Finite Element Simulation Analysis of Diamond Bi-directional Coining Neck Hole Forming Process

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Abstract. A new method of Necking Hole Forming (NHF) is proposed in this paper, which coining metal sheet in two directions by micro-scale effects of the blunt circle at the edge of the diamond. It has an important application value in the industry. For the complexity of NHF forming process, start with technological parameters of the diamond indenter and coining model, deform-3d is used to analyze the plastic flow law inside the material and the pore formation. NHF process is studied from three aspects which are material flow, stress distribution, and load curve. The results show that uses of a small cone angle indenter are beneficial to the formation of NHF and good surface quality could be obtained; The upper and lower indenter cone angle is different, there is a sudden change in the axial force of the copper sheet when the hole is formed, which is used as a basis for monitoring micro-pore formed.

1. Introduction

With the development of science and industry, the micro-pore has been widely used in many fields, such as aerospace, automobile, and other manufacturing fields. The continuous improvement of quality requirements for micro-pore machining has brought great challenges to micro-pore machining. At present, the manufacturer processing of micro-pore is still a technical problem in the world [1, 2]. Therefore, it is of great significance to explore the new necking hole forming method while optimizing the traditional machining technology continuously [3].

Ultrasonic technology is one of the most important methods for gap detection, the core calibration sample is a thin sheet metal with ultrafine micro-pore ≤5μm. Ultra micropore machining can be achieved by using ultrafast laser, its laser focusing lens manufacturing accuracy is very high and the laser spot can be focused to 1μm below. However, the cost of machining is relatively high. Therefore, it is urgent to develop micropore processing technology with independent intellectual property rights. In this paper, an innovative approach of NHF forming was proposed, which coining metal sheet in two directions by micro-scale effects of the blunt circle at the edge of the diamond. It uses double diamond indenter to coining together at the position of the workpiece preprocessing hole and finally forms the necking hole according to the process parameters of the respective in-press [4]. The research of this technology includes the analysis of forming mechanism, optimization of process parameters, construction of the experimental platform and online monitoring technology, etc. For the current research phase, DEFORM-3D finite element simulation software was used to simulate the process, which coining Necking Hole Forming by the bidirectional diamond conical indenter, meanwhile studies the related technological rules and material internal flow law of NHF, and paves the way for further experimental research [5].

2. Establish finite element model

Using CATIA to set up the geometric model of the workpiece and tools, then save the file as STL format, and then import to DEFORM-3D. As shown in Figure 1 and Figure 2, the conical indenter of diamond located in the middle of the copper sheet and perpendicular to the copper sheet, doing the axial linear motion. Considering the diamond tools sharpening and the actual processing conditions, the three kinds of the diamond indenter cone angle of 60 °, 80 °, 100 °are used, and blunt edge radius of 2μm. In order to facilitate the simulation analysis and reducing the amount of calculation, the copper sheet size is 4 × 4 × 0.5mm and the copper material is C10100 (pure copper), the tool material is diamond. In the simulation control setting, the workpiece grid is divided into tetrahedron units and the step size is set to about 1/3 of the minimum unit side length so that the grid is easy to converge and saves the time of calculation [6]. The coining process consists of two parts, firstly, the bidirectional diamond indenter synchronization coining 0.25mm, and the number of steps set to 50 steps while each step is 0.005mm; the second step is withdrawal the lower side indenter of the copper sheet, then the upper indenter continues to coining 0.20mm. The number of steps is set to 40 steps, and the step length is constant.

