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Study of the effect on conductivity and its uniform distribution in injection molded composite polymer bipolar plate

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Abstract: In this study, PPS blended with as high as 50 wt% carbon fiber were injection molded. Effects of molding conditions as well as the melt flow condition parallel and perpendicular to fluid channel on the surface conductivity was investigated. It was found that mold temperature affects the surface conductivity of molded parts significantly. Using a variable mold temperature control system based on electromagnetic induction heating, the conductivity of the molded part increase by about 152% when the peak mold temperature increases from 120 ºC to 210 ºC. The channel layout also helps the fiber to orient more randomly leading to an increase in the conductivity. The channel design parallel to melt flow increases the conductivity by 152% and when it is perpendicular to melt flow, the conductivity increases by 95%. Channel layout perpendicular to melt flow direction provides more influence on the fiber reorientation than that of the parallel design.

Introduction

The fuel cell is one of the most promising forms of clean energy for the future. It has the advantages of low pollution, superior stability, and high efficiency of energy conversion. A fuel cell runs on electrochemical reaction in which the direct conversion of chemical energy is not limited by Carnot-cycle constraints. However, commercial development still faces issues such as low cost mass-production, and the developments of metal or polymer substitute materials.

A fuel cell consists of many single cells, and produces voltages and currents through a series connection. The component that connects one cell to another is called the bipolar plate, which has a channel designed to allow fuel flow. The basic characteristics of a bipolar plate include good mechanical properties, separation of oxidizer and deoxidizer, good chemical resistance and high electric conductivity. Bipolar plates account for about 60%~70% of the entire cell cost. Therefore, one of the major concerns in reducing fuel cell cost is reducing the cost of manufacturing the bipolar plate.

The potential material candidates for bipolar plates may be generally classified into graphite [1], metal [2] and polymer [3]. The advantages of graphite plate include its excellent electric conductivity and good corroding resistance, but it is brittle, hard to manufacture, thick, and heavy, and has a long processing cycle. Metallic bipolar plates made of titanium and stainless steel also provide high conductivity and can be used in a thin form, but are vulnerable to corrosion. The surface-coated oxide film used to reduce corrosion also inhibits conductivity. Polymer bipolar plates are corrosion-resistant, lightweight, and can be mass-produced by injection molding. Unfortunately, polymers are non-conductive, and thus a high proportion of conductive additives must be added, leading to difficulties in the molding.

The injection molding process can reduce bipolar plate processing time, enabling mass-production at low cost. However the polymer bipolar plate must be blended with graphite, carbon fiber, or carbon powder, to increase the electron conduction to meet the required surface conductivity of about 100 S/cm. Although the higher the content of the carbon fiber or other conductive additives, the higher the conductivity the molded parts, higher carbon content may also results in brittleness, leading to extreme difficulties in molding. Further, during the molding process, the carbon fiber will become highly oriented along the flow field leading to a reduction in conductivity and severe warpage due to non-uniform shrinkage. The fuel channel in the bipolar plate may further hinder carbon fiber flow during the melt filling, affecting the conductivity. Shih [4] and Peng [5] point out that the fiber distribution is more uniform and fiber orientation is more random when molded at a higher mold temperature. The higher mold temperature is required to assist melt flow in a high fiber content polymer and to reduce fiber-blockage. Using traditional mold temperature control and running the mold at high temperature could lead to a significant increase in cycle time, impeding low cost, short cycle mass production.

In this study, variable mold temperature control [6], which offers high mold temperature within a short period during the melt-filling stage, is implemented for assisting melt flow with high-content fiber. The effect of fluid channel design layout on the fiber orientation relative to the melt flow direction is also studied by comparison with that of flat part without channel layout.

Results and discussion

In the first experiment, the fibers in the samples with channel layout parallel to melt flow direction (designated as Pa) were observed to be more orientated in the direction parallel to the melt flow, as shown in Figure 1.

