Analysis Effect of Clinching Die Parameters on Joint Strength

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***Abstract*—Numerical simulation of the thin sheets clinching process was carried out, the effect of die parameters on nick thickness, clinch lock and metal flow were studied. It was found that, with the increasing of punch radius R_p, the nick thickness T_n increases and the clinch lock T_u decreases. When the depth of die groove H_d increases, T_n decreases and T_u increases. The bottom thickness X is lied on the moving distance downward of punch, the flow will be shortened and insufficient lock occurs when X is too large, or bottom will be too thin when X is small. It is recommended that the suitable X is 25% of total sheet thickness.**

Keywords—Clinching; Die Parameters; Numerical simulation；DEFORM

I. INTRODUCTION

Clinching is a method of connecting sheets with each other through plastic deformation, which can be used for the connection between similar or dissimilar metal sheets of the same or different thicknesses. Compared with the traditional process such as spot welding and riveting, clinching has the advantages of high productivity, low cost, no special requirements for sheet metal surface, etc., and has been widely used in automobile manufacturing, home appliances and other fields.

The quality of clinching is affected by many factors such as sheet material characteristics, die geometry, friction and joint process state. Abe and Mori et al.[1-4] found that high-strength steel was prone to fracture and trip failure due to poor plasticity, when connecting high-strength steel and aluminum plates, and improved the material flow by optimizing the shape of the die. WIESENMAYER S et al.[5] studied the shear riveting process of dissimilar metals and successfully connected dissimilar sheets through simulation and experiments. Coppieters et al.[6-7] used the finite element method to predict the tensile and shear strength of the connection points. Lee et al.[8-9] conducted the connection between aluminum alloy and high-strength steel sheet, and derived analytical formulas for the neck fracture and upper sheet pull-out failure modes of the connection point under tensile load. Han et al.[10]studied the effect of bottom thickness on the strength of clinching flat bottom joints. Due to there are many factors affecting the quality of clinching connection, and the shape and structure of clinching die are also important factors affecting the joint forming, it is necessary to analyze the law of the effect of die parameters on the joint strength.

In this paper, the effect of different geometric parameters and different pressure on neck thickness, interlock value, forming force and metal flow of the joint point was analyzed by numerical simulation method, which can provide refe rence for the design of clinching die.

II. CALCULATION MODEL

A. *Characteristic parameters of clinching jiont*

Figure 1 shows the geometric parameters of connection points that are closely related to connection quality, including connection point diameter D, neck thickness T_n, interlock value T_u, and bottom thickness X.

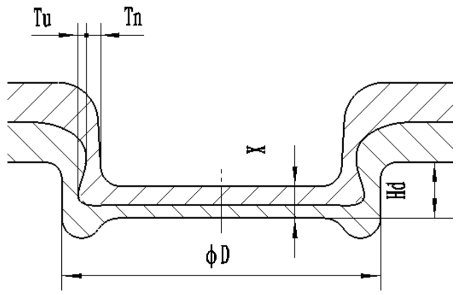


Fig. 1. Characteristic parameters of clinching jiont

B. *Geometric model*

This article takes 1mm thick Al6016 sheet as the research object for clingching connection, and establishes a model using finite element software DEFORM. Due to the axisymmetric structure of the model, only half of it needs to be analyzed, so a two-dimensional axisymmetric model is used in DEFORM-2D. Firstly, draw the model diagram in AutoCAD, and then import it into DEFORM-2D to establish a finite element model. The specific parameters of the die are shown in Figure 2.

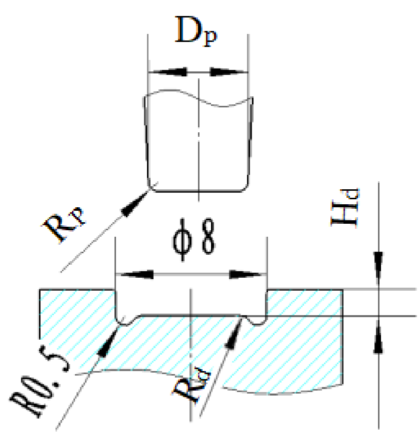


Fig. 2. Dimension of clinching die

The punch diameter D_p=5.4mm, punch radius R_p=0.5mm. And die diameter D_d=8mm, depth H_d=1.4mm, groove width 1mm, die transition radius R_d=0.5mm. The thickness of single sheet material is 1mm.

