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Fabrication of metallic bipolar plate for proton exchange membrane fuel cells by using polymer powder medium based flexible forming

Canbin Zhang, Jiang Ma, Xiong Liang, Feng Luo, Rong Cheng, Feng Gong*

Guangdong Provincial Key Laboratory of Micro/Nano Optomechatronics Engineering, Shenzhen University, Nanhai Ave 3688, Shenzhen 518060, Guangdong, China

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ABSTRACT

Flexible forming process-polymer powder medium based flexible forming (PPFF) is presented in this research. The metallic bipolar plate (BPP) for a proton exchange membrane (PEM) fuel cell, with a micro-scale flow channel on its surface, is formed using rigid die forming and PPFF process, respectively. Pure copper C1100 (with a thickness of 0.1 mm), annealed at 450 °C for 1 h in vacuum condition, is selected as blank material. The forming experiments are carried out at room temperature in dry friction condition. By comparing the limit forming depth, fracture topography, section wall thickness distribution and surface forming quality of micro-scale flow channels between rigid die forming and PPFF process, it reveals that PPFF process could be developed as a feasible technique to fabricate the bipolar plates of PEM fuel cells. The PPFF process has the following advantages: greater forming depth, more uniform wall thickness distribution, and low cost of the die.

1. Introduction

According to Taherian (2014), proton exchange membrane (PEM) fuel cells have drawn much attention recently with raising awareness of environmental protection and energy saving. PEM fuel cells have promising applications in transportation because of the advantages of fast startup, high efficiency and zero emission. However, current researches on PEM fuel cells only stay in the experimental stage owing to existing problem of reliability, endurance, mass and cost. The bipolar plate is a key component in PEM fuel cells, occupying over 30–45% of the cost, 60–80% of the weight, and almost the total volume in a fuel cell stack. Nowadays, there are mainly three kinds of materials to make a bipolar plate: graphite, polymer-carbon composite and metal material. Graphite and polymer-carbon composite bipolar plates are selected as the basic material in the traditional fuel cell research due to its good conductivity, small contact resistance and good corrosion resistance. However, the difficulties in manufacturing the graphite bipolar plate and composite bipolar plate lead to high cost. At the same time, because graphite material is brittle and easy to be infiltrated, the thickness of graphite bipolar plate is large, so are the overall weight and volume of fuel cell. As a result, many researchers have turned their attention to metal materials with better formability. An electrical chemical machining process to create micro-scale flow channels was proposed by Lee et al. (2008) and Lee et al. (2009) used finite element analysis to evaluate the parametric effects of inter-electrode gap, pulse rate, electrolytic inflow velocity and pulse duty cycle on the channel fabrication accuracy. Later on Liu et al. (2017) designed a multi-functional cathode to improve the stability and reliability of machining process. Hung and Lin (2012) used micro-high-speed milling to manufacture the micro-scale channel tool piece electrode, which was then employed in fabricating miniature metallic bipolar plates via micro-electrical discharge machining. Alanís-Navarro et al. (2013) attempted to fabricate micro-scale channels on a light weight and easily machined material-polymethyl methacrylate, combined with surface roughness treatment and physical deposition of copper coating on the surface. Scotti et al. (2014) introduced a laser additive manufacturing method to fabricate micro fuel cells. Yang et al. (2017) fabricated a stainless steel bipolar plate using selective laser melting technique and found that the performance of the cell was excellent.

These methods mentioned above can easily fabricate the channel with high aspect ratio required for bipolar plates. However, the surface quality of the plates fabricated by electrical chemical and discharge machining or additive manufacturing is poor. The process of surface roughness treatment and deposition is complicated, and the life of the bipolar plate is relatively short if the adherence of the metal to the polymer is not good enough. Besides, the thickness of bipolar plates fabricated by these methods must be larger than the depth of micro-scale flow channels, thus increasing the weight and volume of PEM fuel cells. Based on the demand of mass production, light weight and low cost, sheet metal stamping forming is considered as the main forming process for metal bipolar plate. Jin and Kang (2015) formed a bipolar plate by stamping and indirect squeeze casting process. Stamping was

* Corresponding author.
E-mail address: gongfeng186@163.com (F. Gong).

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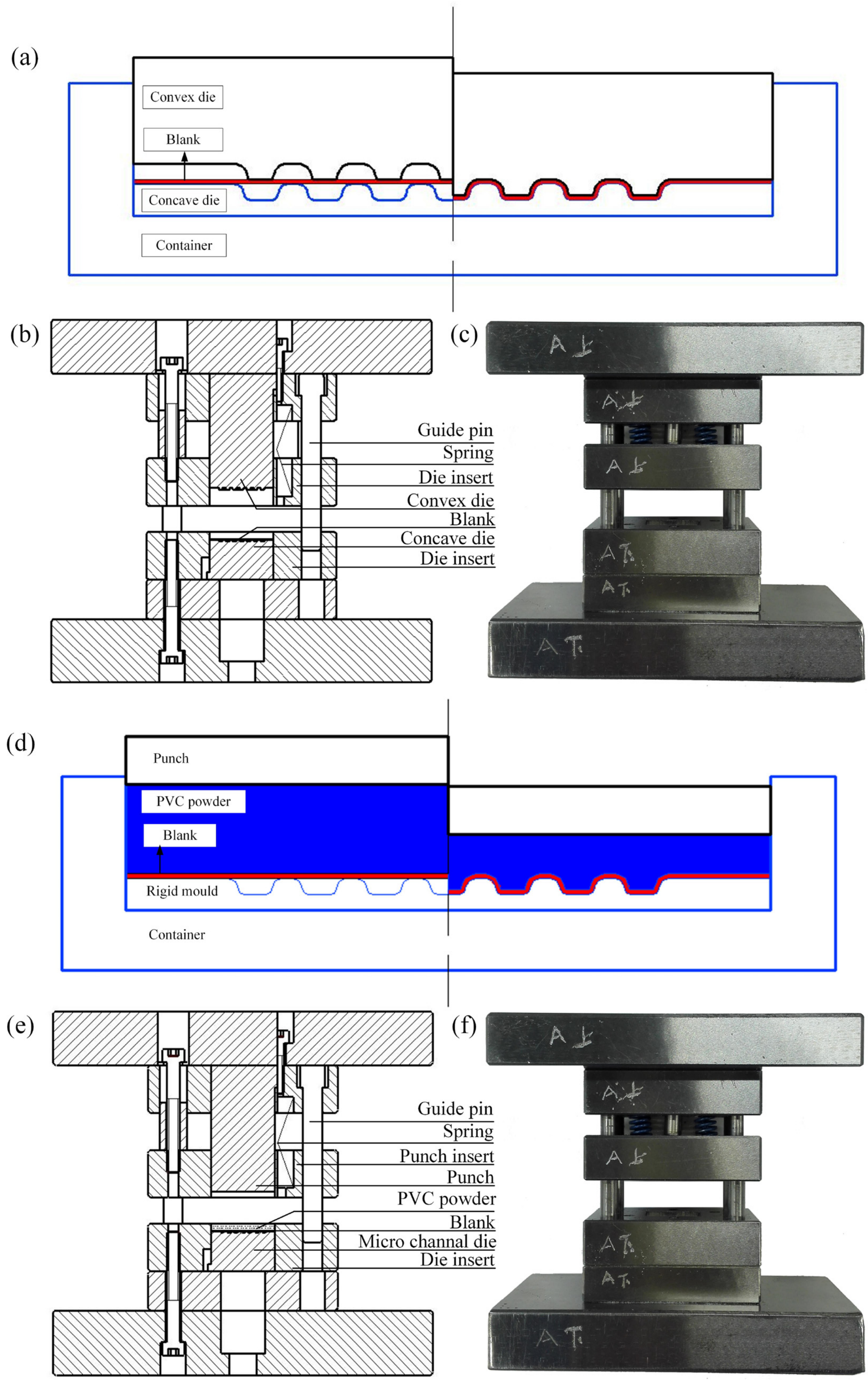