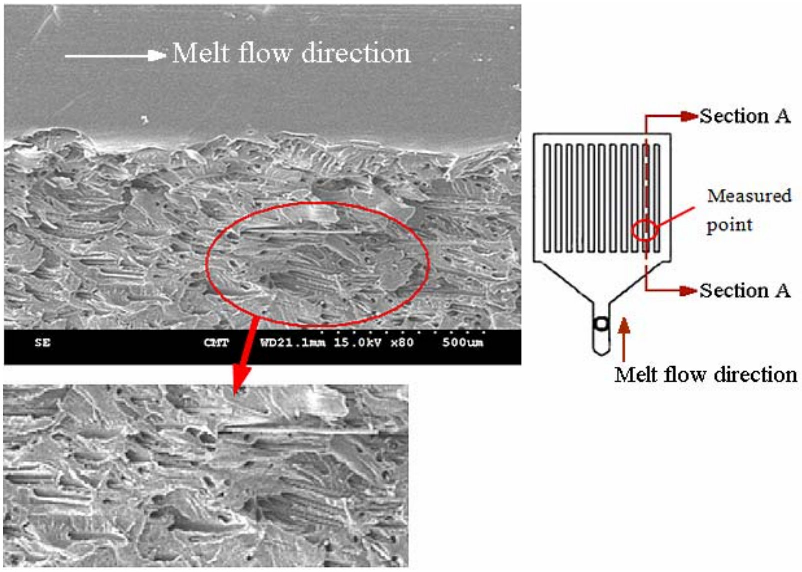


Fig. 1. High percentage of fiber orientated parallel to the melt flow direction (Pa).

The SEM image was taken in a section as indicated. There, one can see more entire fibers in white colour indicating that high percentage of fibers orientated in the channel layout and melt flow direction. When the mold insert was turned 90° to change the gate position, i.e., the melt flow perpendicular to channel layout (designated as Pe), the fibers become more randomly distributed as shown in Figure 2. From the section where SEM image is taken, one can see more part of the fiber instead of the whole one indicating that fibers are more orientated in a direction not parallel to the melt flow. Therefore, the orientation of groove introduced by the channel layout does affect the fiber flow as well as the associated orientations.

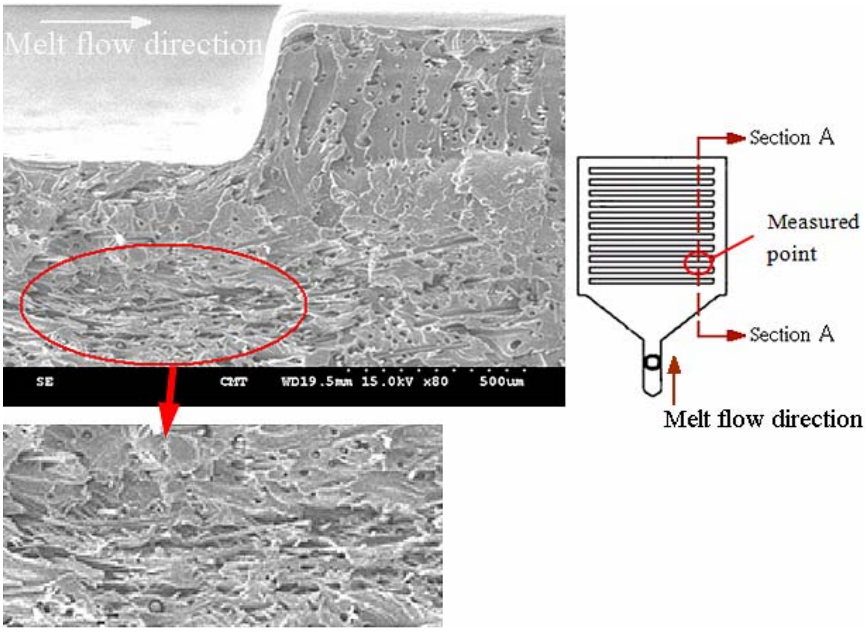


Fig. 2. Fibers orientated in more random manner (Pe) in contrast with the situation parallel to the melt flow direction as case Pa.