C. Material parameters

Clinching is a large plastic deformation process, and the plastic properties of the material have a significant impact on the simulation results. In order to accurately describe the plastic strain behavior of the material used in finite element simulation, unidirectional tensile tests were conducted on the Al6016 sheet used to obtain the basic mechanical parameters of the material (Table 1), which were then imported into the DEFORM material library.

Table1.Material parameters of Al6016

Material	Elastic modulus /GPa	Yield strength/MPa	Tensile strength/Mpa	Elongation/%
Al6016	12.6	198.1	210.2	11.0

D. Finite element model and other conditions

In the actual experiment, the magnitude of the blank holding force has a great impact on the quality of sheet metal connection. When the holding force is insufficient, the sheet material will warp and deform, resulting in loose fit and poor connection quality. When the holding force is too large, it is easy to crush the material, resulting in difficult material flow, so that the material in the connection point area is easy to break.So in finite element simulation, if a certain blank holder force is to be applied, it requires continuous trial and error adjustments, which is a large workload and difficult to determine the magnitude. Therefore, simplified models are often used, which set the blank holder to be fixed and at a speed of zero. After the forming is completed, the required blank holder force is determined by observing the reaction force exerted on the blank holder by the sheet metal.

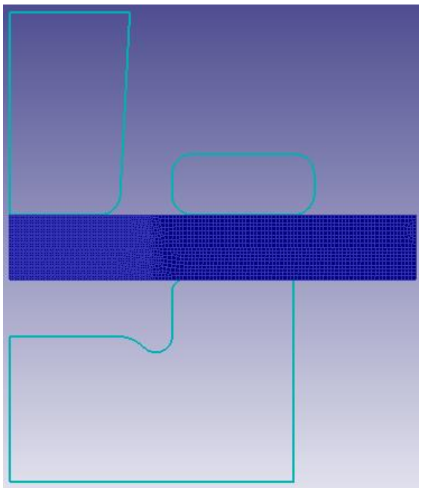


Fig. 3. Finite element model

Since only half of the section of the connection point is taken for simulation, in order to ensure that the element nodes on the upper and lower sheet symmetry planes do not move in the X direction during the simulation, it is necessary to apply boundary conditions to these element nodes, the velocity of a node satisfying X=0 in the X direction is defined as zero, that is, the symmetry plane is set as the non-material flow plane. Otherwise, the element nodes on the symmetry plane will cross the symmetry axis, and the upper and lower sheet mesh will penetrate each other, resulting in an error in calculation.

The finite element model is shown in Figure 3, using constant coefficient friction. The friction factor of the sheet material is set to 0.4, the friction factor between the sheet material and the die is set to 0.12, and the loading speed of the punch is set to 5mm/sec.

III. Analysis of Calculation Results

A. Effect of different punch parameters on connection points

1) Different punch shapes

Figure 4 shows several different profile shapes of the punch, A is the basic shape, the bottom line is horizontal, vertical profile and Y axis has a 3° inclination, and rounded corner transition. B and C are deformation forms on the basis of A, where the bottom line of B is inclined to the horizontal direction of 5° , and the rest is unchanged. There is an arc protruding at the bottom of C, and the other remains unchanged.