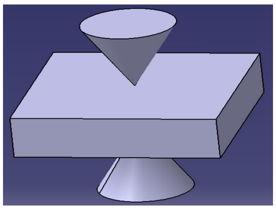


Figure 1. Solid model

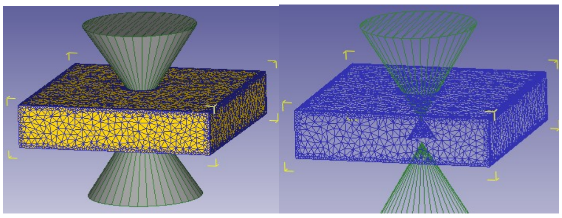


Figure 2. Finite element model

3. Simulation results analysis

3.1. Analysis of the micropore forming law of copper sheet under different cone angles

In order to research the effect of diamond indenter cone angle for micropore forming quality, using indenter cone angle of 60°, 80°and 100°of simulation respectively. After the simulation is solved, the model of the diamond tools is hidden, and the axis of the center hole of the copper sheet is cut off to obtain the influence of different cone angles on the lateral plasticity flow of metal as shown in Figure 3. In the process of bi-directional synchronous coining, with the indenter coining into the copper sheet, the flow of material is lateral and uniform. With the coining depth is increased, the lateral extrusion pressure is gradually increasing, the material inside the copper sheet become tight, the resistance of the lateral flow increases. According to the law of least resistance, the metal material will move in the direction of least resistance. When removing underside indenter support, and the upper indenter continues down coining, the material inside the copper sheet is vertical downward flow. This led to a bulge in the bottom of the copper sheet. And as the indenter cone angle increasing, the plastic deformation zone is larger, more copper bottom uplift, surface quality is poorer after micropore formation.

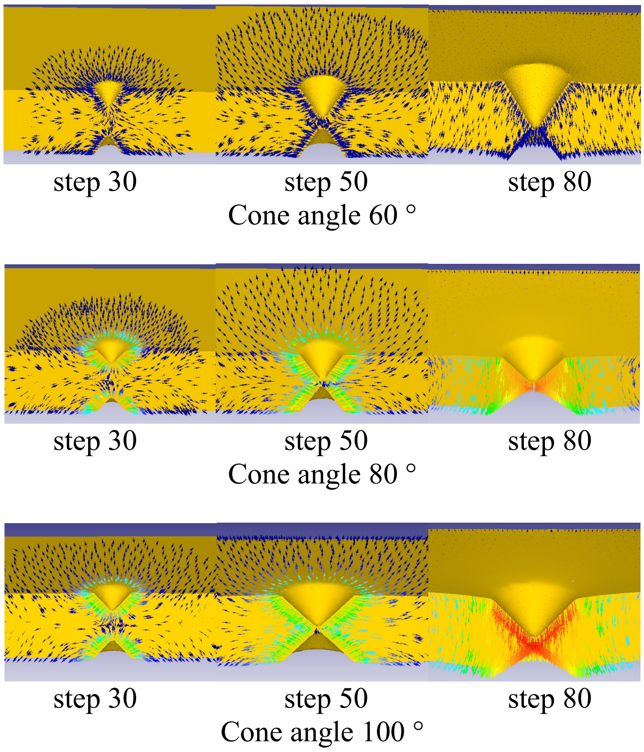


Figure 3. Effect of different cone angle on lateral flow of metal

The effect of different cone angles on the quality of the micropore forming of the copper sheet as shown in Figure 4. It can be seen that when the indenter angle is 60 °, the quality of the micropore is the best and the displacement in the axis direction is the smallest. When the cone angle is 80 °, the bottom surface of the copper sheet is obviously uplift. When the cone angle is 100 °, the lower surface of the copper sheet severely bugles and it is difficult to form a micropore. This is due to the lateral extrusion of the material during the coining process, so that the internal copper material becomes tight, the material hardness is increased; With the upper indenter continues to coining, The tapered hole formed during the coining is further compressed downward, and with the increase of the amount of depression, the material flow resistance is increasing downward, when the resistance reaches a certain critical value, the metal material plastic fracture into holes. And as the indenter cone angle increasing, the force required to reach the critical value increases, the plastic deformation zone is larger, more copper bottom uplift, surface quality is poorer after micropore formation. This is corresponding to the surface uplift features of the front.

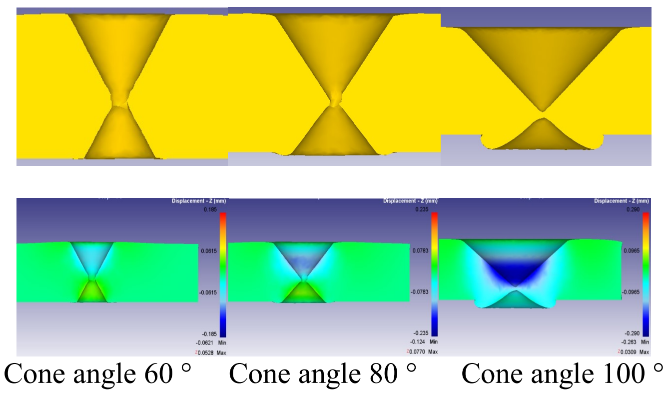
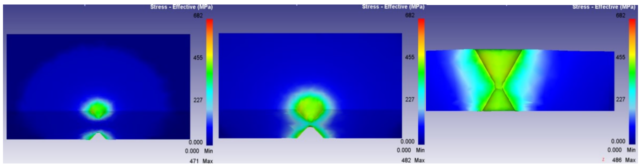


