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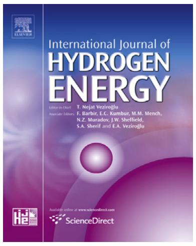

Study on the levelling process of the current collector for the molten carbonate fuel cell based on curvature integration method

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ABSTRACT

The current collector for the molten carbonate fuel cell (MCFC) is manufactured from the sheet metal forming process. After the forming process, the current collector is bent resulting in a specific curvature (κ_i) in the direction in which trapezoidal protrusions are formed due to springback. In the stack of the MCFC, small deformation of the current collector can bring about defects in the electrolyte, non-uniform contact and difficulties in assembling the stack. Therefore, the curvature of the current collector should be minimized in order to reduce defects which can cause critical damage in the long-term operation. In order to straighten the current collector, the levelling process using three rolls was employed. In this work, a simple and effective method for designing the levelling process was proposed. An analytic model and the finite element analysis were used in combination. The optimal curvature minimizing the resultant curvature and the resultant moment of the current collector down to zero was calculated from the bending moment–curvature relationship. The bending moment–curvature relationship of the current collector was determined from the finite element analysis of uniform bending using the simulation results of the three-stage forming process. In the analytic model based on curvature integration method, the proper roll arrangement corresponding to the optimal curvature was calculated. Experiments were conducted using the calculated roll arrangement. The current collector was levelled nearly flat using the levelling process. After the levelling process, the flattened current collector was easily assembled with a centre plate and ensuring uniform contact with the electrolyte.

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1. Introduction

The molten carbonate fuel cell (MCFC) has many advantages in terms of high efficiency and suitability for co-generation of electricity and heat [1]. The MCFC is composed of metallic bipolar plates, a cathode, a matrix and an anode. The metallic bipolar plates of the MCFC are made from stainless steel due to its manufacturability and high corrosion resistance [2–4]. As shown in Fig. 1, the metallic bipolar plates are composed of a centre plate, an anode current collector and a cathode current collector [5].

The current collector for the MCFC is a repeated structure of sheared protrusions [5,6]; it is manufactured from the three-stage forming process that integrates the slitting process, the preforming process and the final forming process [7]. In the slitting process, the sheet is torn open and formed so as to have sheared protrusions with low height. In the preforming process, the sheet is stretched to distribute deformation more uniformly. In the final forming process the sheet is formed to have sheared protrusions with taller height.

In the forming process of the current collector for the MCFC, two main problems exist; the design of the forming process and the deformed shape after springback are major obstacles. The design of the three-stage forming process is one of the most critical problems due to the high aspect ratio of trapezoidal protrusions. Yang et al. [8] designed the three-stage forming process for the current collector to reduce local deformation in the forming simulation of a sheared protrusion. The other problem is the springback of the current collector. After the forming process of the current collector, the sheet is bent, resulting in a specific curvature (κ_i) due to the residual stress [9,10], as shown in Fig. 2.

In the MCFC stack, the anode current collector, the anode, the matrix, the cathode and the cathode current collector are stacked in order. The deformation of the current collector due to the residual stress of the forming process induces further deformation of the anode, the matrix and the cathode. Because the strength values of the anode, the matrix and the cathode are much lower than that of the current collector [11], small deformation of the anode, the matrix and the cathode can induce defects. In the operating condition of the MCFC, defects of the anode, the matrix and the cathode can bring about the gas cross-over, which is a critical type of damage in the long-term operation [12,13].

The unwanted deformation of the metallic bipolar plates due to the springback is also found in other fuel cells, especially for the metallic bipolar plate of the proton exchange membrane fuel cell (PEMFC) [14–17]. Qiu et al. [16] investigated the pressure distribution of the gas diffusion layer (GDL) after assembling. Due to shape error, the pressure profile shows a non-uniform distribution. The uneven distribution of the contact pressure was not eliminated simply by the increased clamping force. Due to the high contact resistance in the low pressure area and the resulting damage of the GDL, performance of the fuel cell was worsened.

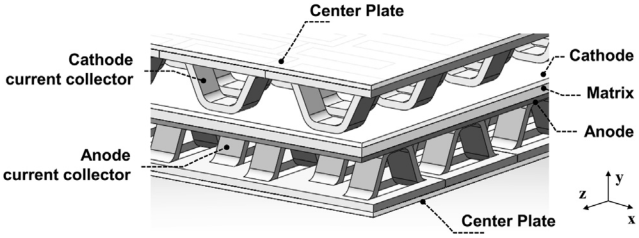

Fig. 1 – Structure of the molten carbonate fuel cell.

In order to minimize the unwanted deformation of the anode, the matrix and the cathode, and to increase the efficiency of the fuel cell, it is necessary to reduce the residual deformation of the current collector. Generally, if the sheet has a curvature, the sheet can be levelled using the continuous combined bending-unbending process. As a correction process for rolled sheets, the continuous bending-unbending process is called as the levelling process. The sheet is subjected to combinations of bending and inverse bending with decreasing curvature between a number of staggered rolls [18].

There have been many studies on the levelling process. Optimization methods used in previous studies can be divided into two categories. One is the process design based on the finite element analysis. The other is the optimization using an analytic model.

With the development of the finite element analysis, the finite element analysis has been used to optimize the levelling process. Yoshida and Urabe [19], Huh et al. [20] Park and Hwang [21] and Zhou et al. [22] designed the levelling process based on the finite element analysis. Schleinzer and Fischer [23] calculated the residual stress distribution of a rail product by combining the explicit simulation method and the implicit simulation method. The FEM simulation demonstrates good results with a simple simulation model for such as flat rolled sheets. However, the FEM simulation has rarely been tried for the levelling process of a sheet with complex geometry due to the large size of the problem for numerical computation.

Another problem of the finite element analysis is the consideration of the forming effect (results of the forming process) such as the plastic strain and the residual stress [24–27]. The mechanical behaviour of the sheet is largely affected by the forming effect due to the work hardening of the sheet material [24]. The forming effect should be considered in the simulation of the levelling process. However, due to the periodic distribution of the unit cell over a wide area, the size of the simulation model is too large to perform full simulation covering both the forming process and the levelling process.

In the optimization using an analytic model, the deflection of the sheet is calculated with some assumptions. Doege et al. [28] and Nastran and Kuzman [29] calculated the optimal levelling conditions using an analytical model with some assumptions about the deformation of the sheet. Behrens et al. [30] developed an analytic 3D-simulation model to investigate edge and centre waves. Liu et al. [31] proposed a new mechanics model to predict the levelling process of plates with the consideration of the deformation in the width direction. The analytic model can be conveniently employed to predict the deflection of the sheet and to design the appropriate levelling process. However, the bending behaviour of the material cannot be considered accurately due to the limitations of the analytic model. In addition, the analytic model is hardly available for sheets with complex geometry.

In order to solve these problems, a simple and effective method for designing the levelling process is proposed. In