Numerical simulation study of wall thickness change rule of single-point progressive molding of Al5083

Abstract: With the development and progress of science and technology, the application of single-point progressive molding is more and more extensive, but single-point progressive molding still exists the problem of excessive thinning of wall thickness of molded parts, which seriously affects the quality of molded parts. The article takes Al5083 plate forming cone as the research object, uses Abaqus finite element simulation software, according to the principle of single variable, respectively explores the influence of process parameters such as tool head diameter, layer spacing, feed rate and residual height on the average wall thickness reduction rate and the maximum wall thickness reduction rate of the molded parts. The results show that: increasing the tool head diameter, the average wall thickness reduction rate increases and the maximum wall thickness reduction rate decreases; the average wall thickness reduction rate and the maximum wall thickness reduction rate increase with the increase of ply spacing; the average wall thickness reduction rate and the maximum wall thickness reduction rate increase with the increase of the tool feed rate; the average wall thickness reduction rate decreases and the maximum wall thickness reduction rate increases with the increase of the residual height.

keywords： Single-point progressive forming Aluminum alloy plate Finite element Wall thickness reduction rate

Introduction:Progressive molding is a moldless, plastic forming manufacturing process that introduces the "layered manufacturing idea" of rapid prototyping.[1],The part is cut into multiple two-dimensional planes along the height direction, transforming the processing of a three-dimensional part into a superposition of multiple two-dimensional shapes, and creating the shape that each two-dimensional plane should have in a hierarchical manner. This forming technology can be processed and produced without molds, and is characterized by low cost and high applicability.[2]， This processing method has a short production cycle and low processing cost, which is in line with the current green cost manufacturing concept, and can meet the market demand for product personalization, diversification and complexity. Yao Zimeng et al.[3]Finite element simulation and experiments are used to study the thickness of the deformation zone of the sheet to obtain the influence law of different process parameters on the distribution of sheet thickness; Gu Yanbo et al.[4]A finite element model of progressive forming of AAA5754 aluminum alloy plate was established and compared with the experimental results to analyze the influence of different process parameters on plate thickness uniformity; L. Filice et al.[5]Reducing the thinning of the deformation zone during progressive sheet forming by designing a more optimized tool path results in a more uniform thickness distribution of the formed part. Zhong Dong et al.[6]A new method is proposed to optimize the single-point progressive forming trajectory, which effectively controls the thinning amount at the gently curved surface of the formed part; Su Chunjian et al.[7]Taking the plate structure of various metal materials as the research object, combined with the finite element simulation and analysis method, simulate the influence law of each process parameter on the forming Mises stress and so on, and verify the accuracy of the simulation results through the test. Liu Xuan et al.[8]Several different tool forming paths are simulated by the finite element method to analyze the effects of various paths on the thickness distribution and thinning rate of the workpiece and verify the optimal tool path forming by the experimental method, and the results are basically similar to the simulation. Zhao Chao Yue et al.[9]The effects of different forming strategies on the accuracy and quality of formed parts were analyzed by simulation prediction. Zhu Zhishou et al.[10]A method of alternating up and down reciprocating forming trajectories was used to experimentally study the TB8 titanium alloy straight-walled square box, and the maximum thinning rate of 42.6% was verified.Zhang Jiaqi et al. studied the effects of temperature, feed rate and feed rate on the forming properties of amorphous alloys, and calculated the forming force theoretically.[11]Zhao Xinhai et al. carried out numerical simulation of the laser-assisted progressive forming process to analyze the influence of different laser spot sizes and laser power on the laser-assisted progressive forming process.[12]Du Zhihao et al. used the optimal process parameters obtained by finite element simulation to establish experimental tooling and obtain ellipsoidal parts with smooth surface.[13]Liu Changxi et al. studied the effects of axial feed, spindle speed and feed rate on the surface quality of the conical table.[14]Zhan Mei et al. established a finite element model of the whole process of spiral bending progressive forming-rebound of aluminum alloy pipes, and analyzed the influence of rotational deformation coupling on the forming results by comparing it with flexible bending forming, and found that the introduction of bending steps on the basis of spinning will cause a certain degree of cross-section deformation and uneven wall thickness[15]Zhao Xinqi et al. proposed a two-pass forming method for straight-walled parts that combines horizontal downward movement and oblique downward movement of the sheet metal to be formed.[16]Wang Yaxin et al. compared the contour accuracy, thickness difference and simulation time difference of single-tool and multi-tool simulation results, so as to verify the efficiency and reliability of the virtual multi-tool algorithm.[17]In this paper, through the ABAQUS finite element simulation software, the Al5083 aluminum alloy pipe fittings processed by the progressive forming machine are taken as the research object to investigate the influence of tool head radius, axial layer spacing, feed rate, residual height. on the thinning rate of wall thickness of the formed parts, so as to provide theoretical basis for the improvement of the progressive forming parts as well as the optimization of the parameter combinations at a later stage.