Fig. 1. Forming process and mold: (a) Schematic of rigid die forming process; (b) Schematic of rigid die forming mold; (c) Photograph of rigid die forming mold; (d) Schematic of the PPFF process; (e) Schematic of the PPFF mold; (c) Photograph of the PPFF mold.

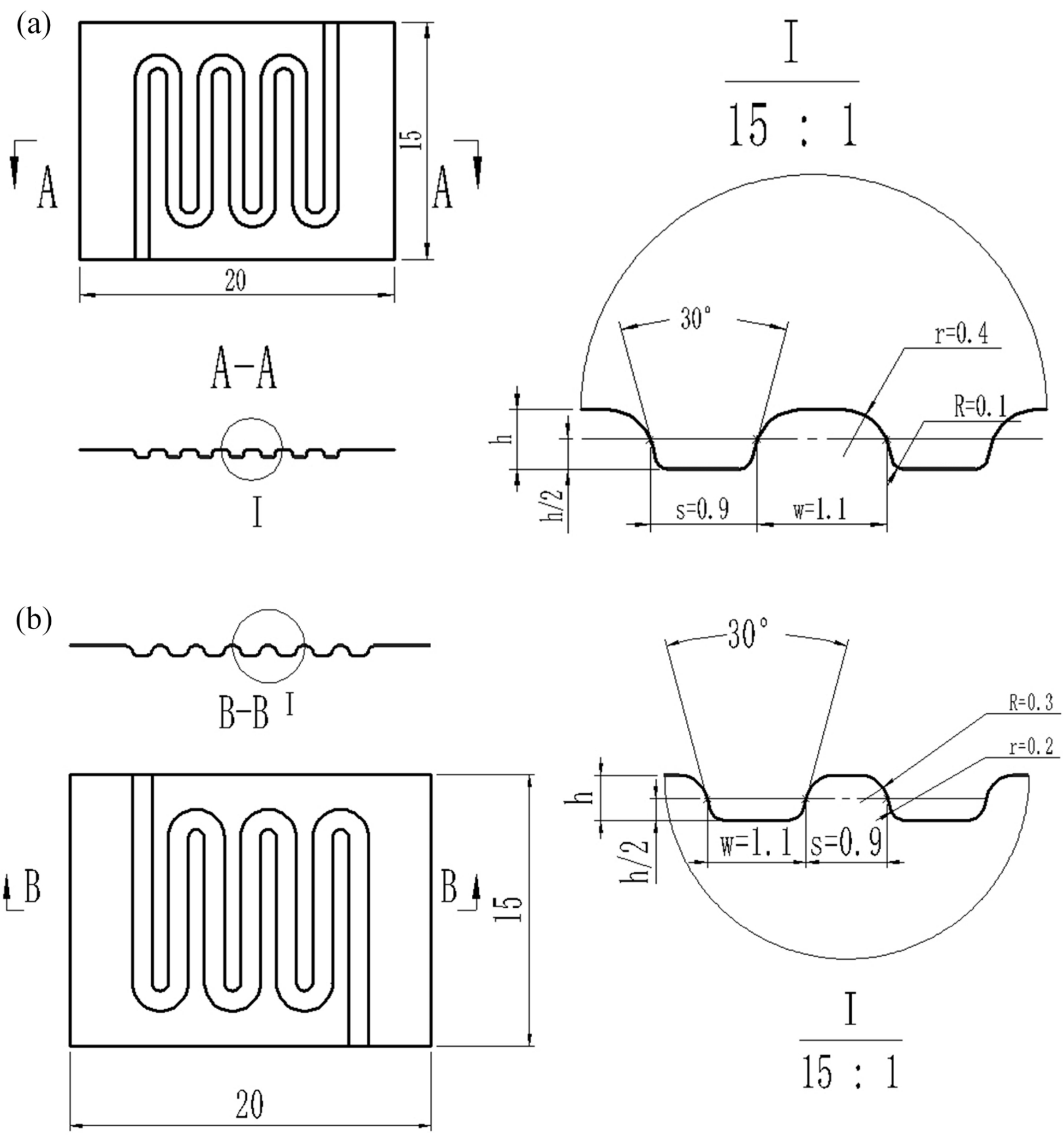

Fig. 2. Schematic of the mold dimensions: (a) Convex mold; (b) Concave mold.

considered as a more feasible technique by comparing the formability of the two processes. In the investigation of Park et al. (2016), stamping variables (static/dynamic loads, heat treatment, and the rolling direction of the sheet) were discussed to enhance the formability of the sheet. Nevertheless, the depth of micro channel fabricated by rigid die stamping is limited, leading to low work efficiency of bipolar plates. To improve the forming depth of the micro channels, flexible forming is considered to be a promising process.

