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Comparison of Fabrication Cost of Composite Bipolar Plates Made by Compression Molding and by Machining

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Summary

The fuel cell is one of promising environment-friendly energy sources for the next generation. The bipolar plate is a major component of the Proton Exchange Membrane (PEM) fuel cell stack, and it takes a large portion of stack volume, weight and cost. In this study, as alternative materials for bipolar plate of PEM fuel cells, graphite composites were fabricated by compression molding and by machining. Graphite particles mixed with epoxy resin were used as the main substance to provide electric conductivity. Flow channels were fabricated by compression molding applying design of experiments (DOE) in order to evaluate moldability. The cost for compression molding of graphite-composite bipolar plate was compared with machining cost to make the same bipolar plate.

Introduction

The fuel cell is one of the most promising power sources for the future. The fuel cell provides good energy efficiency above 40%, no pollution, and no noise. Different fuel cell types are usually distinguished by the kind of electrolyte. Among these, the PEM fuel cell (PEMFC) has advantages of high power density, low operating temperature, relatively quick start-up, and rapid response to varying loads. A fuel cell stack is consisted of many unit cells. One unit cell is composed of anode, electrolyte, and cathode. A bipolar plate makes connections all over the surface of one cathode and the anode of the next cell. At the same time, the bipolar plates provide four functions [1]:

(1) pathway of fuel, air, and water (2) separation of the unit cells in the stack

(3) carrier of current away from the cell (4) support of MEA.

Various materials for bipolar plates have been studied to satisfy functional requirements such as electronic conductivity, resistance to corrosion, manufacturability, low cost, and stack volume [1-2].

In this paper, composite materials made of graphite particles and epoxy resin were fabricated by hot-press method, and its channel moldability was tested by applying the method of design of experiments [3]. In addition, the cost for compression molding of graphite-composite bipolar plate was compared with the cost of making the same bipolar plate by machining. [4].

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Fabrication of graphite composite bipolar plate

For composite bipolar plates, available fabrication methods are compression molding, machining, and injection molding. In general, increasing the number of plate production per year by compression molding and injection molding are more economic than by machining. In this study, graphite/epoxy composite bipolar plates were fabricated by compression molding and by machining.

Compression molding

Conductive graphite particles (*Density: 0.9 g/cm*^{3}*, Diameter: 18.8* μm*)* and thermosetting epoxy resin (*Density: 1.17 g/cc, Viscosity: 11500-13500 cps at 25*$^\circ$*C*) were used in this experiment. Fig. 1 shows the SEM (Scanning Electron Microscope) pictures of the graphite particles (*P-15, Carbonix, Inc.*).

Compression molding process of graphite composite is as follows. First, graphite particles were mixed with epoxy resin and hardener. Second, an aluminum mold for compression molding was machined, and composite bipolar plate was fabricated by hot-press machine. However, compression molding for composite bipolar plate have many influencing parameters. Channel depth, and width seemed to be significant factors affecting compression molding. Other affecting factors are land width, radius of corner, and molding conditions such as pressure, temperature, etc. From the previous research [3], compression molding conditions were selected by design of experiments (DOE). The selected conditions for aluminum mold were 1.0 mm depth, 2.0 mm width, 1.5 mm land width, and 0 mm radius of corner (Fig. 2-a). Also, hot-press machine conditions were 15 MPa pressure and 120 °C temperature during 15 minutes. In addition, graphite particles were mixed with 10 vol % of epoxy resin.

Figure 1: SEM pictures of graphite particles used in this study

The aluminum mold was designed by using SolidWorks, and tool path was generated by PowerMILL (Fig. 2-b). It took about four hours for machining by using 1.0 mm flat endmill with 15,000 rpm, 1 mm/s cutting speed, and 0.7 mm depth of cut (Fig. 2-c). Fig. 3 shows the composite bipolar plate made by compression molding and by machining. The channels made by compression molding show a

