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Simulation and Analysis of One-time Forming Process of Automobile Steering Ball Head

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Abstract. Aiming at the problems such as large machining allowance, low production efficiency and material waste during die forging of ball pin, the cold extrusion process of ball head was studied and the analog simulation of the forming process was carried out by using the finite element analysis software DEFORM-3D. Through the analysis of the equivalent stress strain, velocity vector field and load-displacement curve, the flow regularity of the metal during the cold extrusion process of ball pin was clarified, and possible defects during the molding were predicted. The results showed that this process could solve the forming problem of ball pin and provide theoretical basis for actual production of enterprises.

1. Introduction

Ball pin is an important part of the automobile steering system, its strength and reliability directly concerns steering sensitivity, driving safety of the automobile. Therefore, a wear-resisting ball surface and a heart with certain strength and toughness are required to withstand impact load. Ball head parts processing & manufacturing by ordinary machinery features great difficult, low efficiency and serious material waste. Cold extrusion technology is a plastic forming technology with high production efficiency and material utilization rate. In the process of extrusion, the metal deformation part is subjected to three-way compressive stress, so grain structure of the material is more compact and surface quality of the workpiece is fine[1]. Therefore, forming of ball pin parts by cold extrusion can not only save metal materials, achieve near-net forming, but also improve the ball pin size, surface accuracy and mechanical strength.

In this paper, analog simulation study of cold extrusion forming process of ball pin was made by finite element numerical simulation, the flow regularity of the metal during the cold extrusion process of ball pin was analyzed, and possible defects during the molding were predicted, to reduce industrial production cost of ball pin parts by cold extrusion, improve the product quality and provide theoretical basis for the actual production of enterprises[2-4].

2. Analysis of ball head forming process and die design

For large size ball head pin, the ball head and the ball arm sizes are greatly different. As shown in **Figure 1**, the ball head has a diameter of 38mm, the arm has a minimum diameter of 22mm. Made of material 40Cr, the ball pin belongs to long shaft type part. According to **Figure 1**, such part has an inverted cone structure in radial direction, so extrusion is difficult. To solve this problem, this paper adopted combined die structure molding. As shown in **Figure 2**, two pairs of combined dies are symmetrically arranged, with the bonding accuracy kept by the guide plate fixed on the jacket. The two pairs of female dies are machined with corresponding grooves so that sliding along the guide plate is possible. The two pairs of female dies are closed first before the extrusion forming to form a closed space, and then male die continues to go downward for extrusion forming. After the extrusion forming is completed, the push rod pushes the extrusion part and the combined die upward together, so that the combined die slides along the guide plate to achieve lateral die splitting. Then, remove the part to complete one working cycle[5-7]. As the ball pin parts are all rotary parts with axial symmetry, 1/4 ball pin is analyzed in this paper to render analytical calculation amount small.

