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Numerical simulation study on rolling-chemical milling process of aluminum-lithium alloy skin panel

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Abstract. Single curvature parts such as aircraft fuselage skin panels are usually manufactured by rolling-chemical milling process, which is usually faced with the problem of geometric accuracy caused by springback. In most cases, the methods of manual adjustment and multiple roll bending are used to control or eliminate the springback. However, these methods can cause the increase of product cost and cycle, and lead to material performance degradation. Therefore, it is of significance to precisely control the springback of rolling-chemical milling process. In this paper, using the method of experiment and numerical simulation on rolling-chemical milling process, the simulation model for rolling-chemical milling process of 2060-T8 aluminum-lithium alloy skin was established and testified by the comparison between numerical simulation and experiment results for the validity. Then, based on the numerical simulation model, the relative technological parameters which influence on the curvature of the skin panel were analyzed. Finally, the prediction of springback and the compensation can be realized by controlling the process parameters.

1. Introduction

Single curvature parts such as fuselage skin panels are important parts of the aircraft, and this kind of single curvature parts are usually formed by rolling-chemical milling process. Through the rolling technology, parts can be formed. Moreover, through the chemical milling process, a part of material can be removed to meet the structural requirement and reduce the weight [1]. This sort of technology is usually faced with the problem of geometric accuracy caused by springback. In most cases, the methods of manual adjustment and multiple roll bending are used to control or eliminate the springback. However, these methods can lead to the increase of product cost and cycle, and also cause the degradation of the material performance. Therefore, precisely controlling the springback of rolling-chemical milling process is of important significance.

2060-T8 is the newly developed third-generation aluminum alloy material [2]. So far, domestic and abroad civil aviation companies have not applied it into the airplane parts in quantity. Besides, there are few studies on the numerical simulation of rolling-chemical milling process [3]. In this paper, through using experiment and numerical simulation on rolling-chemical milling process, the simulation model for 2060-T8 aluminum-lithium alloy skin rolling-chemical milling process is established and testified by the comparison between numerical simulation and experiment results for the validity. Then, based on the numerical simulation model, the relative process parameters influencing the rolling results of the skin panel is analyzed. Finally, the prediction of springback and springback compensation are realized by controlling the process parameters.

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2. Establishment of the rolling-chemical milling model

The experimental material used in this paper is the 2060-T8 aluminum-lithium alloy rolled sheet whose chemical composition is shown as Table 1 [4]. The size of the experimental material is 2 mm × 100 mm × 500 mm. According to the feature of fuselage skin material, the roll bending direction is perpendicular to the rolling direction. Figure 1 shows the schematic diagram of the roll bending process.

Table 1. Chemical composition of 2060-T8 aluminum-lithium alloy

Material	Cu	Li	Zn	Mg	Mn	Zr	Ag	Si	Fe	Al
2060-T8	3.9	0.8	0.32	0.7	0.29	0.1	0.34	0.02	0.02	Bal.

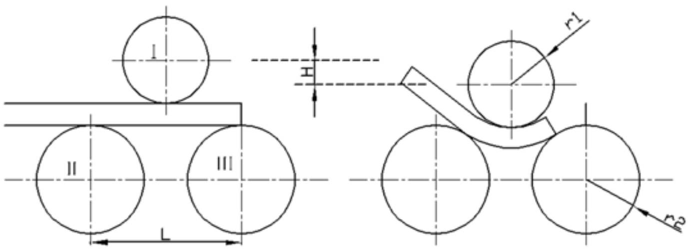

Figure 1. The symmetrical tri-axial roll bending process

A symmetrical tri-axial roll bending machine was selected in the experimental rolling phase. The radius of the upper roller is r1 = 40 mm, the radius of the two-bottom roller is r2 = 50 mm, and the spacing L = 200 mm. During the experimental process, the bending radius was controlled by adjusting the roller stroke H, and the specific process is shown as follows: First, upper roller presses down to the specified amount of stroke. Then, the bottom rollers start to rotate and drive the upper roller and metal sheet through friction. When the rolling comes to the boundary part, the bottom rollers begin the reverse rotation, so the motion is repeated to obtain the required curvature radius. In the end, the rollers are hoisted and the sheet discharges springback. After the roll-bending process finished, the experiment comes to the chemical milling phase. Besides, the size of the chemical-milling area is 400mm × 80mm, and the depth of chemical milling is 0.8 mm.

The roll bending and chemical-milling process of the skin part involve two working procedures. Thus, in order to accurately describe the springback caused by the stress redistribution, the finite element model needs to transmit the residual stress after the roll-bending process as well as the springback into chemical-milling model to realize the stress release after the material has been removed. As a result, the numerical simulation model was divided into two stages according to the rolling-chemical milling process.

Roll bending stage: the metal sheet with the size of 2 mm × 100 mm × 500 mm was used to conduct the experiment of the skin roll bending, and the numerical simulation model is presented in Figure 2.

Chemical-milling stage: The simulation was performed with the sub-model method of the software ABAQUS [5]. Through adjusting the unit thickness of plate, the change of the parts' whole structure during the milling process was stimulated, destroying the balance condition of the original stress inside the material and redistributing the internal stress to make the specimen changed. Finally, the implicit algorithm was selected to compute the springback after chemical milling.