1. Single-point progressive molding technology

1.1 Principle of single-point progressive molding technology

The main idea of single-point progressive molding process is layered manufacturing, that is, the part is discrete in the height direction for a number of parallel planes, and then through the CNC machine tool in accordance with the design of the machining trajectory to drive the tool on the sheet material to apply pressure, point by point, layer by layer, accumulating plastic deformation, and ultimately the formation of the envelope is the shape of the target part. The working principle of single-point progressive molding is shown in Figure 1, single-point progressive molding device usually consists of a tool, pressure plate and support plate and so on. The blank is firmly fixed in the fixture, and the motion of the forming tool can be broken down into three-axis translational and spindle rotational motions. The tool path strategy used is as follows: the forming tool moves from top to bottom and contacts the blank with a predefined amount of vertical interlayer downward pressure to plastically deform the sheet until the desired shape is formed.

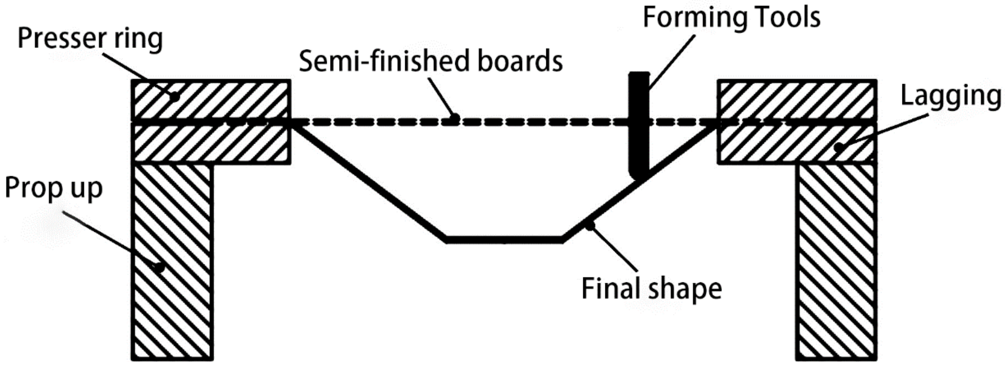

Fig. 1 Schematic diagram of single-point progressive molding

1.2 Numerical simulation scheme

Since the edge length of the selected plate is much larger than its thickness, and the wear and tear of the fixture and tool head during the plate forming process is negligible, the forming process can be simplified to save the calculation and solution time when performing the simulation analysis. The upper and lower fixtures for fixing the plate are set as discrete rigid bodies, and the tool head is set as analytic rigid body. Shell unit is used as the plate model, and Al5083 is selected as the plate material with the size of 160 mm×160 mm, the outer contour of the upper and lower fixtures is 160 mm×160 mm, the inner contour is 140 mm×140 mm, and the thickness is 2 mm, and the molding angle is set to 34°, and the depth of molding is 15 mm. The simulation algorithm adopts the dynamical and explicit solution algorithms.

The plate mesh type is set to S4R shell cell, which is stable and widely applicable. The established forming trajectory is shown in Fig.