Flexible forming, such as hydroforming, viscous pressure forming, laser dynamic forming and rubber pad forming, have the advantages of high accuracy, high surface quality, and especially high formability. Zhang et al. (2014) presented a hydroforming process to draw a sheet with hydraulic pressure acting on both sides of the sheet. The stress and strain distribution of the sheet was investigated, and the result demonstrates that normal stress acting in the sheet can restrict the thickness thinning and increase the elongation of the sheet. Wang et al. (2015a) used a viscous forming method to deal with excessive wall thinning in manufacturing the circular rings with thin wall and complex section. The viscous medium improved the formability of metallic materials greatly and the wall thickness thinning is not apparent. Wang et al. (2013) presented a novel micro scale laser dynamic flexible forming technology to draw sheets. It reveals that parts formed by this process have a larger deformation depth and better surface quality from both numerical simulations and experiments. Later on Wang et al. (2015b) found that despite the decreased formability caused by size effects, the micro flow channel with high aspect ratio could still been formed successfully, exhibiting the super-plastic deformation behavior. Irthiea et al. (2013) reported the research about the effect of process parameters on deep drawing ratio in the drawing process utilizing rubber pad forming process. Numerical predictions and experiments were conducted, revealing that the proposed technique possessed the capability of manufacturing micro metallic cups with large aspect ratio and high quality.

Due to the advantages from flexible forming, some attempts have been made to apply flexible forming technique to form micro channels. Mahabunphachai et al. (2010) conducted several studies on hydroforming for micro channels. Although the depth of micro channels fabricated by hydraulic forming can be large enough in theory, special

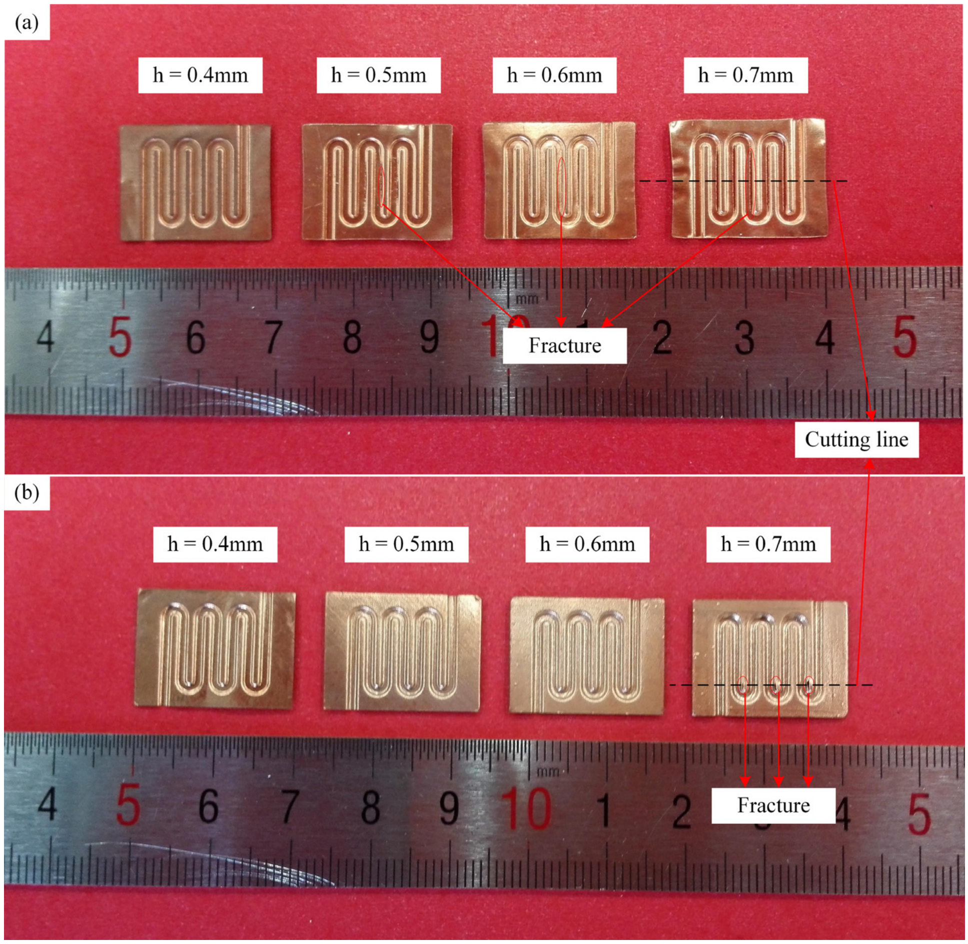

Fig. 3. Bipolar plates formed by rigid and flexible die (a) Rigid die; (b) Flexible die.

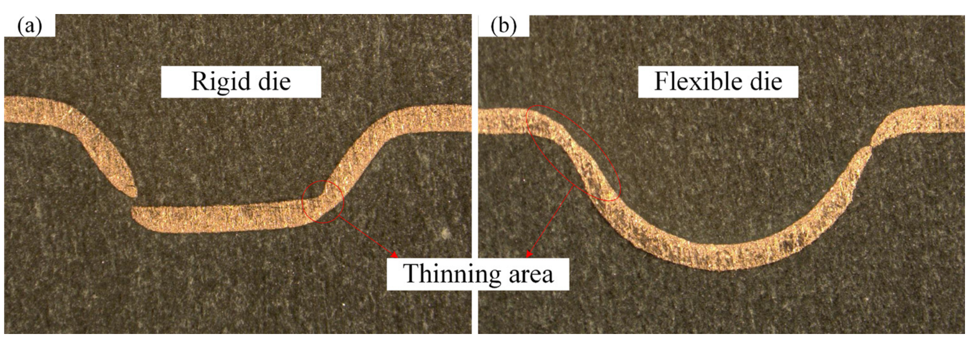

Fig. 4. Cross section of fracture of micro flow channel: (a) Rigid die; (b) Flexible die.

