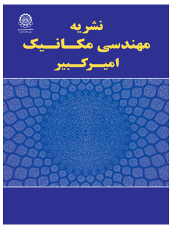

Amirkabir Journal of Mechanical Engineering

Amirkabir J. Mech. Eng., 53(6) (2021) 881-884
DOI: 10.22060/mej.2020.18321.6797

Experimental and numerical investigation of the plastic deformation of metallic bipolar plates with serpentine flow filed

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ABSTRACT: In this study, plastic deformation of the metallic bipolar plate with serpentine flow field was investigated during stamping process. Strain path and thickness distribution in 304 stainless steel bipolar plate with the thickness of 0.1 mm were determined. To this aim, the process was simulated by the commercial finite element code. The validity of the result was evaluated by comparing the experimental and numerical thickness distribution and force-displacement curve which represent 4.76 and 3.85% prediction error, respectively. According to the results, flow of the material has significant effect on the thickness distribution of the central and lateral channels, and the thickness reduction percentage of the central channel in longitudinal, diagonal and transverse direction is much more than that of lateral one. Maximum thickness reduction (critical area) in central channels is placed in longitudinal direction (33% at channel side) while the diagonal direction is considered as critical direction for lateral channels. Due to the existence of the equibiaxial tension strain path in diagonal direction, significant thickness reduction is observed in both the side and the rib zone of the channels.

Review History:

Received: Apr. 25, 2020
Revised: Aug. 01, 2020
Accepted: Oct. 25, 2020
Available Online: Nov. 07, 2020

Keywords:

Fuel cell
Metallic bipolar plate
Metal forming
Thickness distribution
Strain path.

1- Introduction

Clean and renewable energy sources are one of the main alternatives to fossil fuels in various industries. Fuel cells are one of the types of clean and renewable electrochemical energy sources that convert energy from chemical reactions directly into electrical energy.

Due to the higher efficiency and lower pollution of fuel cells compared to internal combustion engines, they have been widely used in the transportation industry [1]. They are composed of various components such as Gas Diffusion Layer (GDL), catalyst layer, Bipolar Plate (BP), and end plates [1-3]. Since bipolar plates make up a significant percentage of the weight and marginal cost of fuel cell [4], considerable research has been carried out on the selection of the material and the appropriate process for the production of bipolar plates. Due to their desirable mechanical properties and high electrical conductivity, Metallic Bipolar Plate (MBP) have received more attention than most of the other types of BPs [5]. Various methods have been used for manufacturing MBPs. Among these methods, stamping process has received much attention due to its process simplicity, high production speed.

In the present study, the stamping process of SS304 bipolar plates with a parallel-serpentine pattern is investigated. Due to the variation of deformation mechanics in different location of the MBPs with serpentine flow field, this study aimed to explore the effect of number of micro-channels on the trend of thickness distribution in different directions. The strain path in the critical areas and its effect on the thickness distribution were determined.

2- Methodology

In the present study, the plasticity behavior of the stainless SS304 sheet with a thickness of 0.1 mm was identified using uniaxial tensile tests. In order to obtain a reliable stress-strain relationship beyond necking, the swift law was adopted. The results are shown in Fig. 1.

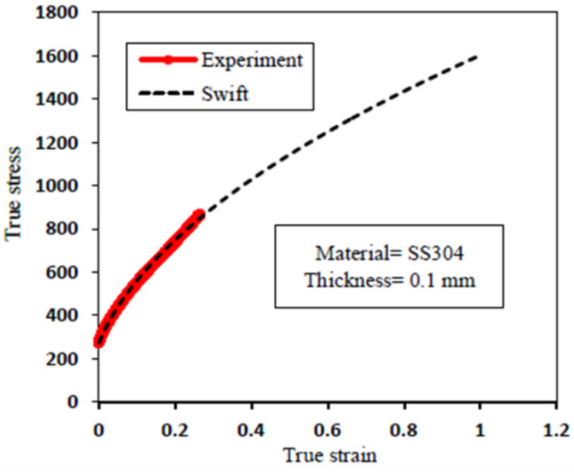

Fig. 1. True stress-strain curve and calibrated swift law results

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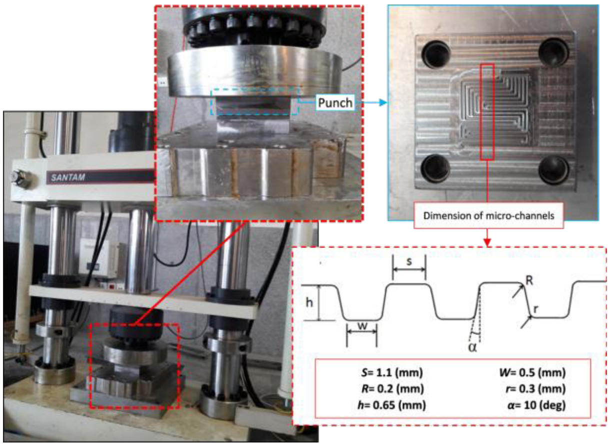

Fig. 2. Dimension of the metallic bipolar plates' micro channel together with experimental equipment.