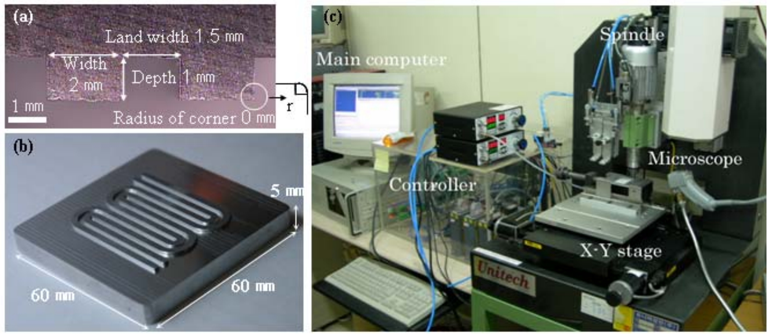

Figure 2: (a) Selected channel parameters of the mold by DOE (b) machined aluminum mold for compression molding, and (c) 3-axis stage for machining

little round corner and tapered wall as well as smaller width.

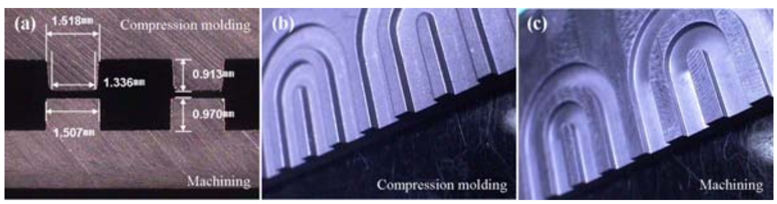

Figure 3: Bipolar plate fabricated by compression molding and by machining.

Machining

Machining is an effective process to make bipolar plates. The machining stage was constructed as shown in Fig. 2-c. In order to control the stage, PMAC2 (Delta Tau Systems Inc.) was used as controller. To monitor the movement of Z-axis and machining status, a digital microscope was installed. The bipolar plate channel was designed by using SolidWorks, a 3-dimensional computer aided design software, and tool path was generated by PowerMILL, a computer aided manufacturing software. It took about 15 minutes in machining by using 2 mm diameter flat endmill with 12,000 rpm, 3 mm/s, and 2.0 mm depth of cut.

Cost efficiency evaluation

The total cost per operation is composed of four items as shown in Eq. (1). The cost estimation model calculates the total fabrication cost for a designed part.

$$C_{total} = C_w + C_p + C_m + C_t \tag{1}$$

where C_{total} is the total cost per part, C_w is material cost, C_p is preparation cost, C_m is machining and molding cost, and C_t is tool cost. Cost estimation is concerned with the prediction of costs related to a set of activities before they have actually been executed. The first term, workpiece material cost (C_w), is estimated using Eq.

(2) .

$$C_w = V\rho C_{um} \tag{2}$$

where V is the raw material component volume (m^3), ρ is the material density (kg/m^3), and C_{um} is the unit price of the material (\$/kg). The second term, preparation cost (C_p) is shown in Eq. (3).

$$C_p = WT_p \tag{3}$$

where $W$is the operator's wage per hour, T_p is the time for preparing the machine setup. The third them, machining and molding cost (C_m) is calculated by Eq. (4).

$$C_m = T_m(W + B_m), \quad B_m = M_t + M_t\left[\frac{machine\_overhead(\%)}{100}\right] \qquad (4),(5)$$

where T_m is the actual machining and molding time, and B_m is the indirect cost which consists of the depreciation cost (M_t) and indirect cost of micro stage such as maintenance and repair. B_m is obtained as Eq. (5). M_t can be calculated by Eq. (6) [5].

$$M_t = \left[\frac{initial\_purchase\_\cos t\_of\_machine}{working\_hours \times repayment\_period}\right] \tag{6}$$

The last term, tool cost term (C_t), is shown in Eq. (7) [4]. The costs of macro and micro tools are gathered from YG-1, OSG Korea, and Sinki Micron.

$$C_t = y\left[\frac{T_m}{T}\right], \quad T = \left[\frac{C}{V}\right]^{\frac{1}{n}} \qquad (7),(8)$$

where y is the initial purchase cost of the tool, T_m is the machining time, and T is the average tool life determined by Taylor's tool life. T is obtained by Eq. (8). V is the cutting speed (m/min), C is a constant when V is one, and n and C is an empirical constants resulting from regression analysis and field studies according to material of tools.