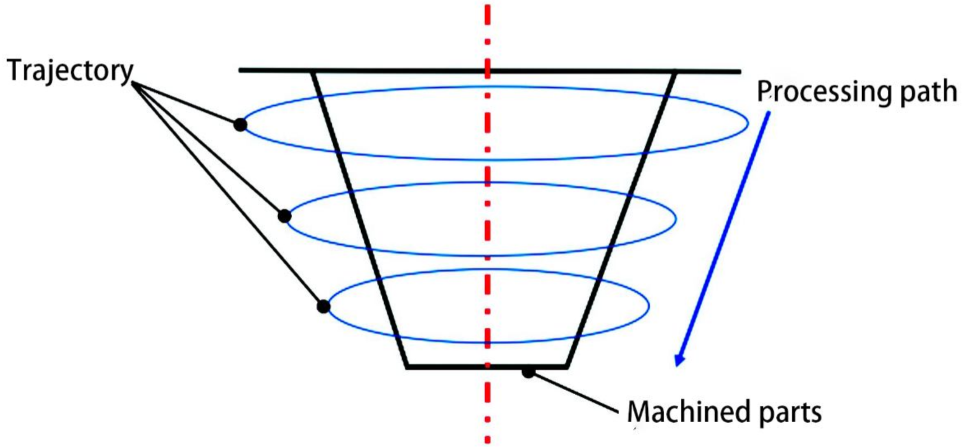

Fig. 2 Machining path trajectory diagram

1.3 Wall Thickness Reduction Rate for Square Tapered Parts

Single-point progressive forming of plates is formed by progressive extrusion of the plate by the tool head, a process in which the plate is continuously stretched and deformed. As a result, the tensile action generated during progressive forming of the plate reduces the thickness of the plate, which has a critical effect on the performance and strength of the formed part. The thickness of the formed part is usually measured by the average wall thickness reduction and the maximum wall thickness reduction. The smaller the average wall thickness reduction, the better the forming quality of the formed part; the smaller the maximum wall thickness reduction, the better the forming performance of the formed part. The thickness of the plate before and after forming is shown in Figure 3, where t0 indicates the original thickness of the plate and t indicates the thickness of the plate after forming.

The formula for calculating the wall thickness reduction rate is as follows:$\psi_t = \frac{t0-t}{t0} \times 100\%$

Where: ψt is the wall thickness reduction rate.

Therefore, the average wall thickness reduction of the formed part is calculated as:$\bar{\psi}_t = \frac{t0-t}{t0} \times 100\%$

formula$\bar{\psi}_t$ is the average wall thickness reduction；$\bar{t}$ is the average wall thickness of the molded part.

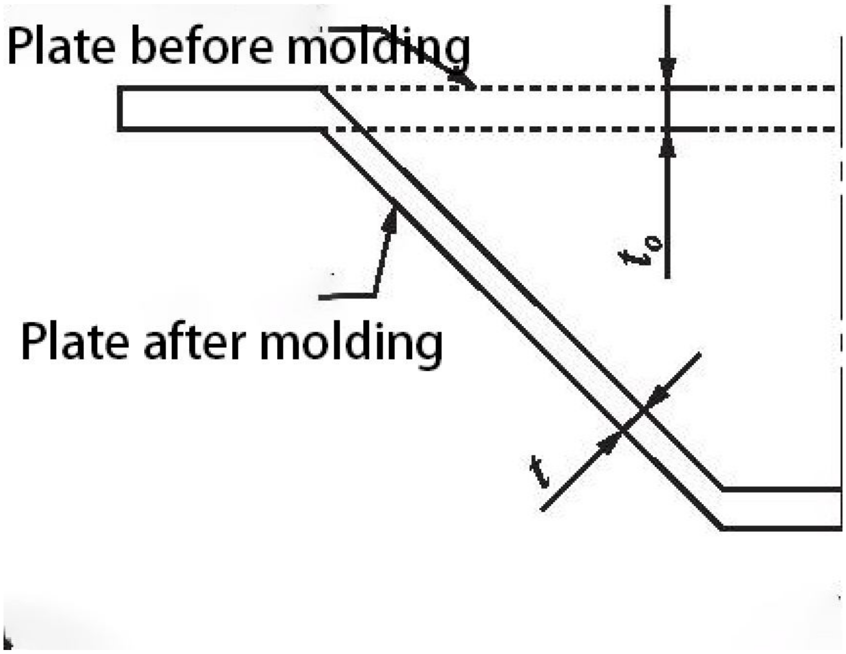

Fig. 3 Schematic diagram of wall thickness before and after plate forming

The formula for calculating the maximum wall thickness reduction of formed parts is：$(\psi_t)max = \frac{t0–tmin}{t0} \times 100\%$

formula：$(\psi_t)_{max}$ is the maximum wall thickness reduction；tminis the minimum wall thickness of the molded part.

