity mould for smaller plate designs.

The BBP4 Show and Tell Plate shown in Fig. 4 has outer dimensions of 120 mm × 220 mm × 4 mm. An improved tooling concept has been worked out to improve the plate parallelism to the required level and to mould larger blank plates with outer dimensions of 250 mm × 300 mm × 3 mm.

4.2. Process capability

Several thousands of PPG86 plates have been injection moulded according to different customer designs. The process capability will be analyzed in more detail using the Demonstrator Plate design and mould in a forthcoming paper.
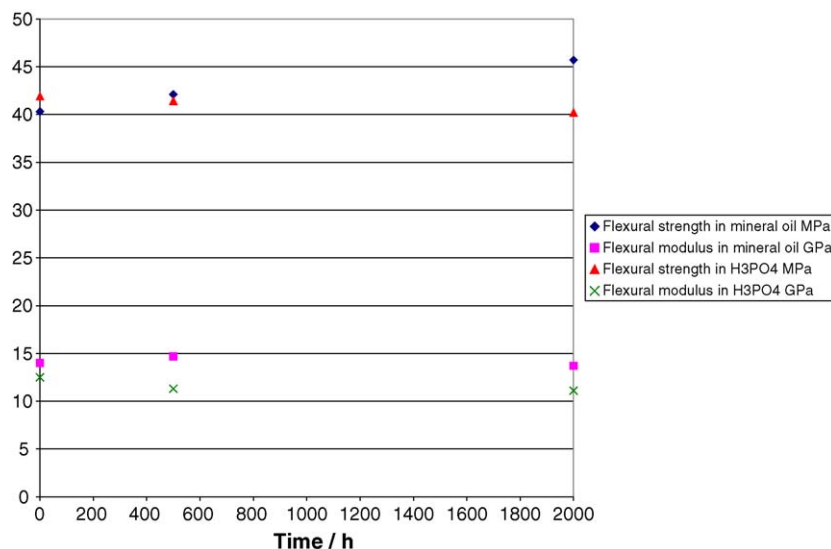

Fig. 7. Flexural strength and Young's modulus of compression moulded ®Sigracet BBP4 plates after storage in mineral oil or concentrated (98 wt.%) H_3PO_4 at 200 °C for 2000 h.
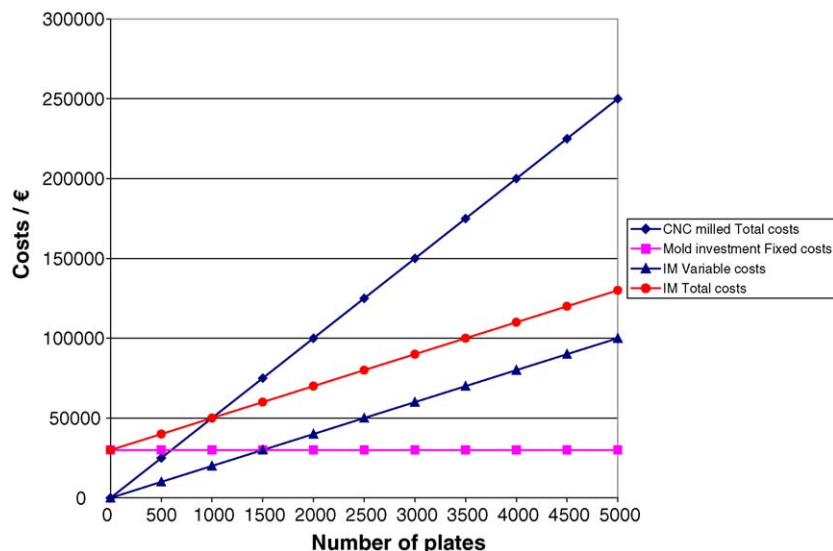
Fig. 8. Comparison of the production costs of machined and injection moulded ®Sigracet PPG86 plates using the modular mould concept by SGL Technologies GmbH.

The process capability of the BBP4 injection moulding process has still to be proven.

4.3. Modular mould

SGL has developed a modular mould concept in order to decrease the initial investment needed to go for injection moulding after using machined plates. In this concept, customer specific flow field inserts are fitted into a proprietary mould frame. A simplified cost example given in Fig. 8 shows that the investment in the mould inserts can pay off even with relative small production series of 1000 plates.

5. Conclusions

The polypropylene bonded ®Sigracet PPG86 compound and the automated injection moulding process are production ready for low temperature PEMFC applications. Using the modular mould concept by SGL Technologies GmbH, the investment in the mould inserts can pay off already for relative small production series of 1000 plates. For larger production series above 100.000 plates/year the target cost of 100 €/kW for stationary applications can be reached.

The phenolic resin bonded ®Sigracet BBP4 plates show improved electrical conductivity and thermal stability above 100 °C. However, further work is needed to establish an improved injection moulding process for the compound and to prove the economics of the more complicated moulding process.

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