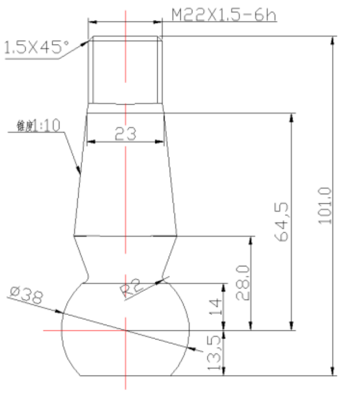


Figure 1. ball pin parts

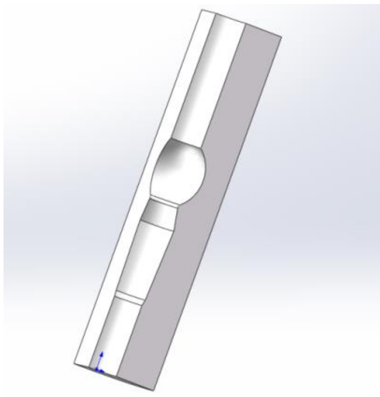


Figure 2. female die

3. Blank dimension calculation

The blank volume is calculated according to the size in the drawing of extrusion part in the principle that the blank volume is equal to the volume of the extrusion part. If machining is needed after cold extrusion, trimming allowance should be added when calculating the blank volume. Main considerations should be given to deformation degree, height-diameter ratio and diameter and length of the thread part during calculation. The larger the blank diameter is, the more stable the extrusion deformation in the die cavity is, and the less difficult it is in ball head forming, but formation of the inverted cone part will be affected. According to experience and calculation, the diameter of 22 mm at the journal is chosen as the reference size of the outer diameter of the blank. The blank length is calculated according to the principle of volume invariance. Finally, the calculated blank length is 165mm.

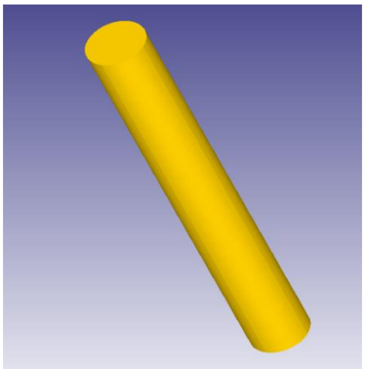


Figure 3. blank

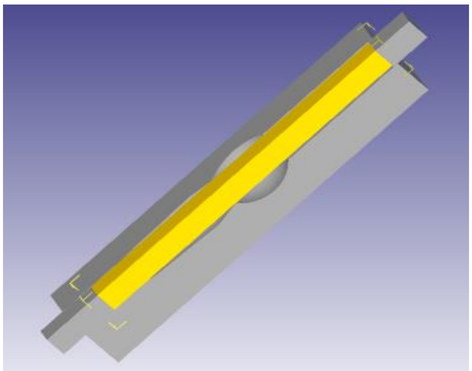


Figure 4. extrusion forming chart

4. Blank pre-treatment

According to the cold extrusion process analysis, softening process, surface and lubrication treatment is a must for blank materials before cold extrusion forming.

4.1. Softening of blank material

Alloy structural steel 40Cr features high hardness, big deformation resistance and poor plasticity in the supply status. It will be difficult if direct cold extrusion forming is performed without softening annealing, not only making forming parts fail to meet the requirements, but also possibly damaging the die. Therefore, spheroidizing annealing is a must before cold extrusion process to improve the plasticity, reduce the hardness and deformation force[8-9]. That is, first heat up to 800°C, keep for 12 hours, and then cool with the furnace to below 500°Cat a speed of 150°C/ h, followed by air cooling to obtain granule microstructures for improved plasticity and reduced hardness. After the softening treatment, 40Cr alloy steel blank hardness is 179HB, tensile strength can be reduced from above 980MPa to below 590MPa to facilitate metal flow forming in the extrusion forming.

4.2. Surface treatment and lubrication

Surface treatment is a key process in the cold extrusion process, which has a significant effect on the surface quality and die life of the extrusion part. Cold extruding steel surface is subjected to phosphating saponification treatment to reduce the metal flow and die friction in the molding process, cut down the extrusion force and improve die life.

5. Simulation of Cold Extrusion Forming Process

5.1 Establishment of finite element model

Build the model graph of ball head forming female die(**Figure 2**) and ball pin blank(**Figure 3**) in the three-dimensional software Solidworks, to be respectively saved and then separately saved as .stl format file.

Open the finite element analysis software Deform-3D, import the blank (.stl format file) for analysis. Set the blank parameters, with elastic modulus of hardening and tempering 40Cr at 2.05 × 105MPa, Poisson's ratio at 0.29, and density at 7.85 g/cm^3. The grid is divided into 24887 smaller grids as shown in **Fig.5**