2 Experimental results and analysis

2.1 Query of wall thickness of formed parts

On the center line of the right side wall of the molded part, take 8 points at equal intervals in different molding depths, query the thickness of each point to take the average value of the average wall thickness of the molded part, and then calculate the average wall thickness reduction rate.

2.2 Influence of wall thickness of formed parts

2.2.1 Effect of tool head diameter on wall thickness reduction rate

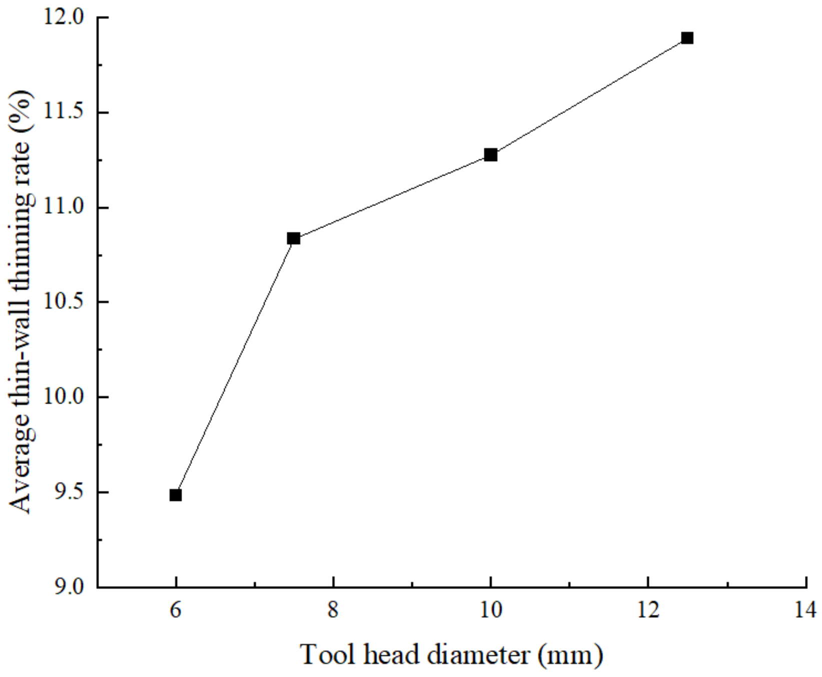

Fig. 4 Average wall thickness reduction versus tool head diameter

Figure 4 shows the relationship between the average wall thickness reduction rate and the diameter of the tool head, the tool head diameter increased from 6 mm to 12.5 mm, the average wall thickness reduction rate increased from 9.486% to 11.890%, because in the process of plate forming, the larger the size of the tool head, the larger the real-time contact area between the tool head and the deformation region of the plate, the larger the real-time crushing of the plate by the tool head area, which makes the region of the wall thickness reduction is more serious, and the average wall thickness reduction rate of formed parts is larger. The average wall thickness reduction rate of the molded part is larger.