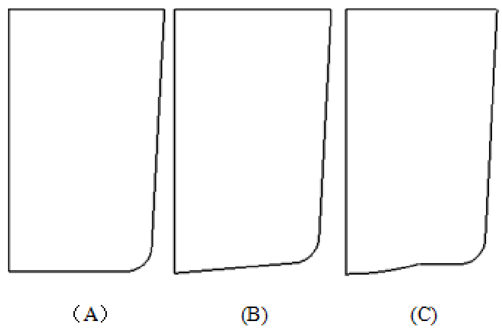


Fig. 4. Different punch shape models

Figure 5 shows the flow trend of sheet metal in the process of filling the groove. As the punch continues to press down, the material accelerates to flow to the groove, and the area below the rounded corner has the largest flow speed.Model B has a certain inclination angle at the bottom, so during the process of squeezing the material towards the groove, it will give a diagonal downward force to push the material to flow horizontally, which is more labor-saving than A simply squeezing the material downward to force it to flow horizontally, so the required forming force is smaller than A. The C model is similar to the B in that the arc protrusion at the bottom also drives the material to flow laterally.

Table 2 shows the neck thickness and interlock value of the connection point formed by the three punch models A, B and C. It can be found that the neck thickness of A is smaller than that of B and C, but the interlock value is larger. The reason is that the punch center of the B and C models is prominent than that of the A model, which first contacts the sheet during the forming process and pushes part of the material into the groove, so the thinning of the neck material is not as serious as that of A.

Table2. T_n and T_u of different punch shape

	A	B	C
Neck-thickness T_n/mm	0.411	0.428	0.420
Interlock T_u/mm	0.210	0.195	0.190

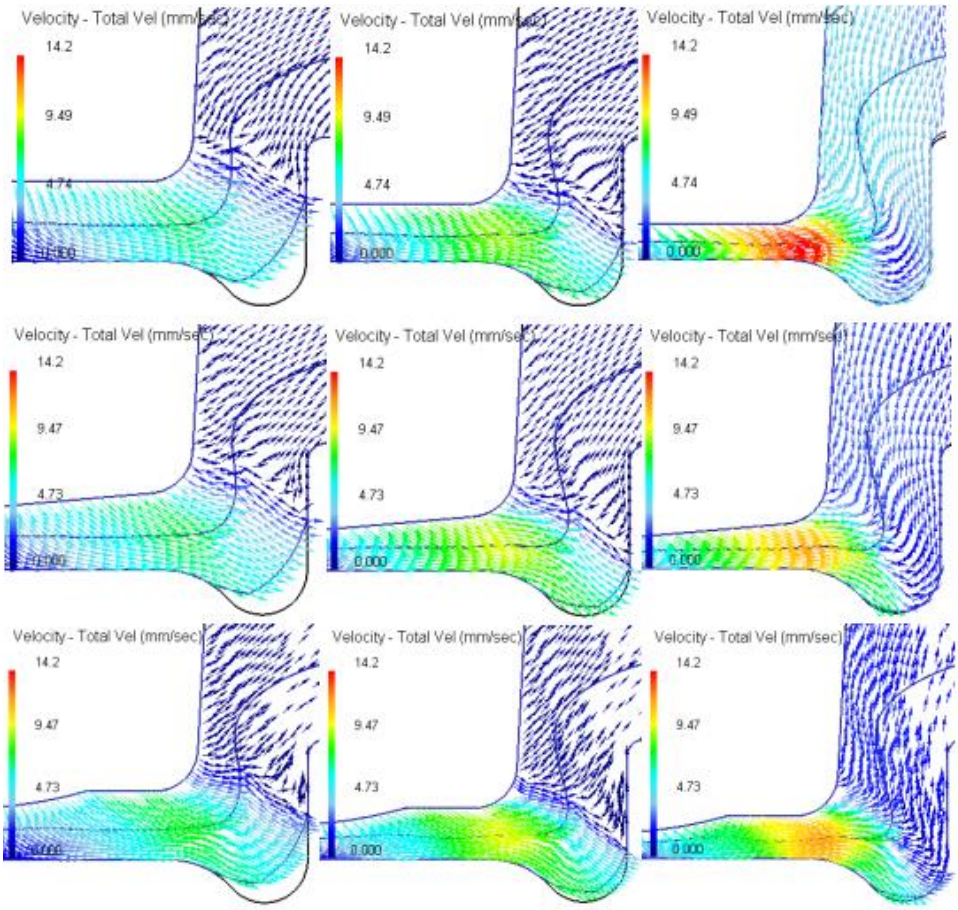


Fig. 5. Material flow trend under different punch shape

2) Punch radius

The punch radius has a certain impact on the neck thickness and interlock value. The radius is 0.3, 0.5, and 0.7mm from the outside to the inside, as shown in Figure 6. Other conditions remain unchanged, and the simulation results are as follows.