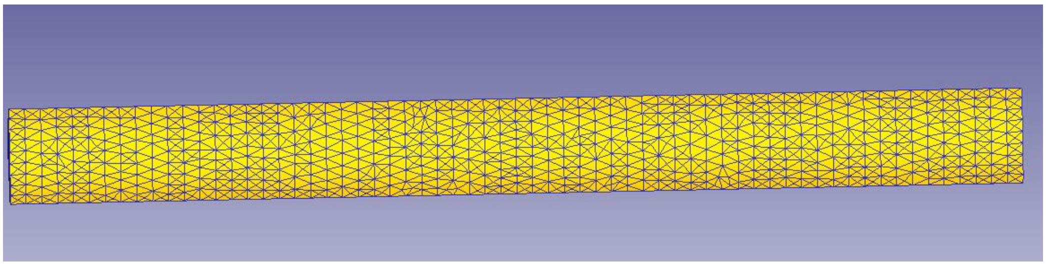


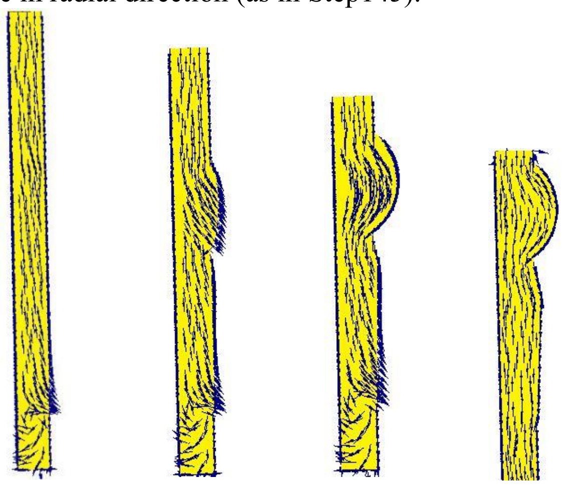
Figure 5. grid partition diagram

Import the die (See **Figure 4**), check the geometry of the die, set its parameters and adjust its position. Then, add the contact relation between movement blank and die, with friction coefficient set at 0.2 and temperature set at 20℃. Then, set the die movement direction as -y, set the movement speed of top die at 1 mm/sec, the distance between the top and lower die at 173mm, set the total number of steps at 145 steps to be saved once every 5 steps, and set the die increment at 0.5mm/sec. Check and generate DB files, run DB files, and wait for computer analog simulation results[10].

5.2 Simulation of ball pin extrusion process and result analysis

During the analog simulation, velocity field, equivalent stress strain, load -stroke relationship is analyzed as follows[11-14]:

5.2.1Analysis of velocity vector field. As shown in **Fig.6**, the left and right female dies are closed first, and then male die goes downward after the start of ball pin extrusion forming. Under the compression of male die, the blank moves downward, generating downward initial velocity field. In the beginning, the metal bottom has the fastest flowing speed. As the blank diameter is equal to the journal width, position with fast speed from the start to Step 15 first contacts with the female die. At this moment, there is still a short distance between the blank and the bottom of the female die. The upper metal makes rigid downward shift, while the bottom metal forms chamfering shape. At Step70, the blank thoroughly contacts with the bottom of the female die, with the blank entering upsetting stage. Metal at the journal has significantly faster flowing speed at this time, which is because the metal flow is always in the direction with the minimum resistance. Ultimately, the female die is filled at Step130. Then, the male die continues downward movement, the metal flows uniformly in the enclosed space, forming inverted cone shape in radial direction (as in Step145).



Step15 Step70 Step130 Step145

Figure 6. diagram of velocity vector field

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At different stages of metal forming, the velocity field shows that the metal deformation process is smooth, the surface has no folding, breakage defects, and metal flow stops after the completion of forming, which is conducive to the part stability and die life.

