Research on the forming effect of convex surface part in flexible rolling process

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Abstract. Flexible rolling process (FRP) is a rapid and effective three-dimensional (3D) surface forming process. Forming tool is a pair of bendable forming roll sets controlled by controlling units. In this process, the transversal bending deformation is obtained by the shape of forming rolls. The longitude bending deformation is obtained by the uneven longitude elongation of sheet metal which is due to the uneven thickness thinning. The sheet metal is continuously bent in the transverse and longitudinal directions at the same time. Therefore, the 3D surface part is formed. The deformation process is cumulative, so the size of the sheet metal has a significant influence on the forming effect. In this paper, taking the convex part as an example, the forming effect of different length and width of sheet metal is discussed through numerical simulation in FRP. The results demonstrate that FRP is more sensitive to the width of the sheet metal and is almost unaffected by the length of the sheet metal. In the case of a constant width, the utilization of the sheet metal can be increased by increasing the length of the sheet metal in a certain extent.

1. Introduction

3D surface parts are widely used in many fields, such as airplanes, ships, trains and modern architectures. The conventional forming processes are applied for producing mass and single shape of surface parts. As the market demand for products tends to be single and small batch products, a new forming process which can meet the market demands is urgently required in many industrial fields. Yamashita tried to continuously forming surface parts in the earlier times. As the forming tool contour is a segmented line, the connection is not continuous and the smoothness is so poor. Therefore, the forming effect is not ideal [1]. In recent years, Yoon et al. [2,3] have proposed the line array roll set (LARS) process. Three upper roll sets and three lower roll sets are employed as forming tools and each roll set composed of many short rolls which arranged in a linear array. The longitude bending deformation is obtained by three-point bending; the transversal bending deformation is obtained by forming roll contour. Li proposed continuous flexible forming (CFF) based on the idea of roll-bending with flexible rolls [4,5]. The forming tools of CFF process employs three flexible rolls. In this process, the sheet metal is bent simultaneously in both directions, thus a 3D part is formed continuously [6]. In the LARS and the CFF processes, the 3D surface part is bent in two orthogonal directions. Therefore, at least three flexible rolls or three roll sets are employed. More recently, Cai and Li proposed continuous roll forming (CRF) process for 3D surface parts [7]. CRF is proposed based on rolling process and flexible multi-points technic. A pair of roll set is employed as forming tools [8]. The flexible roll sets act on the sheet metal with continuously distributed pressure, and continuous contact between the forming roll sets and sheet metal leads to a better surface quality. The basic principle of
CRF was described [9,10]. Forming precision of flexible rolling method for 3D surface parts was studied through simulation [11]. The influence of process parameters about the sheet parts shape has been analysed through numerical simulation [12]. In this paper, the influence of sheet metal length and width on the forming effect is analyzed by finite element method; the feasibility of numerical simulation is verified by forming experiments.

2. Forming process in flexible rolling
Flexible rolling forming equipment is presented in Figure 1. Forming tools are a pair of bendable roll set and their contour can be configured by adjusting controlling units. Before the processing, the forming roll sets contour is configured to target shape, so that an uneven roll gap is formed between the upper and lower roll sets. Sheet metal is clamped by roll sets. The forming roll set rotates around its own axis by torque, driving the sheet metal continuously to feed under the friction between roll sets and sheet metal. As a result, the sheet metal is continuously bent in the transverse and longitudinal directions at the same time and the 3D surface part is eventually formed.

3. Finite element model
ANSYS/LS-DYNA is an effective software for finite element analysis. Finite element model (FEM) is established according to the experimental equipment as shown in Figure 2. So the simulation results approach to the experimental results. In the FEM, roll set consists of many discrete short rolls and each short roll rotates around its axis centre by torque. Each short roll is defined as rigid body. Sheet metal is defined as flexible solid. C3D8 elements are applied in the sheet metal. The material is 1050Al; the density is 2720 kg m\(^{-3}\); Young’s Modulus is 76000 MPa and Poisson’s ratio is 0.34.

4. Analysis of numerical simulation results
4.1. The effect of the longitude length of sheet metal on the forming effect
In order to analyse the forming effect of the different length of sheet metal in the FRP, the compared simulations are performed. The initial thickness of sheet metal is 1.8mm. The width is 120mm and the longitude length is 200mm, 300mm, 400mm, and 500mm in order. Figure 3 shows the plastic strain distribution of the forming parts with different sheet metal length. Due to the decreasing distribution of the roll gap from the both sides to the middle, the plastic strain is correspondingly increasing from the both sides to the middle. In the longitudinal direction, the plastic strain near the front and the back ends is gradually changing. Far away from the front and back ends, plastic strain is continuous strip, indicating the forming process is continuous and stable. Thickness distribution in the FRP is an important parameter to measure the forming effect. Figure 4(a) is the thickness distribution of the forming part with different initial length at the minimum roll gap. It can be seen that, as the length of the sheet increases, the length of stable forming area becomes longer, the thickness of the stable forming area did not change significantly. Gaussian curvature radius (GCR) can intuitively represent...
the whole bending deformation. The GCR of different sheet metal length is given in Figure 4(b). With the sheet metal length increases, the bending deformation is almost stable. Thus, the forming process has high stability and the error is small enough to be negligible. Reasons for the forming result: As the sheet length increases, the thickness distribution along the width direction has no change; the longitudinal fibre elongation distribution does not change. Therefore, changing the sheet length has no significant effect on the forming effect. At the same time, with sheet length increase, the sheet utilization can be greatly improved.