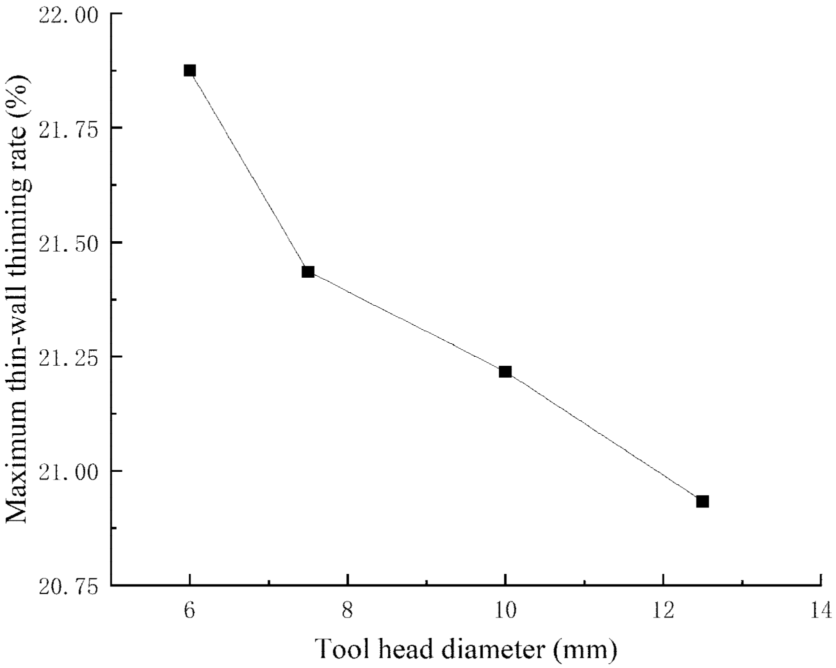

Fig. 5 Maximum thin-wall thinning rate vs. tool head diameter

Figure 5 shows the effect of tool head diameter on the maximum wall thickness reduction rate, with the increase of tool head diameter from D=6mm to D=12.5mm, the maximum wall thickness reduction rate decreases from 21.875% to 20.934%. This is because the smaller the diameter of the tool head, the smaller the real-time contact area between the tool head and the plate, the easier it is to produce stress concentration during the forming of the plate, which makes the maximum thinning rate of the molded part larger.

2.2.2 Effect of layer spacing on wall thickness reduction rate

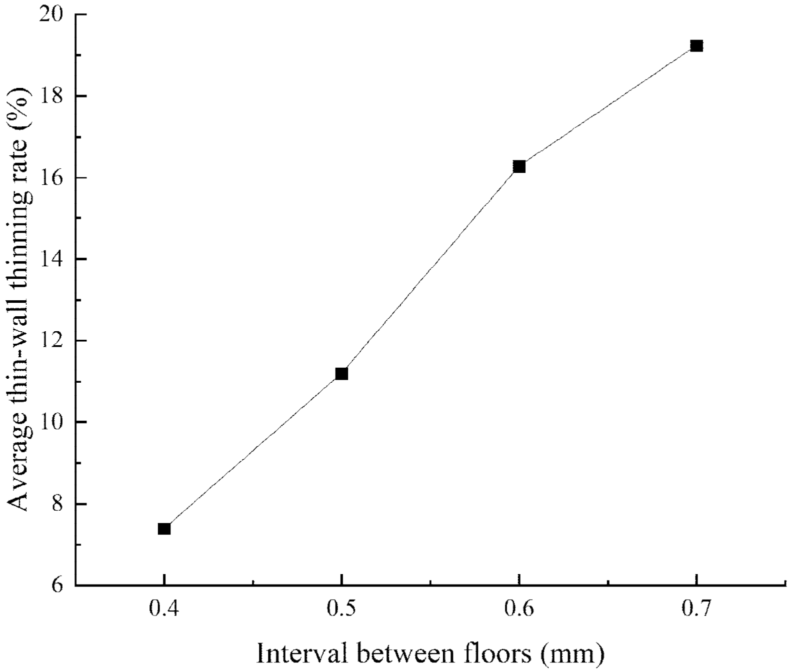

Fig. 6 Average thin-wall thinning rate vs. layer spacing

As shown in Fig. 6, the relationship between the wall thickness reduction rate and the layer spacing of the molded part cross-section under each amplitude is shown. In the case of other parameters remain consistent, respectively selected △ Z = 0.4mm, △ Z = 0.5mm, △ Z = 0.6mm, △ Z = 0.7mm a total of four groups of different layer spacing as the object of study, from the figure can be seen with the increase of the layer spacing, the wall thickness thinning rate increases significantly. When the layer spacing increases from 0.4mm to 0.7mm, the average wall thickness reduction rate increases from 7.387% to 19.236%.。