equipment needs to be designed to maintain an ultra-high pressure; otherwise, an ordinary pressure can only form a channel with aspect ratio of 0.35, according to the study of Hung et al. (2012). Liu and Hua (2010) proposed to form metallic bipolar plates via a rubber pad forming process. The parameters, such as internal radii, outer radii and draft angle of the rigid die and hardness of the rubber were investigated through software Abaqus. Elyasi et al. (2017) made a comparison of filling depth and thickness distribution between bipolar plates formed by convex and concave die under different forming forces. In general, the rubber pad forming can improve the formability of sheets, while the rubber pad is clumpy, large stress occurs at the rounded corners when it is used to form complex parts with small radius, causing the rubber pad to be damaged. On the basis of the research on deep drawing of cylindrical cups using polymer powder medium based flexible forming, performed by Zhang and Gong (2018), the work presented a novel method to produce a metallic bipolar plate for PEM fuel cells: polymer powder medium-based flexible forming.

2. Experimental setup

2.1. Die and principle

Fig. 1(a) shows the schematic of rigid die forming process. The basic working processes are as follows: Put the blank on the concave die (the original length and width of the blank are 20 and 15 mm). As the convex die moves down, the blank begins to deform until it totally replicates the outline of the mold. Fig. 1(b) and (c) show the die assembly of rigid die forming. In rigid die forming process, the convex die and concave die must have the same depth of micro flow channel. They can be inserted into the die insert (with channel depth of 0.4, 0.5, 0.6

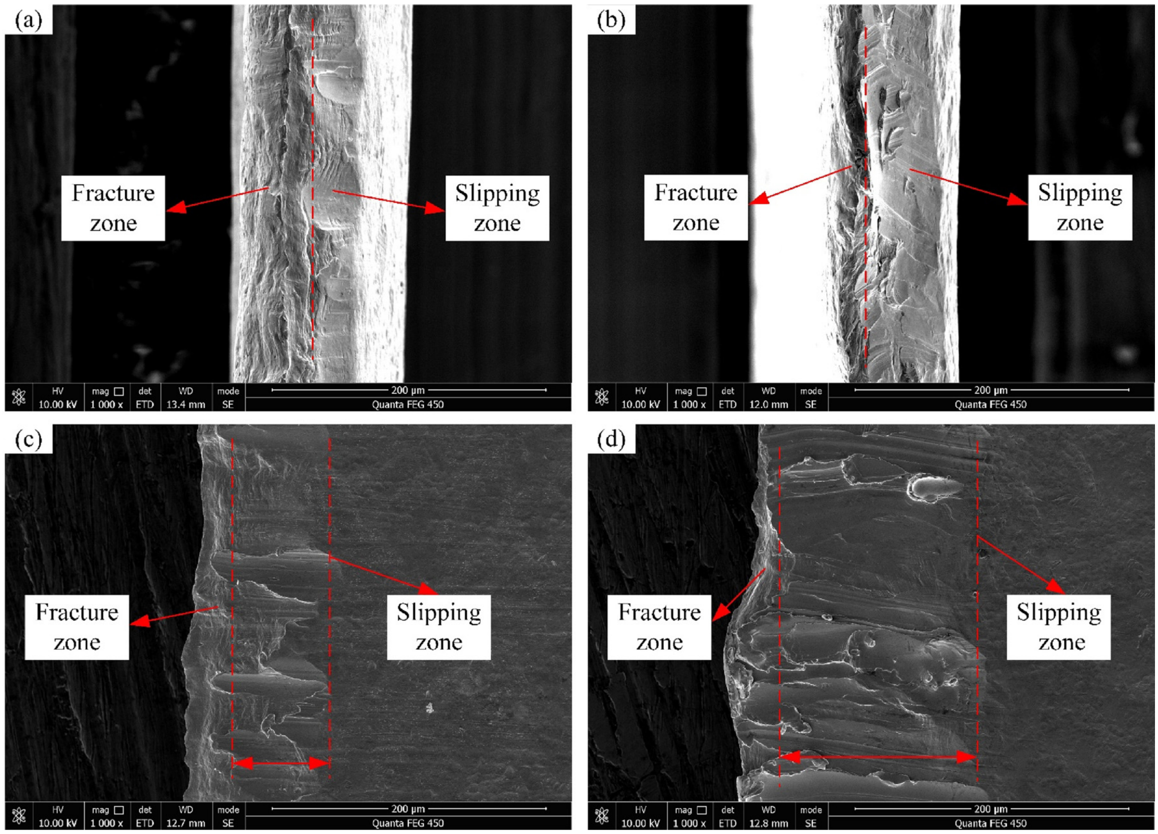

Fig. 5. SEM of fracture topography: (a) Vertical view of fracture in rigid die forming; (b) Vertical view of fracture in flexible die forming; (c) Lateral view of fracture in rigid die forming; (d) Lateral view of fracture in flexible die forming.