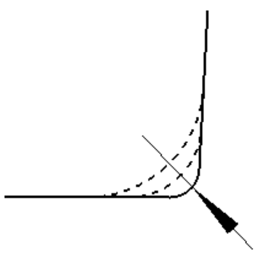
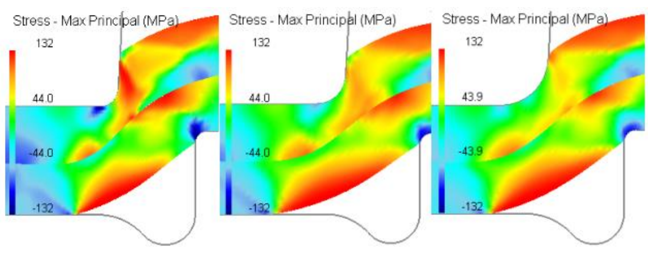


Fig. 6. Different punch radius

It can be seen from the maximum principal stress distribution diagram, as shown in Figure 7,when the lower sheet metal just contacts the concave die and the punch pushes the sheet metal towards the inner cavity of the concave die, the smaller the radius, the more concentrated the stress, and the more obvious the phenomenon of "punching". The upper sheet metal is stretched and thinned more severely, and the risk of neck shearing is greater.



(a) R=0.3mm (b)R=0.5mm (c)R=0.7mm

Fig. 7. Distribution of maximum principal stress of different punch radius

From the section shape of the final formed connection point, as the punch radius increases, the neck thickness T_n increases and the interlock value T_u decreases. The increase of neck thickness is due to the fact that when the punch has a large rounded corner, the stress concentration phenomenon near the rounded corner area is not so serious in the forming process, and the neck material will not be stretched and thinned significantly, so the neck thickness shows an increasing trend after final forming.In the groove filling stage, the smaller the punch radius, the more obvious the upsetting effect on the materials in the rounded corner area, and more materials will flow into the groove, so the interlock value is greater.

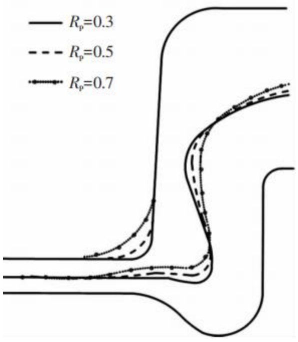


Fig.8 . The effect of punch radius on section shape

Therefore, the punch radius can neither be too large nor too small, as shown in figure 8, if the radius is too small, although the interlock value T_u is larger, but the neck thickness T_n is relatively smaller, the punching phenomenon may occur due to the neck material is too thin in the forming process of the joint point. If the radius is too large, although it ensures a larger neck thickness, but the interlock between the upper and lower sheets after final forming is very small, resulting in weak connection and easy detachment. So when determining the punch radius, it is necessary to find a balance point between the neck thickness and interlock value to achieve the best joint strength.

B. Effect of different concave die parameters on connection points

In order to further clarify the specific impact of each concave die parameters on the connection point, the following model is set up, as shown in figure 9. "a" decreases the width and depth of the groove, and the total volume decreases. "b" the width of groove remains the same, but the depth increases. and "c" increases the transition fillet at the bottom of the die.