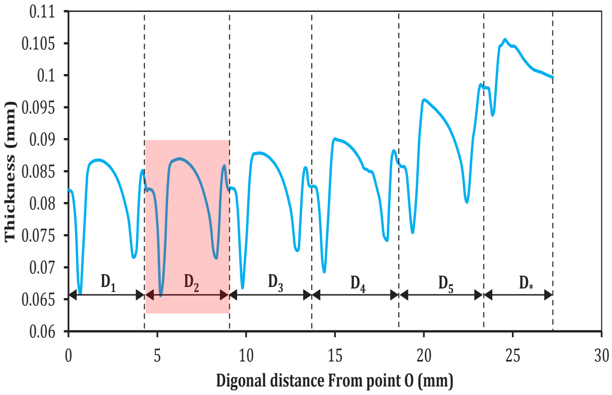

Fig. 4. Thickness distribution in diagonal direction

The stamping process was used to form a 0.1mm-thick steel sheet and produce SS304 MBPs. The micro-channels with rib and channel widths of 1.1 and 0.5 mm, respectively, were investigated in this study. Parameters such as inner radius (r) and outer corner radius (R) were equal to 0.3 and 0.2 mm, respectively, and draft angles were equal to 10°. The die, press, and dimensions of the micro-channels are shown in Fig. 2. Moreover, ABAQUS finite element commercial code was used to simulate the process. Punch and die were rigidly modeled. The sheet was modeled shell-like and deformable. The displacement boundary condition was applied to the punch while the die was bound in all directions. Surface-to-surface contact conditions were used to define the interaction between the punch, die, and sheet metal.

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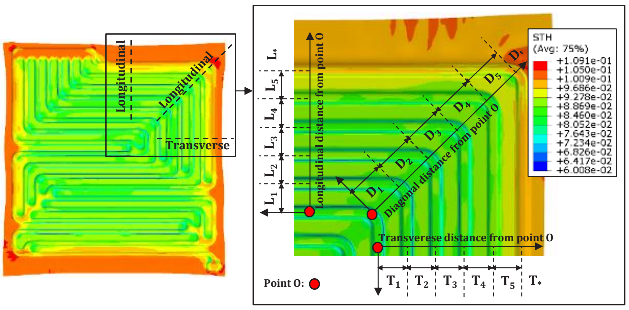

Fig. 3. Longitudinal, diagonal, and transverse direction together with divided area

3- Results and Discussion

In this research, since the MBP forming with serpentine flow field pattern has been thoroughly investigated, it is important to determine the metal flow in different regions (lateral and middle regions). For this purpose, the thickness distribution in different channels along longitudinal, transversal, and diagonal directions was investigated. The position of the investigated channels is shown in Fig. 3.

The thickness variations in different channels in the diagonal direction are shown in Fig. 4. In this case, the thickness reduction in the lateral channels (D5) is also less than the middle channels (D1). Under these conditions, feeding sheet metal from the non-critical areas (D*) toward the lateral channels also improves the thickness distribution. The effect of sheet flow from the outer regions on the thickness distribution in the diagonal direction only affects the three initial channels (D5 to D3), and in the subsequent channels, the maximum thinning percentage and thickness changes will be the same. Furthermore, the thickness distribution non-uniformity in each channel is greater in the diagonal direction than in the longitudinal direction. To quantitatively evaluate the thickness reduction in different directions and to determine the critical direction, the thinning percentage based on the minimum thickness created in each area is calculated and shown in Fig. 5.

According to the results, the thinning percentage increases in all directions as it moves from the external channels to the internal channels. The thinning percentage in the outer channels in the diagonal, longitudinal, and transversal directions is 6.2, 3.9, and 2.3%, respectively. In the middle channels in the directions above, these are 34.1%, 36%, and 38.6%, respectively. In the lateral regions, due to the strain caused by the corner radius (serpentine (helix) curvature), the amount of thinning in the diagonal direction (critical area in the lateral channels) is greater than in the other two directions.

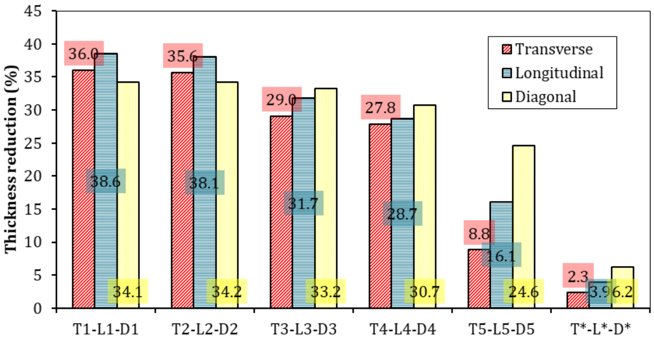

Fig. 5. Maximum thinning percentage in various directions

4- Conclusions

The results of this study showed that thickness of the specimen increase in the lateral area. The effect of sheet flow on the thickness distribution is visible in the three lateral channels and will not have a significant effect on the other channels. The thinning percentage in diagonal, transversal and longitudinal directions in plates formed to 0.65mm depth is 34.1%, 36%, and 38.6%, respectively. The highest thinning percentage occurs in SS304 MBPs in the longitudinal direction. Also, the use of a lubricant improves thickness distribution in SS304 bipolar plates

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HOW TO CITE THIS ARTICLE

H. Talebi-Ghadikolaee, M. M. Barzegari, Experimental and numerical investigation of the plastic deformation of metallic bipolar plates with serpentine flow filed, Amirkabir J. Mech. Eng., 53(6) (2021) 881-884.

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