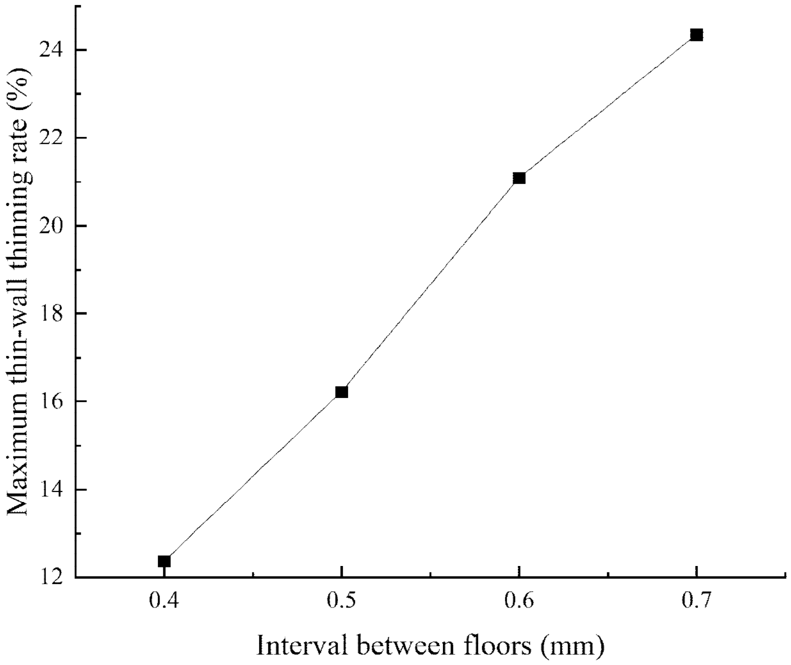

Fig. 7 Maximum thin-wall thinning rate vs. layer spacing

As shown in Fig. 7, the maximum thin-wall thinning increases from 12.362% to 24.346% when the ply spacing is increased from 0.4 mm to 0.7 mm. Increasing the ply spacing causes drastic thinning of the thickness and greatly reduces the formability. Excessive ply spacing causes further stretching of the sheet, resulting in even more severe thinning of the sheet, making it more susceptible to sources of fatigue, and also reducing the formability of the sheet.

2.2.3 Effect of feed rate on wall thickness reduction rate

In single-point progressive molding, the tool "walks" on the surface of the sheet according to a set path. When the spindle to give the tool an appropriate amount of interlayer downward pressure, the tool will exert a certain pressure on the surface of the plate, and in the x and y direction by the resistance from the surface of the plate in the opposite direction, at this time due to the existence of friction, when the tool walks all the way after the surface of the plate will produce a large number of lines. In the case of other parameters remain consistent, respectively, the feed rate of 600mm/min, 800mm/min, 1000mm/min, 1200mm/min.

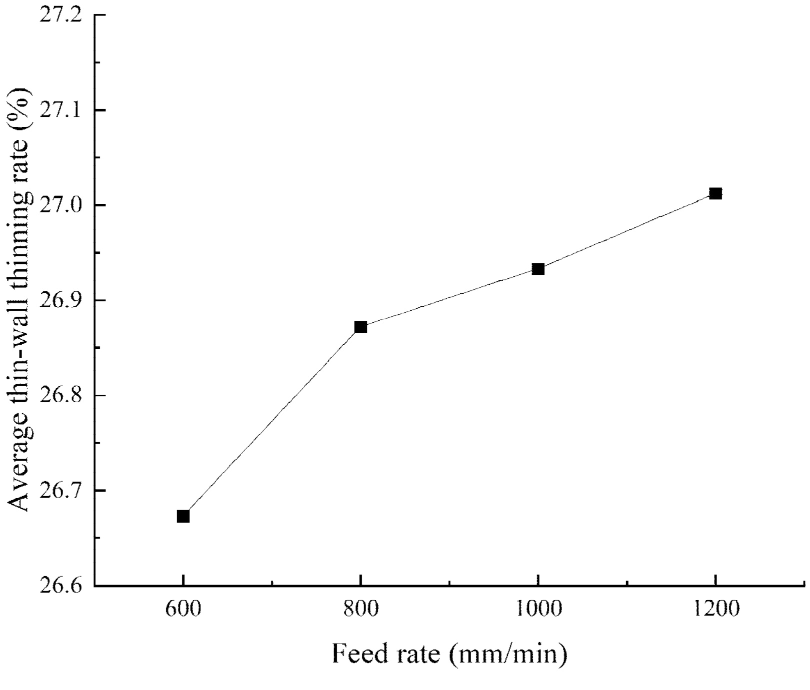

Fig. 8 Average thin-wall thinning rate vs. feed rate

Figure 8 shows the relationship between the feed rate and the average thin-wall thinning rate, the feed rate increased from 600 mm/min to 1200 mm/min, the average thin-wall thinning rate increased from 26.673% to 27.012%.