Figure 4. Effect of different cone angles on the quality of pore-forming of copper sheet

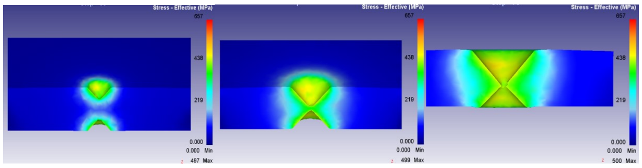
3.2. Equivalent stress distribution of copper under different cone angles

The influence of diamond indenter cone angle on necking hole forming is further analyzed from the angle of internal stress variation of copper sheet during the coining process. As shown in Figure 5, with the help of software post-processing analysis of copper equivalent stress distribution under different cone angle. The results show that the stress distribution of diamond conical indenter is mainly concentrated in the middle region of copper sheet and the stress increases with the increase of indenter displacement. At the same time, the larger the cone angle, the greater the stress on the hole formation location.



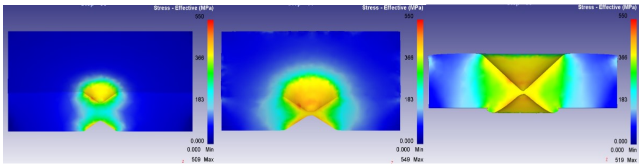
step 30 step 50 step 80

(a) Cone angle 60 °



step 30 step 50 step 80

(b) Cone angle 80 °

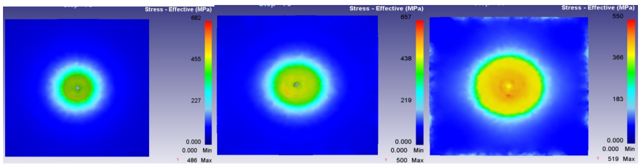


step 30 step 50 step 80

© Cone angle 100 °

Figure 5. Equivalent stress distribution of copper under different cone angles

Figure 6.shows the equivalent stress distribution of the copper surface under different cone angles. It can be seen that in the formation of the NFH, the surface of the copper sheet will form a stress ring extending from the center to the surrounding area; The bigger indenter cone angle is, the greater stress ring is.



Cone angle 60 ° Cone angle 80 ° Cone angle 100 °

Figure 6. Equivalent stress distribution of copper surface under different cone angle

3.3. Load - Stroke curve of indenter under different cone angles

The load and displacement of the indenter are analyzed in order to research for subsequent processing technology. Combination of indenter cone angle according to Table 1. Take group D as an example, 60 is the indenter cone angle of the upper side of copper sheet, and 80 is the indenter cone angle of the underside of copper sheet.

Figure 7 illustrates that different indenter cone angle load-stroke curve, it can be seen from the figure that under different cone angles, the displacement and load force of the indenter are different when the copper sheet is formed into a hole. The red mark on the curve in the figure indicates the moment of micropore forming. The D group copper sheet is first formed into a hole and the required load force for forming a hole is 98N and indenter displacement of 0.32mm; The pore-forming load force of the C group is the smallest, which is 84N, and the displacement of the indenter is 0.335 mm at this time. As the cone angle of the diamond indenter increases, the force required for forming a hole increases exponentially.