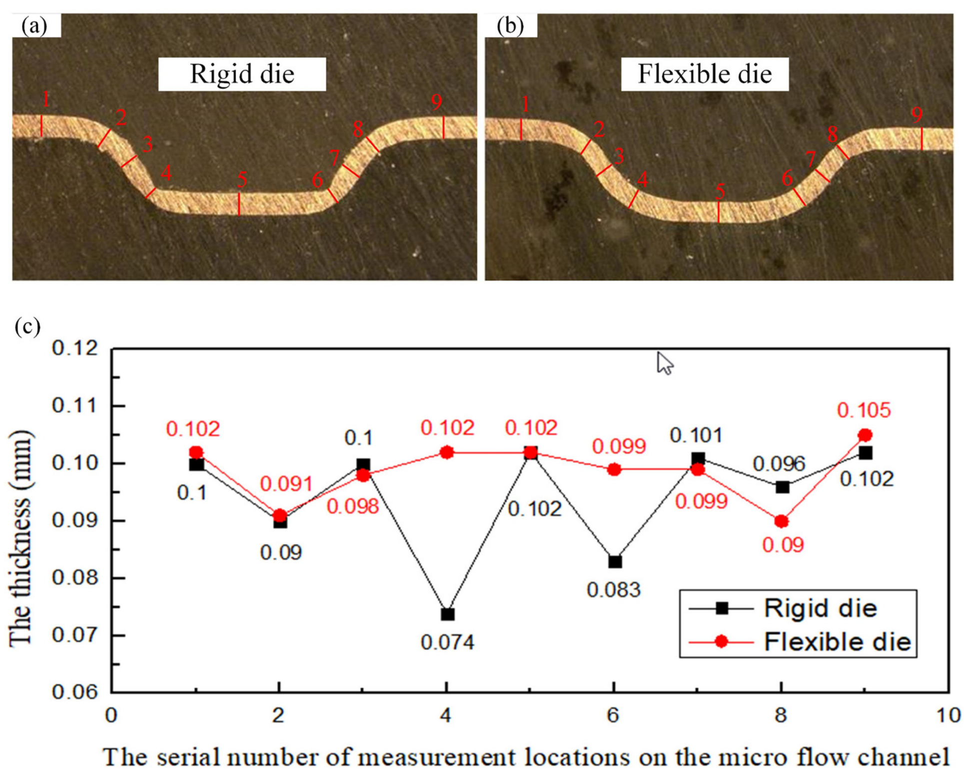

Fig. 6. Thickness measurement of the micro flow channel: (a) (b) Schematic of locations of thickness measurement at the cross section of micro flow channels; (c) Thickness values of measured locations using rigid and flexible die.

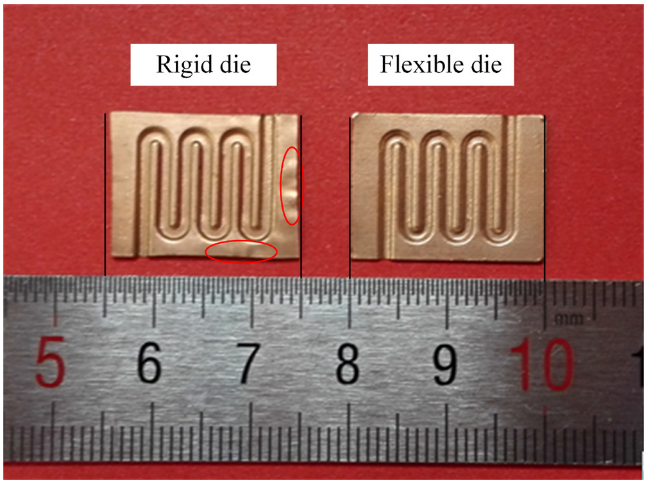

Fig. 7. Bipolar plates formed by rigid and flexible die.

and 0.7 mm). Therefore, by replacing the convex and concave die with different channel depth, bipolar plates with different channel depths can be formed on the same set of die assembly.

Fig. 1(d) shows the schematic of flexible die forming process (PPFF process). The basic working processes are as follows: Put the blank on the micro channel die (the concave die), and let some polymer powder into the container until it reaches the top surface of container (the depth of container is 2.5 mm in this experiment). Then, put the punch onto the powder. Along with the punch downward, the polymer powder is condensed. The blank begins to deform and is slowly pulled into the die until totally touching the die. After bringing the punch back, remove the polymer powder, and take out the forming metallic bipolar plate. Fig. 1(e) and (f) show the PPFF mold assembly. In flexible die forming process, a flat punch was used, micro-scale channel dies with channel depth of 0.4, 0.5, 0.6 and 0.7 mm can be inserted into the die insert.

The dimensions of the die have a major impact on the formability of the blank. In order to investigate the effect of the flow channel dimensions on bipolar plate forming quality, the schematic of the convex and concave die dimensions was given in Fig. 2. The micro flow channel is single snake-liked in shape. According to the studies of Peng et al. (2008), the major dimensions of the micro channel of the die (the concave die) consist of the internal fillet radius (r = 0.2 mm), outer fillet radius (R = 0.3 mm), rib width (s = 0.9 mm), flow channel width (w = 1.1 mm), draft angle (θ = 30°), and flow channel depth (h = 0.4, 0.5, 0.6 and 0.7 mm) in the PPFF process (See Fig. 2(b)). Correspondingly, the major dimensions of the micro channel of the convex die consist of the internal fillet radius (r = 0.4 mm), outer fillet radius (R = 0.1 mm), rib width (s = 0.9 mm), flow channel width (w = 1.1 mm), draft angle (θ = 30°), and flow channel depth (h = 0.4, 0.5, 0.6 and 0.7 mm) in the rigid die forming process (See Fig. 2(a)).

2.2. Experimental parameters

Pure copper C1100 was selected as blank. The hard rolled pure copper sheet, with the thickness of 0.1 mm, was annealed at 450 °C for 1 h in vacuum condition. The elasticity module (E), yield stress and tensile stress of the blank material were about 110 GPa, 40 MPa and 435 MPa, respectively. The C1100 chemical compositions were as follows (wt.%): Cu + Ag: ≥99.90, Sn: ≤0.002, Zn: ≤0.005, Pb: ≤0.005, Ni: ≤0.005, Fe: ≤0.005, Sb: ≤0.002, S: ≤0.005, As: ≤0.002, Bi: ≤0.001, O: ≤0.06, impurity: ≤0.1.

The quenched tool steel alloy SKD11 was selected as die material, with a hardness of 60 HRC, which is hard to machine directly. In the machining process, a pure copper die was machined by CNC milling first, which was used as an electrode to manufacture the ultimate die by electric discharge machining.

Polymer powder medium-PVC powder (Polyvinyl chloride powder, with a diameter of 80 μm measured by scanning electron microscopy) was selected as flexible punch to replace the convex die in PPFF process. It is polymerized by vinyl chloride monomer under the action of light and heat.

Experiments were performed on a MTS-SANS CMT5504 electronic universal testing machine at room temperature on dry friction. The punch velocity was 0.1 mm/s. The punch forces in rigid and flexible forming process were 10 and 50 kN respectively, if there is no other explanation. The original height of PVC was 2.5 mm. The depth (h) of micro-scale flow channels of die were 0.4, 0.5, 0.6, and 0.7 mm, which were converted to aspect ratio (h/w) of 0.36, 0.45, 0.55 and 0.64, respectively.