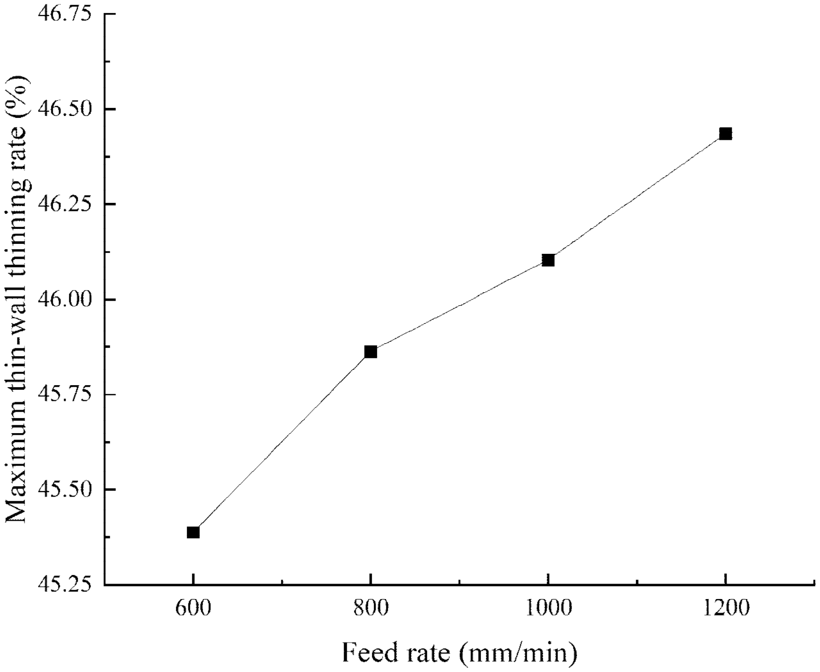

Fig. 9 Maximum thin-wall thinning rate vs. feed rate

When the feed rate is increased from 600mm/min to 1200mm/min, the maximum thin-wall thinning rate increases from 45.387% to 46.879%. This is because when processing formed parts with the same molding angle and the same molding depth, the higher the feed rate is, the smaller the amount of plastic flow generated in this area due to the implicating effect when forming the plate, and the greater the amount of thinning of the formed part's side-wall thickness, and the higher the average wall thickness and the maximum wall thinning rate are. The greater the average wall thickness reduction rate and the maximum wall thickness reduction rate.