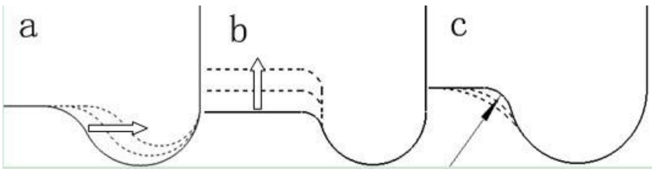


Fig.9 . Concave die models with different parameters

1) Reduction in groove width and depth

Figure 10 shows the distribution of hydrostatic stress at the connection point with a bottom thickness of X=0.6 mm. It can be observed that when the groove is too large, the material cannot fully fill the groove, and the hydrostatic pressure of the material at the groove is positive, subjected to tensile stress, and is prone to cracking. As the groove decreases, the hydrostatic pressure of the material at the groove becomes negative, resulting in compressive stress and a reduced probability of fracture.However, the smaller the groove, the more severe the phenomenon of material "backflow". The lower sheet of the smallest groove and the concave die have already shown significant warping, seriously affecting the appearance quality of the connection point. So the groove should not be too large or too small, otherwise it will affect the quality of the connection point.

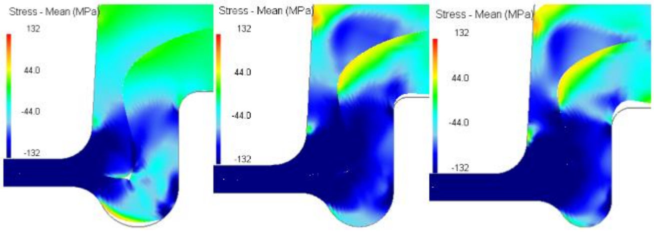


Fig.10 . Distribution of hydrostatic stress

2) The width of the groove remains the same, but the depth increases

Figure 11 shows the flow trend of the material at different groove depths. It can be seen that when the groove depth is too large, the material will not be able to effectively fill the groove, and the material at the groove will be subjected to significant tensile stress, making it prone to cracking. From the section shape of the joint point, when the depth of die groove H_d increases, T_n decreases and T_u increases.

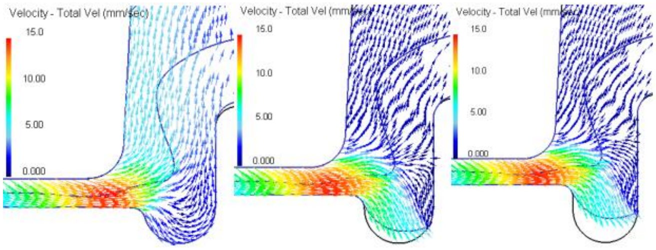


Fig.11 . Material flow trend under different groove depth

3) Transition radius of concave die

Figure 12 shows the material filling situation when the transition radius R_d of the concave die is 0, 0.5, and 1.0 mm, with other parameters unchanged. When the R_d is too small, it is difficult for the material to flow into the groove, and the groove is not easy to fill. With the increase of R_d, the flow resistance of the material to the groove decreases obviously, and the forming force decreases slightly. Overall, R_d has little effect on T_n and T_u (Figure 13).