5.2.2Equivalent stress and strain analysis. The stress diagram of the cold extrusion forming is shown in **Fig.7**.It can be seen from the fig.7 that the maximum equivalent stress of the extrusion forming occurs where the outer edge of the ball head and inverted cone is about to be filled. As the male die moves downward, the blank fills the entire female die, with the stress shifted to the male die inlet, journal rounded corner and the bottom chamfer. The outer edge and inverted cone of the ball head is subjected to great deformation, large stress, thus prone to wear, cracking. According to the forming deformation, the stress and strain trajectories of extrusion are studied by 9 points of P1~P9. As can be seen from the graph in **Fig.7**, point P3 is the maximum stress point, with value at 910Mpa; followed by points P4, P7, P6, which indicates that outer edge and inverted cone of the ball head withstands larger stress during forming; Point P4 rises sharply in the end, indicating that the final forming part is the outer edge of the ball head.

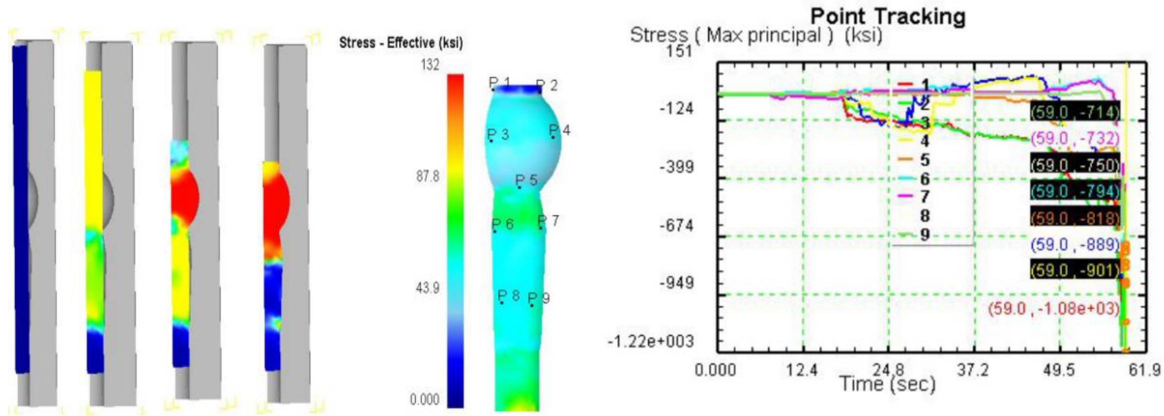


Figure 7. Stress diagram of extrusion forming

In the strain diagram of extrusion forming as shown in **Fig.8**, when the extrusion starts, the bottom chamfer tends to be zero, and the strain is layered distributed from the outer edge to the center of the ball head during upset-extruding. The maximum strain appears at the finally extruded inverted cone, which is because the flow direction of metal above the journal is against the inverted cone should be formed, then the maximum equivalent strain with value at 2.01 generates in between. The maximum strain at the time of final forming occurs at the journal turning, which is because metal of the formed ball head needs further downward flow to form the cone structure, and then the metal at the heart of the journal withstands excessive tensile stress and additional stress. According to the forming deformation, the stress and strain trajectories of extrusion feature points are studied by 9 points of P1~P9. It can be seen from the graph that, point P3 withstands the largest strain, which is because the core is subjected to axial compressive stress and radial additional tensile stress; the next is point P5 which is the last point with largest strain. This is because the formed ball head forces the metal to further flow downward to form a cone structure; point P4 rises sharply in the final forming, indicating that the ball head is the final part to complete forming. Points P6, P7, P8, P9 withstand relatively gentle strain with small deformation, indicating normal flow of metal.