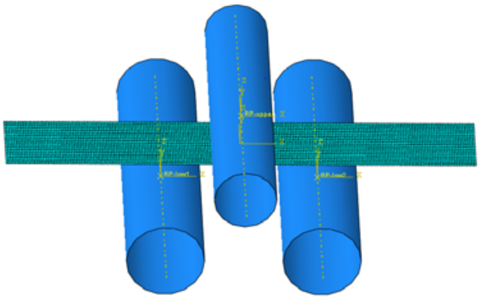

Figure 2. Numerical simulation model for the roll-bending

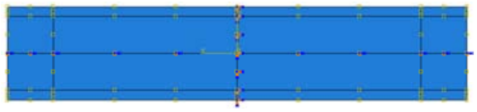

Figure 3. Numerical simulation model for the chemical-milling process

Figure 4 shows the test specimen of the roll-bending and chemical-milling process. And it can be seen the comparison of the simulation and the experimental results, as shown in Figure 5. The overall error is 3.8%, and the biggest error is 7.9%, appearing in the springback change after the chemical-milling process with the roller stroke of 28mm. Thus, in this paper, the finite element model of the whole process of the roll-bending and chemical-milling is accurate, and it can meet the production demand.

Figure 4. Roll bended-chemical milled workpieces

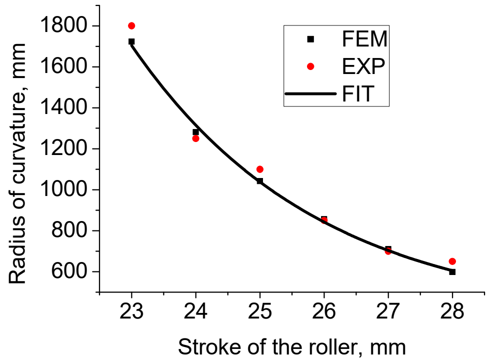

Figure 5. Comparison of numerical simulation results and experiment results

3. Results and discussions

3.1. The effect of the roller stroke

In this paper, five sets of different roller stroke were selected to understand the influence on the forming curvature radius. The simulation results are shown in Figure 5. It can be seen that the relationship between the part curvature radius and the centre roller stroke is close to a power exponential function. Additionally, the roller stroke volume for other formed curvature radius can be quantitative analyzed with the fitted result data. Thus, this paper obtains the approximate map relationship between central roller and radius through substituting experiments based on numerical simulation, and basically meets the requirement of actual production.

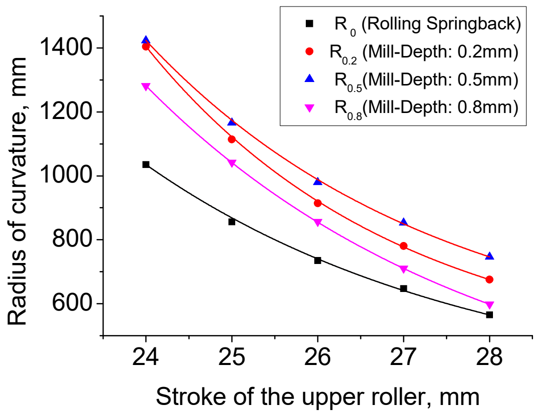

Figure 6. Effect of chemical-milling depth on curvature radius

3.2. The effect of the chemical-milling depth

The numerical simulation result of parts with different chemical-milling depth is shown in Figure 6. According to the figure, the impact of the chemical-milling process on the springback of the formed parts caused by the roll bending is relatively large, and the deformation of the curvature radius is up to 40%. This is because that there exists milling stress in the interior of the part after the chemical-milling process. And the release of the stress leads to the increase of the curvature radius. Thus, certain radius compensation should be considered during roll-bending process of this kind of parts. In addition, with the increase of the milling depth, the curvature radius of the parts increases first and then decreases. This is caused by the following conditions: the stress distributes unevenly along the thickness direction after the roll-bending process; the difference of the chemical-milling depth directly causes the parts to generate internal stress after the chemical-milling process; besides, the difference of the milling stress directly influences the change of the curvature radius after the stress has been released.

Figure 7 presents the distribution of internal stress after the roll bending process. When it reaches to the milling depth of area which is distributed tensile stress, the part curvature radius increases. Besides, the main reason is that the stress balance of the sheet is broken when the stress area has undergone the chemical-milling process, which causes the crushing stress being greater than the tensile stress. Therefore, to achieve the rebalanced state, the sheet leads to the release of the crushing stress, and then causes the enlargement of the curvature radius. With the increase of milling depth, it turns to the crushing stress distribution area, which gradually lessens the crushing stress inside the material. Therefore, the material releases the tensile stress to gradually reduce the internal stress, resulting in the enlargement of the curvature radius.

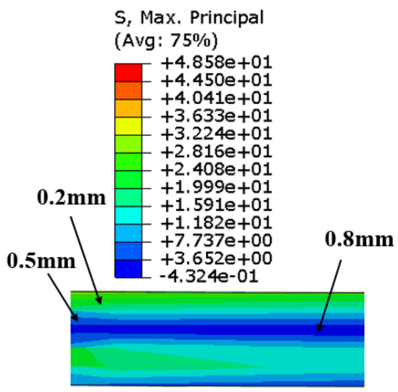

Figure 7. Distribution of the internal stress

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4. Summary

This paper analyzes the technology of the roll-bending and chemical-milling process. Combined with the features of the two kind of processing technology, a numerical simulation model of the whole roll-bending and chemical-milling process was established based on the ABAQUS software. Through the contrastive analysis between the simulation results and experimental results, the correctness of the finite element model was verified and the following conclusion can be drawn:

Firstly, An approximate map relationship between central roller and part radius was obtained through substituting experiments by numerical simulation, and basically meets the demand of actual production, providing guiding significance for the determination of roll bending process parameters. Secondly, based on the established model, the effect of chemical-milling depth on the part springback was discussed. That is to say, with the increase of the milling depth, instead of increasing progressively, the springback volume increases firstly and decreases later.

Acknowledgments

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