Case study: Cost estimation of molded and machined bipolar plate

According to Eq. (1) $\sim$ Eq. (8), total costs of each process to fabricate the bipolar plate were estimated. In calculation, wage of operator and indirect cost of machine was based on statistics data of Korean Ministry of Labor. Table 1 shows the comparison of estimated cost for compression molding and machining for bipolar plate. The estimated manufacturing cost of the compression molded plate was about \$41, and the machined plate was about \$19. As a result, fabrication cost of machining process is about half of compression molding for the first part. However, the mass-produced, here for each 1000 parts, bipolar plate by compression molding using one Al mold are expected to decrease the fabrication cost. Per part cost of compression molding and machining are estimated to \$2.02 and \$5.28 respectively as Fig. 4.

Table 1: Cost estimation of molded and machined bipolar plate (For the first part)

Item	Compression molding		Machining	
C_w *(Material cost)*	$Graphite_{(\$5.3/kg)}$	\$0.097	$Graphite_{(\$5.3/kg)}$	\$0.097
	$Epoxy_{(\$4.2/kg)}$	\$0.01	$Epoxy_{(\$4.2/kg)}$	\$0.01
	$Al_{(\$7.9/kg)}$	\$4.94	$Al_{(\$7.9/kg)}$	\$4.94
Subtotal		\$5.05		\$5.05
C_p *(Preparation cost)*	$T_{p,\,mixing}$	30 min	$T_{p,\,mixing}$	30 min
	$T_{p,\,mold\ machining}$	240 min	$T_{p,\,mold\ machining}$	45 min
	W	\$6.93 / hr	W	\$6.93 / hr
Subtotal		\$31.19		\$8.66
C_m *(Machining and molding cost)*	$T_{m,\,machining}$	-	$T_{m,\,machining}$	15 min
	$T_{m,\,molding}$	15 min	$T_{m,\,molding}$	15 min
	$M_{t,\,machining}$	-	$M_{t,\,machining}$	\$1.81
	$M_{t,\,molding}$	\$0.24	$M_{t,\,molding}$	\$0.24
	$B_{m,\,machining}$	-	$B_{m,\,machining}$	\$4.53
	$B_{m,\,molding}$	\$0.6	$B_{m,\,molding}$	\$0.6
	W	\$6.93 / hr	W	\$6.93 / hr
Subtotal		\$1.88		\$4.75
C_t *(Tool cost)*	$y_{(1mm)}$	\$9.13 /ea	$y_{(2mm)}$	\$9.13 /ea
	$T_{m,\,mold\ machining}$	240 min	$T_{m,\,machining}$	15 min
	C	120	C	170
	V	47.1 m/min	V	75.4 m/min
	n	0.14	N	0.14
	T	796 min	T	333 min
Subtotal		\$2.75		\$0.41
Total		**\$40.87 /ea**		**\$18.87 /ea**

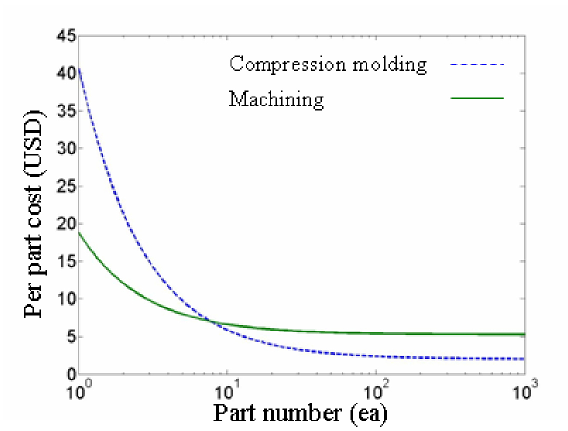

Figure 4: Per part cost of compression molding and machining

Conclusions

In this research, as a material for bipolar plate, graphite composite was fabricated by compression molding and by machining. The machined bipolar plate is more accurate than compression molded plate. However, compression molded plates have suitable dimensions for PEM fuel cell component. In general, increasing the number of plate production, compression molding is less expensive than machining. As a result, it is proved that compression molding proposed in this research offers low cost for mass production.

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