Research on Improvement of Cold Extrusion Technology of Connecting Screw

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Abstract. In order to solve the flange and dent defects in the end face of the cold extrusion of the connecting screw, the Deform3D software is used to simulate the extrusion forming process of the connecting screw, and the velocity vector is used to study the metal flow law of the part in the cold extrusion process. According to the velocity field and deformation law obtained by the simulation, the end face depression defect in the forming process is predicted. An improved production process is proposed, and the simulation results show that the new process scheme effectively eliminates the “sag” defect on the end face of the part. Finally, the extruded parts with qualified dimensional accuracy are obtained through experiments, and the results are basically consistent with the simulation results.

1. Introduction
Cold extrusion processing technology has many advantages such as good mechanical properties, high dimensional accuracy, good surface quality, simple production process, high material utilization, and low equipment investment. It is widely used in actual production [1]. Due to the large deformation resistance of the metal in cold extrusion production and the large stress on the mold, the life of the mold is generally short, and the requirements for the processing of the blank, the production process and the equipment are relatively high [2]. The connecting screw is a steel part, which plays an important role in the oil circuit of the automobile engine. When working under the action of high pressure oil, its mechanical properties are required to be high. The cold extrusion process of steel parts and the design of the die directly affect the forming quality of the parts. When formulating the cold extrusion process plan, numerical simulation software is often used to study the law of metal flow, predict the causes of defects, and improve the production process or mold [3] [4]. In this paper, by numerically simulating the original production process plan of cold extrusion, analyzing the velocity field and deformation law of metal flow, analyzing the causes of defects, and then improving the production process plan. The simulation results show that the improved scheme effectively solves the defects in the original process. According to the improvement plan, the mold was redesigned and experiments were carried out.

2. Analysis of Original Process Plan of Parts

2.1. Analysis of Process Characteristics
The part drawing of the connecting screw is shown in Figure 1. This part is a stepped shaft part with an inner hole, there are two steps, and the head is a regular hexagon. Analyze the characteristics of the cold extrusion process of parts: ①The diameter d of the small end of the part is close to half of the diameter D of the head, which is most suitable for forward extrusion processing [5]; ②The material
of the part is cold heading 10 steel, which exists severe work hardening, large deformation resistance, and high molding requirements. ③ The section shrinkage rate of the parts is 84%, and the high section shrinkage rate increases the difficulty of the material flow.

2.2. Original Process Plan and Defects

In order to reduce the forming stress, the original process plan is divided into two extrusions. The production process is shown in Figure 2(a). In the first step, the two steps of the connecting screw are formed; in the second step, the regular hexagon head is formed. The external thread and the internal hole are formed by machining. Although this process scheme effectively reduces the forming stress, it can produce parts that meet the requirements. However, when forming the regular hexagonal part, a flange with a thickness of 1.5mm is formed on the regular hexagon, as shown in Figure 2(b), the flange is concave and has an inner hexagonal shape.

![Figure 1. Parts of valve-bolt](image)

![Figure 2. Original forming process and parts of valve-bolt](image)
2.3. Finite Element Simulation of the Original Scheme

2.3.1 Establishment of the model
It adopts a solid cylindrical blank with a diameter \( D = 30 \text{mm} \). After modeling with UG, the volume of the part is calculated as, and the thickness of the blank is calculated according to the principle of constant volume:

\[
H = V_1 \left( \pi R^2 \right)^{-1}
\]

(1)

Where \( H \) is the thickness of the blank, \( V_1 \) is the volume of the workpiece, and \( R \) is the radius of the blank. The thickness of the blank is calculated as \( H = 17.8 \text{mm} \).

The connecting screw blank and mold have an axisymmetric structure. In order to reduce the amount of simulation calculations and improve efficiency, take 1/6 of it for modeling. And save it as stp format and import Deform2D/3D for meshing and numerical simulation. In the simulation process, it is assumed that the mold material is a rigid body, and the rigid viscoplastic finite element method is adopted, and the elastic deformation of the material is ignored. The simulation material is AISI1010, the minimum mesh size is 0.512, and the number of meshes is 36000. When the side length of the mesh exceeds 1.6 after deformation, it will be re-divided. The displacement of each step is set to about 1/3 of the minimum grid size, which is taken as 0.2mm. The simulation temperature is 20\(^\circ\)C, the punch is the main moving mold, the speed is 5mm/s, the friction coefficient is 0.12, and the numerical simulation is carried out.