3. Experimental results

3.1. Forming of micro-scale flow channel

Fig. 3 shows the bipolar plates formed by rigid and flexible die. Micro flow channels of the bipolar plates with depth of 0.4, 0.5 and 0.6 mm were successfully formed by PPFF, while only that of 0.4 mm was formed by rigid die. It shows that using PPFF can increase the forming depth to 0.6 mm compared with that of 0.4 mm for rigid die forming. The bipolar plates with micro flow channel's depth of 0.7 mm formed by rigid and flexible die were cut through the fracture and cold mounted in transparent solids as shown in Fig. 4. In rigid die forming process, the sheet did not contact with the surface of the punch completely. The areas bearing the punch force were mainly the internal fillet of the sheet, where stress concentration and large tensile stresses occurred. Hence, thinning or even fracture took place in the internal fillet of the channel, as shown in Fig. 4(a). With the use of PPFF, the powder kept in touch with the sheet in the whole forming process, avoiding stress concentration. The thinning or fracture took place in the outer fillet of the channel due to the larger degree of bending deformation compared with that of other places, as shown in Fig. 4(b). It can be noted that the thinning area of the micro channel formed by flexible die is larger than that by rigid die, so the blank in PPFF has a greater elongation in the deformation of micro-scale flow channel. Furthermore, when the micro flow channel is cracked, the minimum thickness in the thinning area of the micro channel formed by flexible die is smaller than that by rigid die. This is consistent with the previous statement of stress concentration. Both increase the aspect ratio of micro-scale flow channel.

In order to investigate the stress status of flow channel in the rigid and flexible forming process, The SEM of the fracture topography of flow channel is presented in Fig. 5. The fracture can be divided into two zones: slipping zone and fracture zone. Fig. 5(a) and (b) show the vertical view of the micro channel fracture in rigid and flexible die forming, respectively. The fracture of micro channel in flexible die forming appears with apparent slipping and fracture zone, while the slipping and fracture zone in rigid die forming were not apparent and alternately appeared in the fracture. Furthermore, the slipping zone of the fracture of micro channel in flexible die forming is wider than that of rigid die forming. The slipping zone occurred in the side of the sheet clinging to the rigid die (the convex die in rigid forming and the concave die in flexible forming). This is due to the friction arising between the sheet and the rigid die in the forming process, whose direction is opposite to that of tensile stress, thus restraining the thinning of the sheet. The other side of the sheet will be directly thinned due to tensile stress. Wider slipping zone means better stress condition and more adequate sheet elongation. The lateral view of the fracture shows that the slipping zone of the fracture of micro channel in flexible die forming is longer than that of rigid die forming (See Fig. 5(c) and (d)). Longer slipping zone of the lateral view, equal to wider slipping zone of the vertical view, means more complete deformation. Therefore, flexible

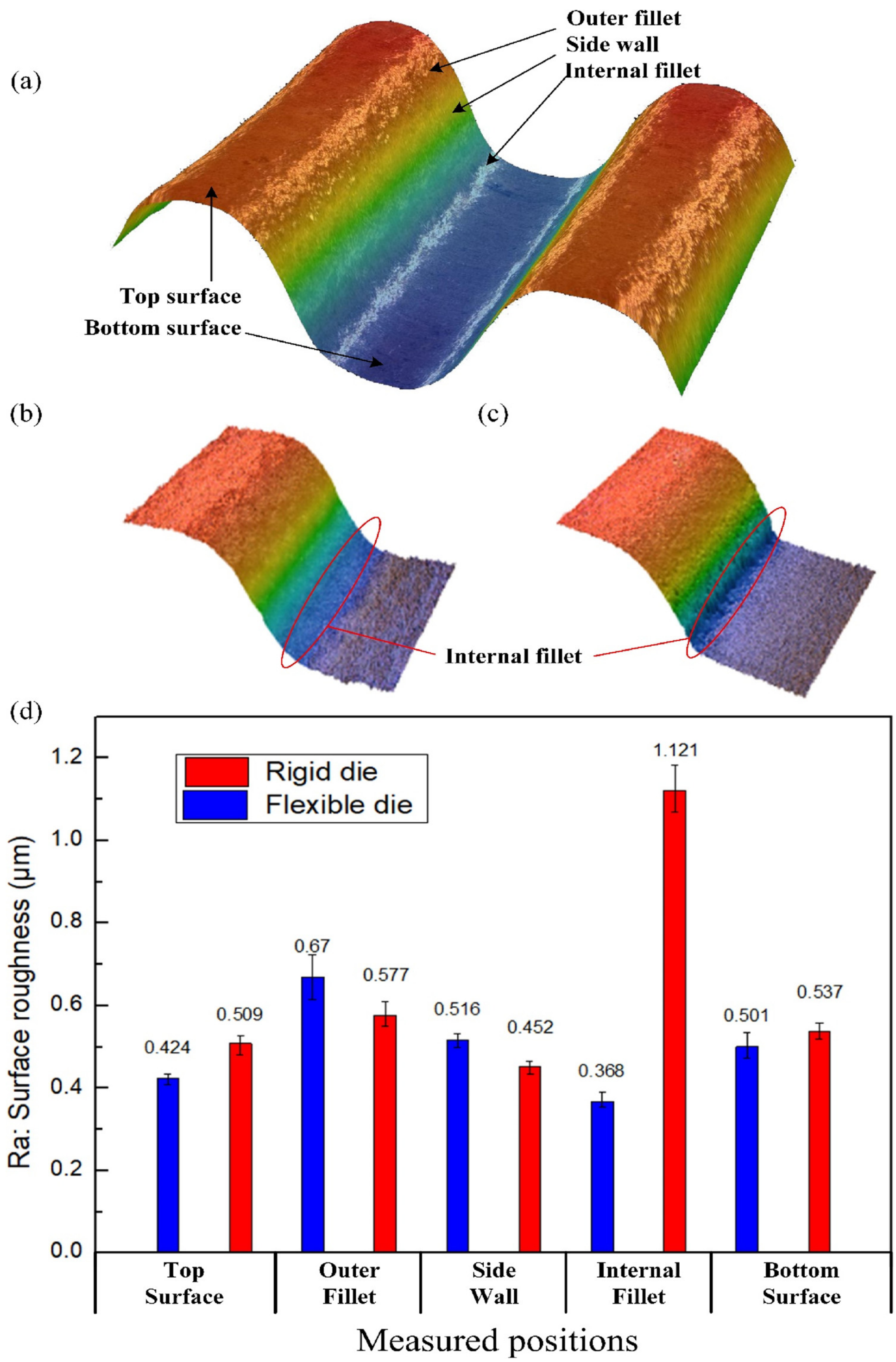

Fig. 8. Toughness measurement of the BPPs: (a) 3D panorama of the BBP channel; (b) 3D surface topography of the BPP formed by flexible die; (c) 3D surface topography of the BPP formed by rigid die; (d) The roughness values in different locations of the BBPs formed by rigid and flexible die.

forming can increase the aspect ratio of micro-scale flow channel.