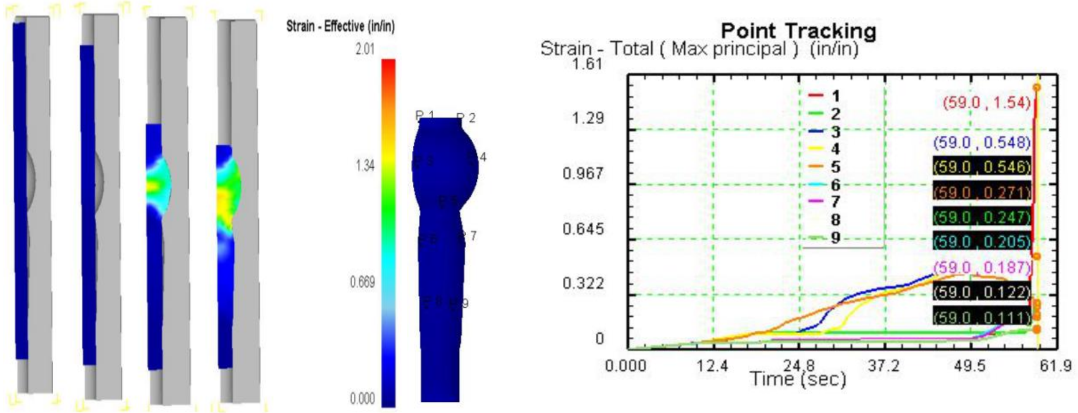
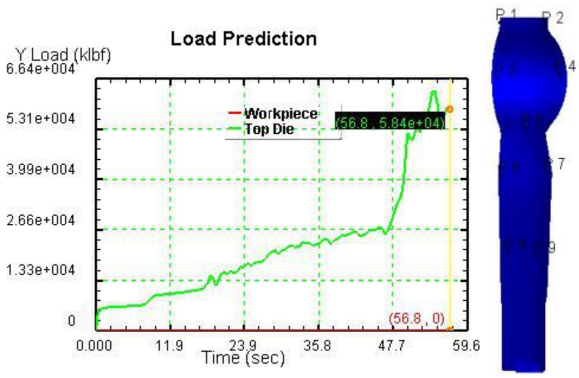


Figure 8. Strain diagram of extrusion forming

As shown in **Figure 9**, the load-displacement diagram demonstrates that the load is stable throughout the forming process, there is no obvious fluctuation and the load is also small, which is very beneficial to improvement of the die life. The load rises sharply after forming is basically completed in later stage of forming, which, however, does not exceed the bearing load of the die.

As shown in **Fig.10**, the wear coefficient diagram indicates that the wear coefficient is increasing as a whole, and as the extrusion process progresses, workpiece wear increases due to uneven deformation of the workpiece, residual stress and growing metal lattice distortion. It can be seen from the **fig.10** that point P3 has the largest wear coefficient, followed by points P4, P5, indicating that these parts are prone to destruction for ball pin.



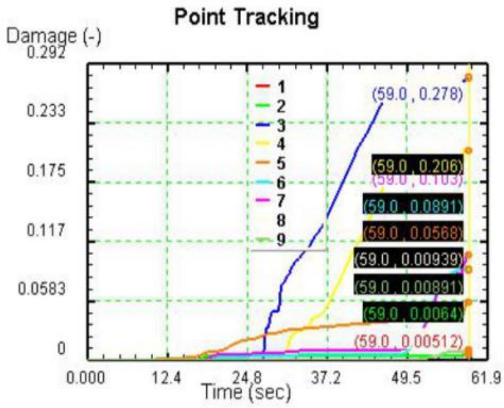


Figure 9. Load – Displacement diagram **Figure 10.** Wear coefficient diagram

Comprehensive analysis of the above concludes that the ball head axis withstands the maximum stress in the forming process, while the inverted cone withstands the maximum strain. The ball pin maintains stability in the extrusion process. The extrusion force has been in steady growth, and the load rises quickly before the process completion, which is in line with the law of rheology; however, the extrusion force remains within a reasonable range, not beyond the bearing load of die.

6.Conclusion

(1) The use of closed upset-extruding, one-time extrusion forming of combined die can better solve problems of large-scale ball pin in big machining allowance, low utilization of materials and low production efficiency.

(2) Through analysis of structure of the ball pin, a reasonable production process was selected. The analog simulation of the forming process was carried out by using the finite element analysis software Deform-3D to find out the flow regularity of the metal during the cold extrusion process of ball pin.
(3) The simulation can effectively shorten the product development cycle and reduce the cost. Providing some theoretical basis for the actual industrial production of ball pin, it has certain research and guiding significance.

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