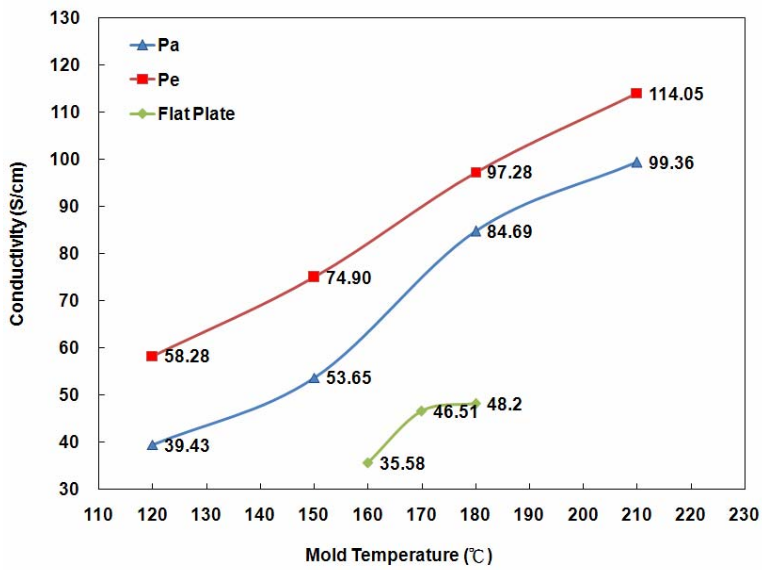


Fig. 3. Molded conductivities variation with mold temperature and channel design.

Figure 3 shows the variation of conductivities under different gate positions, with mold temperature. The design without channel layout (flat part) was also included as a reference. As mold temperature rises, surface conductivity increases. The fiber orientation becomes more randomly distributed as mold temperature increases. The mold temperature becomes less significant when mold temperature is raised to 170 ºC as seen in the case of flat part. In the case of channel design (both Pa and Pe), channel layout continues to affect fibre orientation when mold temperature is higher than 170 ºC.

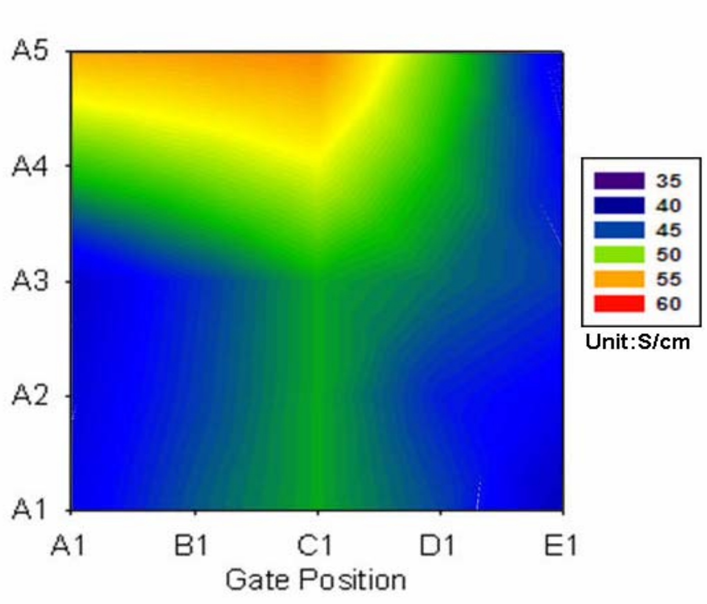


Fig. 4. Distribution of part surface conductivity molded at 180 ºC mold temperature (Flat Plate).

Figure 4 shows the distribution of surface conductivity of flat plate at a mold temperature of 180 ^{0}C.

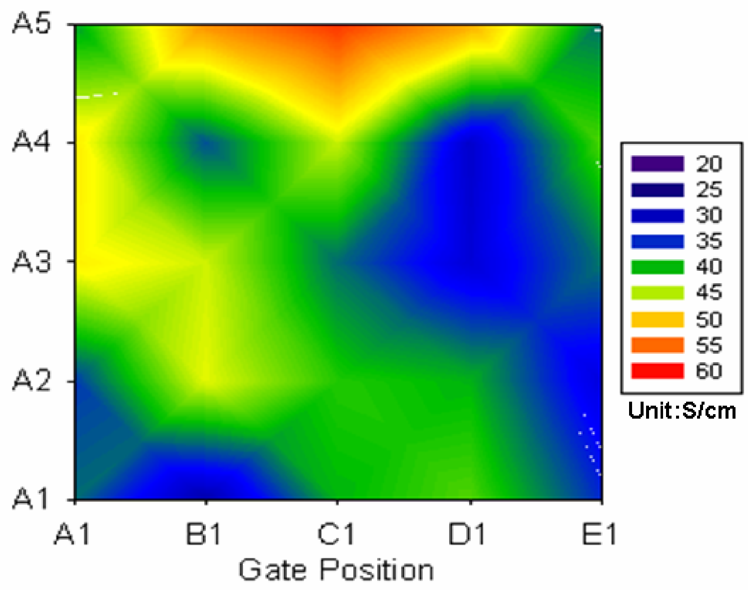


Fig. 5. Distribution of part surface conductivity molded at 120 ºC.