3.2. Thickness variation

The micro flow channels with depth of 0.4 mm (successfully formed by rigid and flexible die) are cut in the direction vertical to the micro flow channel utilizing a wire cutter and cold mounted in transparent solids. The locations of top surface, outer fillet radius, side wall, internal fillet radius and bottom surface were chosen to measure the thickness, as shown in Fig. 6(a) and (b). Fig. 6(c) shows the thicknesses of measured points. It can be noticed that apparent thinning appears in the locations of the internal fillet radius of micro-scale flow channel formed by rigid die. This is caused by stress concentration and large radial tensile stresses aforementioned. Although the points in the outer fillet radius of the micro-scale flow channel formed by flexible die appear with slight thinning, the thicknesses of measured points are uniform in general.

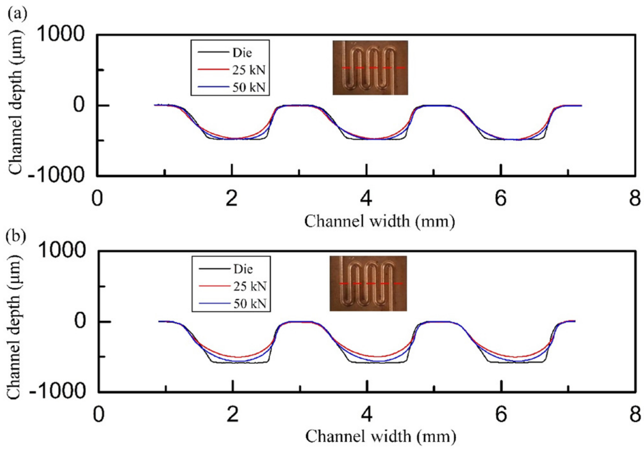

Fig. 9. Profiles of micro-flow channels measured by probe surface profile meter: (a) the depth of 0.5 mm; (b) the depth of 0.6 mm.

3.3. Surface topography

Fig. 7 shows the bipolar plates (with flow channel depth of 0.4) formed by rigid and flexible die. A few wrinkles (See the marked region in Fig. 7) appear in the rim of the bipolar plate formed by rigid die, while no wrinkles are found in the bipolar plate formed by flexible die. This is because forming a bipolar plate by rigid die is a mixed process of drawing and bulging. During the forming process, the outer perimeter of the sheet became smaller and smaller, thus the circumferential compressive stress was produced at the edge of the plate, which caused the sheet metal to buckle and wrinkle. However, in the PPFF process, PVC powder can always hold the edge of the sheet and prevent from producing wrinkles. The wrinkles of bipolar plate are not conducive to the seal of the fuel cell. Moreover, the drawing process in rigid die forming makes the size of the bipolar plate become smaller (the length and width of the formed the bipolar plate are less than 20 and 15 mm, respectively), leading to different shapes and sizes of bipolar plates. Therefore, rigid die forming needs to design an additional blank holder structure.

Generally, bipolar plates with large roughness on its surface would cause high contact resistance and low corrosion resistance, resulting in poor performance and even shorten the service life of PEM fuel cell. In order to evaluate the surface roughness of the bipolar plate, a confocal microscope (KEYENCE VK- X 260 K) was employed in capturing the surface topography of the BPPs formed by rigid and flexible die.

Fig. 8(a) shows the surface panorama of a BBP. To improve the measurement accuracy, Fig. 8(b) and (c) show a higher magnification of the surface topography. Fig. 8(d) shows a comparison of roughness values in different locations between BBPs formed by rigid and flexible die. Each value was measured at least three locations on the same plate for increasing the reliability of the roughness measurement. It can be noted that the roughness values in the same locations are not much different between BBPs formed by rigid and flexible die, except in the internal fillet. The roughness value in the internal fillet of the BBP formed by flexible die is much smaller than that by rigid die. The reason is that the BBP formed by rigid die deformed more thoroughly, with a more intense bending in the internal fillet. A greater compressive stress arose on the top surface of internal fillet, thus causing the surface to buckle and wrinkle. Besides, as the PVC polymer could always provide a positive pressure perpendicular to the surface of the sheet, the degree of buckling and wrinkling slowed down.

3.4. Profile measurement

Micro flow channels of the formed bipolar plates with depth of 0.5 and 0.6 mm were successfully formed by PPFF. To investigate the punch force required to make the blank cling to the surface of the micro channel die, punch forces of 25 and 50 kN were used. The profiles of the surface of the die and the back surface of the formed bipolar plate were measured using a probe surface profile meter (DEKTAK-XT) with a probe radius of 2 μm in the direction vertical to the micro flow channel. Fig. 9 shows the comparison of the profiles between the bipolar plate and die. The blank can reach the bottom surface of the die with micro flow channel depth of 0.5 mm when using punch force of 25 kN. The punch force of 50 kN made the blank fully fill the bottom surface of the die. For the micro flow channels with depth of 0.6 mm, the 50 kN punch force could not make the blank cling to the bottom surface of the rigid die, with a maximum depth of 0.57 μm. To ensure the replicability of the micro flow channel die, a greater punch force is required.

4. Conclusions

The work presents a novel flexible forming process (PPFF process) to form metallic bipolar plates for a proton exchange membrane fuel cell. The following results can be concluded:

1. The metallic bipolar plate with micro channel depth of 0.6 mm were formed by PPFF, which was deeper than that of 0.4 mm by rigid die forming.