Table 1. Indenter cone angle combination

group	A	B	C	D	E	F	G
upper	60	80	100	60	80	60	80
lower	60	80	100	80	60	100	100

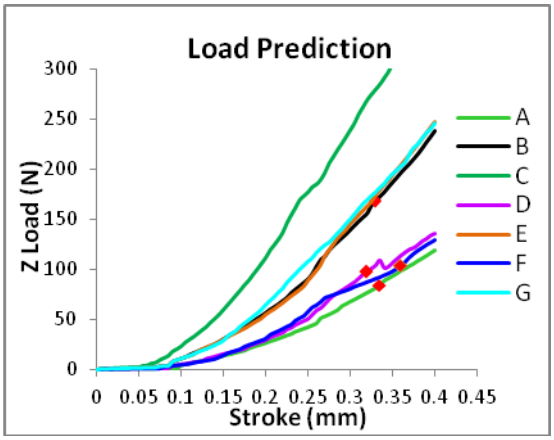


Figure 7. Load-Stroke curves of indenter under different cone angles

Through the analysis, when the underside indenter cone angle is greater than the upper side, the bottom of the copper sheet can provide enough support and obstruct the flow of material downward. It reduces the bulge of the bottom of the copper sheet, and the quality of the pore-forming is better. When the cone angle is small, the indenter stress is more concentrated, and it is easy to form holes at the tip of a conical hole. The upper and lower indenter cone angle is different, there is a sudden change in the axial force of the copper sheet when the hole is formed, which is used as a basis for monitoring micro-pore formed.

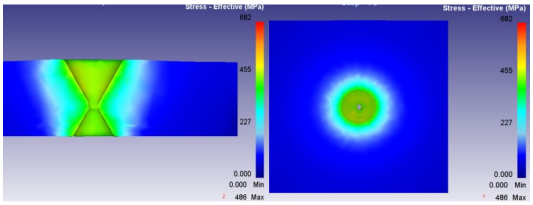
3.4. Analysis of micropore formation under different coining methods

In order to research the effect of different coining methods on the micropore formation of copper sheet, two plans were used to coining the copper sheets respectively.

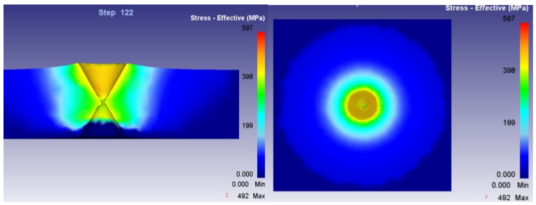
Plan 1: Both side indenter synchronization coining 0.25mm, and then the upper side indenters to continue coining to forming the hole;

Plan 2: Both side indenter is coining respectively. First, the underside indenters coining into 0.25mm, then the upper sides indenter coining the thickness of h to forming the hole.

Figure 8 shows the equivalent stress distribution of the copper forming process under different coining methods. Figure 9 shows the load-stroke curve of the indenter under different coining methods. As can be seen from the two figures, the press amount of indenter of the two plans is close. However, the load of plan 1 is lower than that of plan 2, and the quality of the copper surface is poor after forming the hole by plan 2. There is obvious uplift, and the stress ring formed is larger after pore-forming. Therefore, the experiment should be as far as possible the use of bilateral synchronous coining.



plan 1



plan 2

Figure 8. Equivalent stress distribution of the copper forming process under different coining methods.

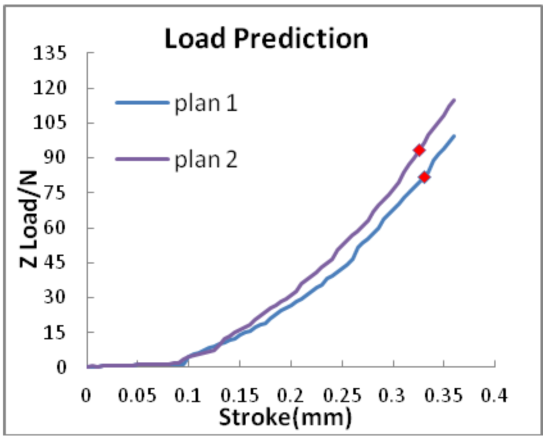


Figure 9. Load-stroke curve of the indenter under different coining methods.

4. Conclusion

The results show that uses of a small cone angle indenter are beneficial to the formation of NHF and good surface quality could be obtained; The upper and lower indenter cone angle is different, there is a sudden change in the axial force of the copper sheet when the hole is formed, which is used as a basis for monitoring micro-pore formed; It

Is more advantageous to use bilateral indenter synchronous coining to neck hole. The above research laid the foundation of process analysis for the follow-up work of diamond bidirectional NHF technology.

Acknowledgments

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