Figure 5 shows the distribution of surface conductivity at a mold temperature of 120 ºC, while Figure 6 shows the distribution of conductivity at a mold temperature of 210 ºC. The result shows that the higher mold temperature facilitates melt flow and makes the fiber distribution more randomly orientated, enabling good distribution of conductivity. Higher mold temperature is thus useful in improving conductivity. When mold temperature reaches 210 ºC, conductivity improves 60.31% in Pa and 48.89% in Pe (Table 1).

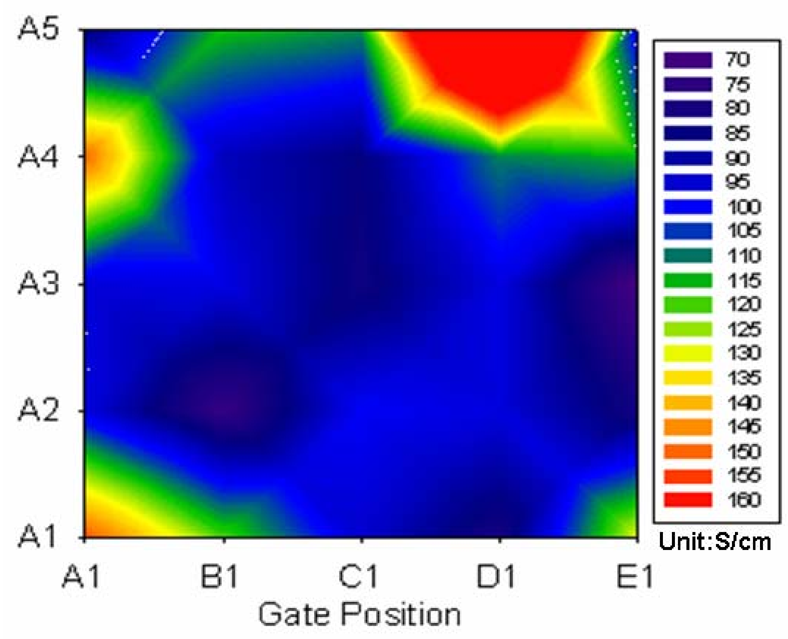


Fig. 6. Distribution of part surface conductivity molded at 210 ℃.

Tab. 1. Part surface conductivity improvement molded at variable mold temperature as compared to case when molded at initial 120 ºC.

Mold Temp. (^{0}C)	Pa (%)	Pe (%)
150	36	28.5
180	114.7	67
210	152	95.7

Tab. 2. Part surface conductivities molded under various channel designs (Pa and Pe) and mold temperatures.

Mold Temp. (^{0}C)	Pa (S/cm)	Pe (S/cm)	Improvement (%)
120	39.43	58.28	47.8
150	53.65	74.9	39.6
180	84.69	97.28	14.8
210	99.36	114.05	14.7

When the melt flow is perpendicular to the groove layout, the conductivity can be increased substantially at identical mold temperatures as compared with case Pa.