2. As a transmission medium, the PVC powder improves the stress condition of the sheet, making the wall thickness of the sheet more uniform.

3. The roughness values of the formed surface between BBPs formed by rigid and flexible die were almost the same. Using PVC powder as pressure-transmitting medium did not make the surface roughness of the sheet poor for application.

As a kind of powder material, there is no need to make a different size of pressure-transmitting medium when forming another part of different size. Therefore, PPFF is more flexible than rubber pad forming when producing parts of different sizes. Liu et al. (2010) used a stainless steel SS304 sheet to manufacture metallic bipolar plates by the concave and convex rubber pad forming process. In concave forming process, the bipolar plate with aspect ratio of 0.5 was successfully formed while that of 0.7 was cracked. In the work, the PPFF process can be regarded as a concave process and can reach the aspect ratio of 0.55, which is quite close to rubber forming.

Besides, only three kinds of polymer powder (EVA, UHWPE and PVC) were tested. PVC is the best pressure medium, yet there may be other powder types with better forming properties. The other polymer powder types with better formability and capability to fill the cavity of the micro flow channel die remain to be explored in the future.

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References

AlanÍS-Navarro, J.A., Reyes-Betanzo, C., Moreira, J., Sebastian, P.J., 2013. Fabrication and characterization of a micro-fuel cell made of metallized PMMA. J. Power Sources 242, 1–6.
Elyasi, M., Khatir, F.A., Hosseinzadeh, M., 2017. Manufacturing metallic bipolar plate fuel cells through rubber pad forming process. Int. J. Adv. Manuf. Technol. 89, 3257–3269.
Hung, J.C., Lin, C.C., 2012. Fabrication of micro-flow channels for metallic bipolar plates by a high-pressure hydroforming apparatus. J. Power Sources 206, 179–184.
Hung, J., Chang, D., Chuang, Y., 2012. The fabrication of high-aspect-ratio micro-flow channels on metallic bipolar plates using die-sinking micro-electrical discharge machining. J. Power Sources 198, 158–163.
Irthiea, I., Green, G., Hashim, S., Kriama, A., 2013. Experimental and numerical investigation on micro deep drawing process of stainless steel 304 foil using flexible tools. Int. J. Mach. Tools Manuf. 76, 21–33.
Jin, C., Kang, C., 2015. A comparative study on the formability of aluminum bipolar plate

with channels using indirect squeeze casting and stamping. Int. J. Precis. Eng. Manuf. 16, 1233–1238.
Lee, S., Lee, C., Yang, K., Kuan, F., Lai, P., 2008. Simulation and fabrication of micro-scaled flow channels for metallic bipolar plates by the electrochemical micro-machining process. J. Power Sources 185, 1115–1121.
Lee, Y.M., Lee, S.J., Lee, C.Y., Chang, D.Y., 2009. The multiphysics analysis of the metallic bipolar plate by the electrochemical micro-machining fabrication process. J. Power Sources 193, 227–232.
Liu, Y., Hua, L., 2010. Fabrication of metallic bipolar plate for proton exchange membrane fuel cells by rubber pad forming. J. Power Sources 195, 3529–3535.
Liu, Y.X., Hua, L., Lan, J., Wei, X., 2010. Studies of the deformation styles of the rubber-pad forming process used for manufacturing metallic bipolar plates. J. Power Sources 195, 8177–8184.
Liu, G., Zhang, Y., Deng, Y., Wei, H., Zhou, C., Liu, J., Luo, H., 2017. The tool design and experiments on pulse electrochemical machining of micro channel arrays on metallic bipolar plate using multifunctional cathode. Int. J. Adv. Manuf. Technol. 89, 407–416.
Mahabunphachai, S., Cora, M.N., Ko, M., 2010. Effect of manufacturing processes on formability and surface topography of proton exchange membrane fuel cell metallic bipolar plates. J. Power Sources 195, 5269–5277.
Park, W.T., Jin, C.K., Kang, C.G., 2016. Improving channel depth of stainless steel bipolar plate in fuel cell using process parameters of stamping. Int. J. Adv. Manuf. Technol. 87, 1677–1684.
Peng, L.F., Lai, X.M., Liu, D.A., Hu, P., Ni, J., 2008. Flow channel shape optimum design for hydroformed metal bipolar plate in pem fuel cell. J. Power Sources 178, 223–230.
Scotti, G., Matilainen, V., Kanninen, P., Piili, H., Salminen, A., 2014. Laser additive manufacturing of stainless steel micro fuel cells. J. Power Sources 272, 356–361.
Taherian, R., 2014. A review of composite and metallic bipolar plates in proton exchange membrane fuel cell: materials, fabrication, and material selection. J. Power Sources 265, 370–390.
Wang, X., Du, D., Zhang, H., Shen, Z., Liu, H., Zhou, J., Liu, H., Hu, Y., Gu, C., 2013. Investigation of microscale laser dynamic flexible forming process—simulation and experiments. Int. J. Mach. Tool Manuf. 67, 8–17.
Wang, Z., Xiang, N., Yi, J., Song, H., 2015a. Forming thin-walled circular rings with corrugated meridians viaquasi-bulk deformation of metal blank and viscous medium. J. Mater. Process. Technol. 236, 35–47.
Wang, X., Ma, Y., Shen, Z., Gu, Y., Zhang, D., Qiu, T., Liu, H., 2015b. Size effects on formability in microscale laser dynamic forming of copper foil. J. Mater. Process. Technol. 220, 173–183.
Yang, G., Mo, J., Kang, Z., Iii, F., Jr, J., 2017. Additive manufactured bipolar plate for high-efficiency hydrogen production in proton exchange membrane electrolyzer cells. Int. J. Hydrogen Energy 42, 14734–14740.
Zhang, C., Gong, F., 2018. Deep drawing of cylindrical cups using polymer powder medium based flexible forming. Int. J. Precis. Eng. Man.-Green Technol. 5, 63–70.
Zhang, F., Li, X., Xu, Y., Chen, J., Chen, J., Liu, G., Yuan, S., 2014. Simulating sheet metal double-sided hydroforming by using thick shell element. J. Mater. Process. Technol. 221, 13–20.