2.2.4 Effect of residual height on wall thickness reduction rate

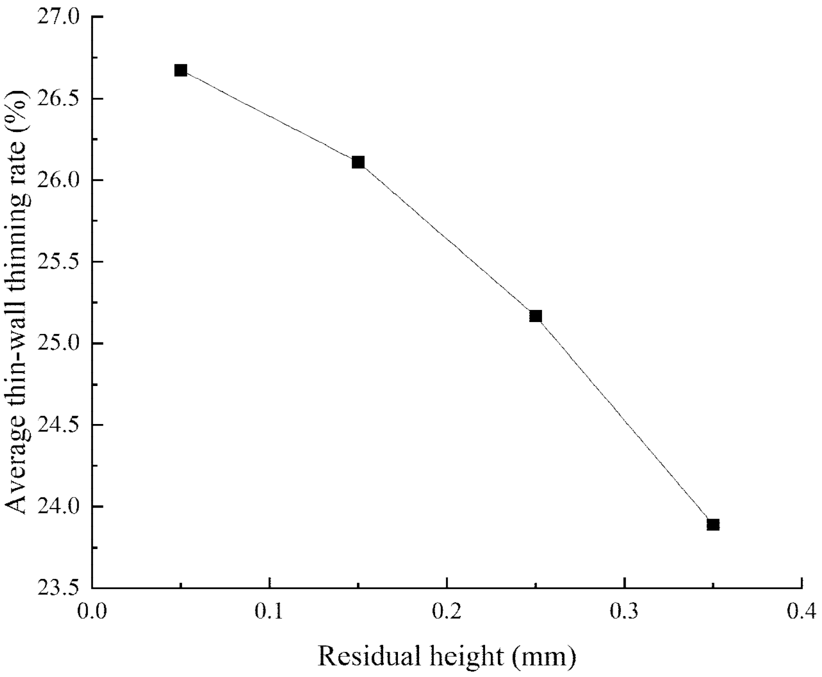

Fig. 10 Average thin-wall thinning rate vs. residual height

Figure 10 shows the relationship between the residual height and the average wall thickness reduction rate, when the residual height increases from 0.05 mm to 0.35 mm, the average wall thickness reduction rate decreases from 26.673% to 23.889%. It can be seen that increasing the residual height of the tool head forming trajectory, the average wall thickness reduction rate of the molded parts decreases. The main reason is that increasing the residual height reduces the area of the deformed area where the tool head continuously crushes the plate, resulting in a smaller thickness reduction in this area and a smaller average wall thickness reduction rate.

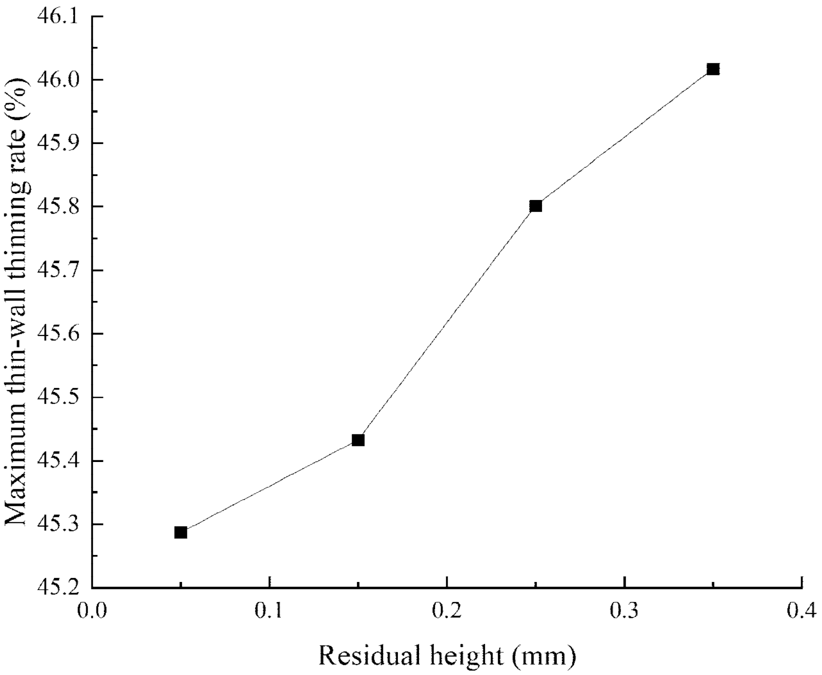

Fig. 11 Maximum thin-wall thinning rate vs. residual height

The relationship between the residual height and the maximum wall thickness reduction rate is shown in Fig. 11, when the residual height increases from 0.05 mm by 0.35 mm, the corresponding maximum wall thickness reduction rate increases from 45.286% to 46.017%. This is due to the increase of the residual height, the layer spacing of the forming helix trajectory increases, the tensile effect on the plate increases, and the maximum wall thickness reduction rate also increases.

3 Conclusion

In this paper, Abaqus finite element simulation software is used to carry out simulation experiments of single-point progressive molding of metal plates based on Al8053 plates to study the influence of different process parameters on the wall thickness reduction rate of molded parts, and the conclusions are as follows：

(1) When using different diameters of tool head to form the same molding piece, the larger the diameter of the tool head, the larger the average wall thickness reduction rate, the smaller the maximum wall thickness reduction rate.

(2) When processing molded parts with the same molding depth, control other process parameters unchanged, increase the layer spacing of molded parts, the average wall thickness reduction rate and the maximum wall thickness reduction rate are increased.

(3) When machining the same molded part, other conditions remain unchanged, the average wall thickness reduction rate and the maximum wall thickness reduction rate increase with the increase of feed rate.

(4) Control other processing parameters remain unchanged, with the increase of the residual height of the tool head molding, the average wall thickness reduction rate decreases, the maximum wall thickness reduction rate increases.

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Reference

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