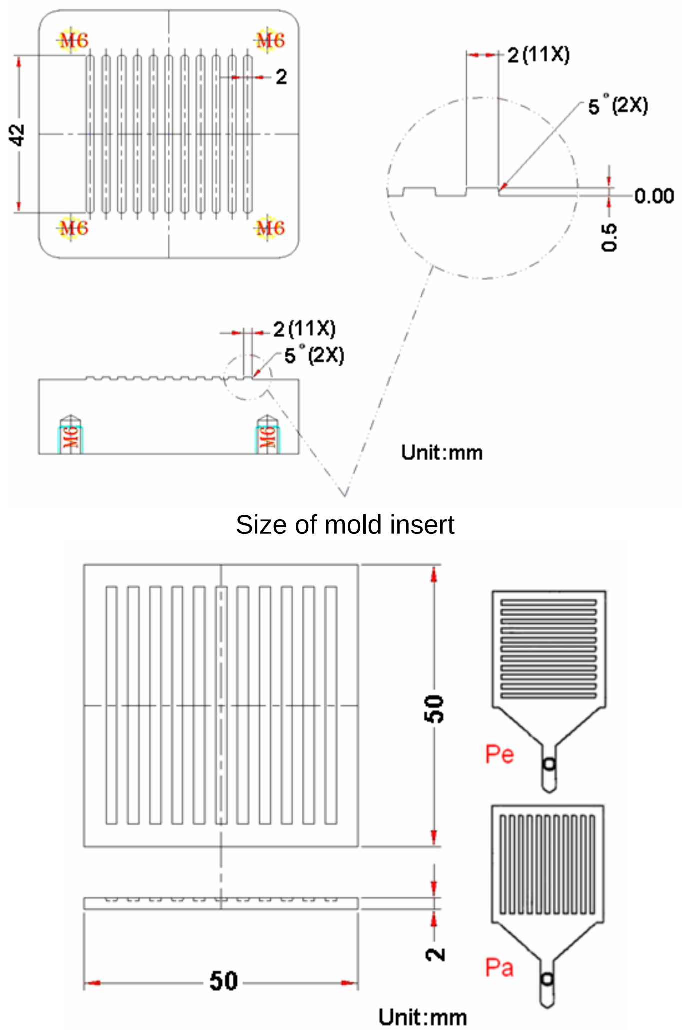
The result shows that the channel layout blocks the melt flow, leading to a more random distribution of the fibers, resulting in better conductivity. At a mold temperature of 120 ºC, conductivity improves by 32.34% in Pe (Table 2).

Conclusions

In this study, it is found that composite bipolar plate PPS blended with high fiber content can be injection molded with improved conductivity and good quality at an instantaneous high mold temperature during the filling process. In addition, the fuel channel design also helps the random distribution of carbon fiber during the melt flow stage, instead of hindering the fiber flow. When the melt flow is perpendicular to the channel layout, the fiber is more randomly disturbed, leading to higher conductivity values. It is also found that the variable mold temperature control, which keeps the mold temperature at a high temperature for a short period of time, assists the melt flow and improves the conductivity while keeping the cycle time at a reasonable level.

Experimental part

In this research, the composite PPS is blended with a 50% carbon fiber characterized by stable dimensions, heat-resistance, and chemical resistance.



Size of part

Fig. 7. Size of mold insert and part.

The injection molding machine was a Sodick TR30EH (Neo Plustech Taiwan Co., Ltd.) equipped with a filling velocity up to 500 mm/s and a maximum injection pressure of 262 MPa. The mold insert for the flat part has a dimension of about 50 mm by 50 mm, and the cavity thickness is 2 mm. A fan gate design was used. For the part with the channel, the channel groove was 2 mm wide, 42 mm long, 0.5 mm deep, and the pitch between the grooves was 2 mm. The mold insert can be rotated 90° to change the gate position so that the melt flow direction is parallel to the channel length in one case (designated as Pa) and perpendicular to the groove in the other case (Pe) Figure 7. A schematic of the conductivity measurement by four-point probe is shown in Figure 8. The molded specimen was divided into 25 points from the gate to the end of filling.

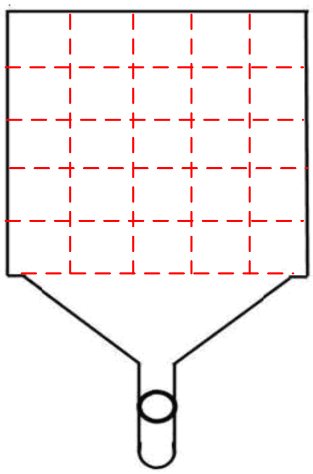


Fig. 8. Measurement points.

A variable mold temperature system using electromagnetic induction heating to raise mold temperature [6] was implemented, with heating rates as high as 30 ºC/s. Mold surface temperature was raised by placing the induction coil in front of the cavity surface and heating for few seconds (2 to 3 seconds) prior to melt injection. After induction heating, the mold was closed for melt injection and cooled down to the regular mold temperature before the next cycle starts. The parameters of injection molding were 60 mm/s in filling velocity and 120 ºC in initial mold temperature, as recommended by the materials supplier. The variable mold temperature control achieved peak temperature values of 150 ºC, 180 ºC and 210 ºC.

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