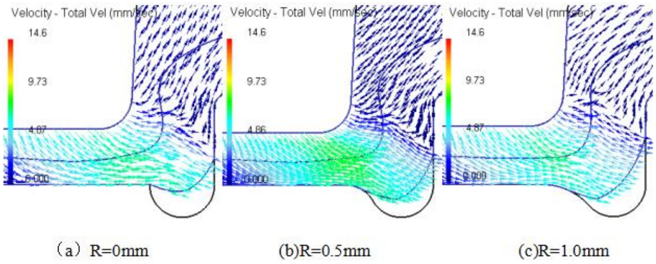


Fig.12 .Material flow trend under different die radius

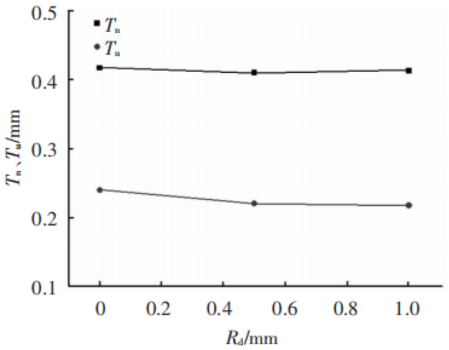


Fig.13 .Change trend of T_n&T_u under different die radius

C. Effect of different downforce on connection points

In addition to the significant impact of different punch and concave die parameters on the connection point forming process, the bottom thickness value X is also an important index affecting the strength of the connection point, and the bottom thickness X is determined by the moving distance downward of punch. If the bottom thickness X is too large, the bottom material may not flow properly, and the material may not be fully upset and squeezed into the groove, forming effective interlock, resulting in ineffective connection. If X is too small, the bottom is too thin, and the joint may be worn out or corroded. Moreover, due to the insufficient support of the material for the connection point, the tensile strength decreases and the sheet material separates. From Figure 14, it can be seen that as the bottom thickness X decreases, the material flow speed between the punch and die shows a significant acceleration trend. The material accelerates to flow into the groove, squeezing the upper sheet into the lower sheet, forming an interlock.

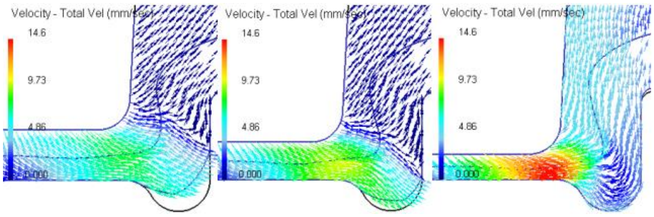


Fig.14 .Instantaneous material flow trend with different bottom thickness X

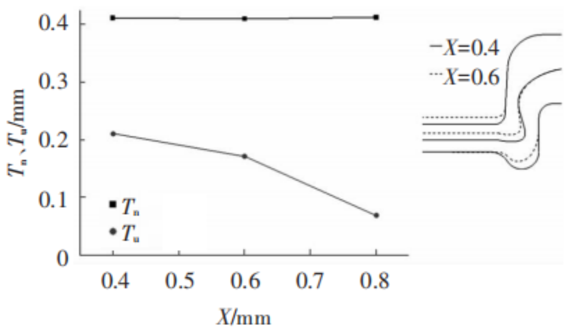


Fig.15 .The effect of different X on section shape and T_n&T_u

When the bottom thickness value X decreases, the neck thickness T_n remains basically unchanged, but the interlock value T_u increases. As shown in Figure 15, the "S" curve between sheets at X=0.6 is smoother than that at X=0.4, and the neck thickness is basically the same, but the interlock value is significantly smaller than the latter. The smaller the X, the greater the forming force required, and it is generally recommended that X take 25% of the total sheet thickness.

IV. CONCLUSION

The main conclusions are as follows:

(1) The strength of clinching joint depends on the geometric parameters such as joint diameter D, neck thickness T_n and interlock value T_u, which are affected by die and process parameters such as punch, concave die and bottom thickness X. Numerical simulation can provide effective guidance for connection process and die design and joint strength prediction.

(2) Different punch shapes have an impact on material flow, and when there is an inclination or protrusion at the bottom, it is more advantageous for the material to flow radially. With the increase of the punch radius R_p, the neck thickness T_n of the joint increases and the interlock value T_u decreases. If the R_p is too small, punching may occur due to the thin neck material, and if it is too large, the interlock value may be small, which affects the joint strength.

(3) The groove shape, transition radius R_d, depth, and other factors of the concave die have a significant impact on the deformation process and joint strength. When the R_d is too small, it is difficult for the material to flow into the groove, and the groove is not easy to fill. With the increase of R_d, the flow resistance of the material to the groove decreases obviously, and the forming force decreases slightly. Overall, R_d has little effect on T_n and T_u. And the groove depth H_d increases, T_n decreases, and T_u increases.

(4) The bottom thickness X is determined by the moving distance downward of punch. If X is too large, the bottom material may not flow properly, affecting interlock; If X is too small, the bottom is too thin and the joint strength decreases. It is generally recommended that X take 25% of the total plate thickness.

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