2.3.2 Metal flow and analysis during forming
Figure 3 is the metal flow vector diagram at 4 key moments in the simulation process of the hexagonal depression forming. In order to facilitate the observation of the metal flow, a 30% node velocity vector is selected here. Figure 3(a) shows the downward movement of the punch. When the punch just touches the blank, the speed vector of the blank. At this time, the blank has not undergone a lot of deformation, and the metal only flows near the contact point. Figure 3(b) shows that the punch continues to squeeze the billet downward. The metal near the die mouth forms a plastic zone under the action of three-way compressive stress, and the extrusion force causes the metal in the plastic zone to flow out to the die mouth [6]. At this time, the metal flow velocity at the die mouth is the largest, and the metal in the remaining area moves downward at a relatively small velocity, and the metal velocity at the contact part with the bottom of the die is only 0.25mm/s. At the same time, the "sag" phenomenon began to appear at the back end of the blank [7] [8]. Figure 3(c) shows that the metal flow rate is 3.67mm/s when forming a hexagonal edge, which is higher than the metal flow rate when forming a right-angle edge, and the metal flows unevenly in adjacent areas. Therefore, the "recess" is hexagonal on the rear end surface. During the extrusion process, the metal in the extruded part moves downwards uniformly at a relatively large speed, and the "concavity" formed in the previous stage is further enlarged to form the final extruded part. As shown in Figure 3(d), at the end of the hexagonal forming, the metal velocity at the part contacting the bottom of the die is 0.00861mm/s. A metal "dead zone" is formed at the step of the transition from the cylinder to the hexagon, which prevents the material from continuing downward. Flow, and finally formed a flange with a thickness of 1.5mm with a recess in the middle.
The simulation in Figure 3 shows that the billet is continuously deformed during extrusion, and the movement of various internal particles affects each other, and the influence between adjacent particles is greater. The flow of the entire metal material is the manifestation of the microscopic motion of the particles. At the same time, the flow state of the metal is determined by the stress state. Therefore, the change in the shape and size of the extruded part caused by the change of the metal flow direction is essentially that the friction force and the die step change the stress field of the extruded part, and the stress field The change is the internal cause of changing the external dimensions of the extruded part. During the extrusion process, the material at the die is in a plastic state, and the flow direction of each particle is parallel to the direction of the increase of the principal stress. When passing through the die sizing belt, the flow space of the metal decreases and the direction of the flow velocity changes. The friction force and steps between the extruded metal and the side wall hinder the flow speed of the metal, while the metal in the center area has no frictional resistance and step influence. Because of this, the flow speed remains unchanged, and finally a hexagonal "sag" on the end face is formed. At the same time, when the metal extrusion thickness on the steps is close to the metal "dead zone" thickness, the extrusion force rises faster, which is likely to cause overload.

3. Process Improvement and Simulation Results

3.1 Process Improvement
According to the above simulation analysis of the metal flow law, it is found that controlling the flow rate of the metal can effectively improve the quality of the back end. The plastic deformation volume of the continuum remains unchanged, the greater the reduction of area, the greater the flow velocity difference between the center and the outer edge of the metal in the late extrusion stage, and the more obvious the depression of the rear end surface. Therefore, two extrusions are considered when designing the process flow to reduce the deformation of a single extrusion. The blank is a bar material with a design diameter of Φ26mm. According to the principle of constant volume, the length of the blank is 24mm from equation (1). The calculation formula of the reduction of area from the forward extrusion [9]:

$$\zeta = (F_0 - F_1)F_0^{-1}$$  \hspace{1cm} (2)

Among them, F0 is the cross-sectional area of the blank, and F1 is the minimum cross-sectional area of the deformed part.
The improved process flow is shown in Figure 4. The first step is upsetting and squeezing the hexagon, and the second step is squeezing the last step.

Figure 4. Improved forming process

The original plan section shrinkage rate $\xi_0=78.2\%$; the improved plan preformed hexagonal end face shrinkage rate $\xi_1=28.4\%$, secondary forming section shrinkage rate $\xi_2=59.5\%$. The maximum reduction of area of the improved scheme is greatly reduced, which can effectively reduce the forming stress. The flange is produced at the step when the hexagon is extruded, and the hexagonal "concavity" on the flange is formed by the uneven flow of the hexagon and the right-angle side metal when the hexagon is extruded. It can be squeezed into a hexagonal part. In order to eliminate the influence of metal flow rate during forward extrusion.

3.2 Simulation Results
Figure 5 is a diagram of the metal flow law of the improved blank. The simulation conditions are exactly the same as those of the original plan. Figure 5(a) is the metal flow velocity diagram of the pre-formed hexagonal stage. The blank flows downward when subjected to squeezing force, and at the same time it flows laterally, that is, it is upset to form a hexagon. Figure 5(b) shows that after the hexagon is formed, the metal material continues to flow downwards. Compared with the original solution, there is no difference in flow velocity between the hexagon and the straight side of the material, so there is no hexagonal "sag" at the back end. As the steps from the cylinder to the hexagonal transition were cancelled, no flanges appeared until the end of the pre-forming simulation. Figure 5(c) is the flow velocity of the metal when the secondary forming blank is in contact with the bottom of the mold, and the plastic body moves toward the front end of the die, forming a denser velocity vector area. Figure 5(d) is the velocity vector when the simulation enters the stable stage. At this time, the metal flow inside the billet is uniform. Compared with the original solution, there is no flow velocity difference in the hexagonal part of the rear end. Therefore, by the end of the extrusion, the end face of the extruded part does not appear depression.

Figure 5. Node velocity vector of option in improved process
4. Process Verification
The extrusion die is mainly improved in two points: one is that the working part of the pre-formed and secondary-formed punch is designed to be hexagonal; the other is that the pre-formed die is designed to directly form a hexagon, eliminating the transitional step, as shown in Figure 6. Shown. According to the improved process plan, the experiment was carried out on a 315t hydraulic press. Phosphating-saponification treatment on the surface of the blank, using molybdenum disulfide as a lubricant. The formed test piece is shown in Figure 7. In the experiment, the parts were formed smoothly, and there was no flange and "sag" phenomenon. Although the size of the blank was reduced, the size of the extruded part was acceptable. Experiments prove that the extrusion scheme is feasible.

![Figure 6. Extruding die scheme of oil valve-bolt](image)

![Figure 7. Vale-bolt obtained from experiment](image)

5. Conclusion
(1) Through the analysis of the metal flow law of the original plan, it is shown that the "sag" defect is caused by the uneven flow of the metal at the hexagon and straight edges when the hexagon is formed by the forward extrusion. The flange is the metal "dead zone" at the step. Caused by poor material flow.
(2) Improved the production process, determined the pre-formed hexagonal and secondary forming process plan, eliminated the flange and "sag" defects on the rear face of the formed part, and improved the utilization rate of the material.

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