Figure 3. The plastic strain distribution of convex surface parts with different sheet length.

Figure 4. The forming effect of different sheet metal length in FRP (a) thickness (b) GCR.

4.2. The effect of the transversal width of sheet metal on the forming effect

To investigate the forming effect of the different width of sheet metal in FRP, the compared simulations are carried on. The initial thickness of sheet metal is also 1.8mm. The length is 180mm and the transversal width is 60mm, 70mm, 80mm, and 90mm in order. Figure 5 presents the plastic strain distribution of the forming parts with different width. It can be seen that, as the sheet metal width increases, the plastic strain on both sides of the sheet metal shows a decreasing trend due to the characteristics of the roll gap distribution. Figure 6(a) shows the thickness distribution with different initial widths at the minimum roll gap. It can be observed that, as the width of the sheet metal increases, the thickness distribution of the stable forming area remains stable, but the thickness value of the stable forming area is increased. The GCR of different sheet metal width is shown in Figure 6(b). With the sheet metal width increases, the bending deformation is unstable, the trend of forming curve is decreasing, and the forming error cannot be ignored. The reason is that: as the sheet width increases, the difference between the maximum longitude fibre elongation and the minimum fibre
elongation becomes larger, so there have larger longitude bending deformation and the corresponding smaller thickness reduction. Therefore, changing the sheet width has significant effect on the forming effect.

Figure 5. The plastic strain distribution of convex surface parts with different sheet width.

Figure 6. The forming effect of different sheet metal width in FRP (a) thickness (b) GCR.

5. Analysis of experiment results

5.1. The effect of the longitude length of sheet metal on the forming effect
The experiments have been conducted on FRP apparatus. Sheet metal sizes are 120×200mm, 120×300mm and 120×400mm. The bending deformation of forming parts are shown in Figure 7, it can be seen that the surface of the forming part are smooth. Thus, there is no defect such as wrinkles, which indicating the forming quality is high. The transversal and longitude bending deformation did not change significantly, so the bending deformations are same. The Figure 8 presents the measuring tool which can measure the chord height and thickness of sheet metal. The curvature radius is obtained by the chord height and length. The thickness and GCR in the stable forming area of forming parts are shown in Table 1. It can be seen that the thickness and GCR of the stable forming area almost did not change. Forming results indicate that the length of sheet metal has no significant effect on the forming effect. The experimental results are agreed with the simulation results.
Figure 7. The bending deformation of forming parts with different length in FRP.

Figure 8. The measuring tool.

Table 1. The GCR and thickness of forming parts with different length.

| Longitude length (mm) | Thickness (mm) | GCR (mm) |
|-----------------------|----------------|----------|
| 200                   | 1.76           | 215      |
| 300                   | 1.76           | 219      |
| 400                   | 1.76           | 218      |

5.2. The effect of the transversal width of sheet metal on the forming effect

Sheet metal sizes are 60×180mm, 70×180mm and 80×180mm. The bending deformation of forming parts are given in Figure 9, it can be observed that the transversal bending deformations are same. In contrast, the whole bending deformation becomes larger with the sheet width increases. The thickness and GCR in the stable forming area of forming parts are shown in Table 2. It can be seen that the thickness and bending deformation are increasing with the width increases. The experimental results are agreed with the simulation results.
6. Conclusion
In this paper, the forming effect of convex surface part in FRP is analysed by finite element method. The feasibility of numerical simulation is verified by forming experiments.

1. Under the same conditions, with the sheet metal length increasing, both the thickness and the bending deformations of stable forming area did not change significantly. Thus, the forming effect is almost stable. In other words, FRP is an effective and stable forming process. Moreover, as the length of the sheet metal increases, the length of stable forming zone also increases to a certain extent. Thus, the utilization of the sheet metal can be greatly improved.

2. With the sheet metal width increases, the thickness of the stable forming area is increasing and the bending deformation become larger. Therefore, the forming error cannot be ignored. So the sheet metal width has significant effect on the forming effect.

3. Above all, FRP is more sensitive to the width of the sheet metal and is almost unaffected by the length. As a result, in the case of a constant width, the longer the sheet length, the better the forming effect.

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