Materials Research Proceedings 44 (2024) 589-596 https://doi.org/10.21741/9781644903254-63

# Eccentricity-resistant process design and finite element analysis of deep hole cylindrical parts

LI Shuo[1,a], ZHAI Yuewen[1,b]*, HE Xiaomao[1,c], QIN Sixiao[1,d] and JIN Hong[1,e]

[1]China Academy of Machinery Beijing Research Institute of Mechanical & Electrical Technology Co., Ltd., No.18 Xueqing Road, Haidian District, Beijing, P.R. China

[a]957729591@qq.com, [b]zhaiyuewen@163.com, [c]hexiaomaos@163.com, [d]sxgcxb_qsx@126.com, [e]jinhong2020@hotmail.com

**Keywords:** Deep Hole Cylindrical Parts, Double-Process Hot Extrusion, Extrusion Off-Center

**Abstract:** In this paper, finite element analysis software was used to simulate and compare the deep-hole cylindrical parts formed by single process hot extrusion and double-process hot extrusion under the condition of uneven initial circumferential temperature of billet. The results show that the deformation resistance of the material is affected by the uneven temperature, and the strength of the single process hot extrusion parts is weakened because of the long punch length, which is easy to cause the eccentricity problem of the deep-hole cylindrical parts, and the wall thickness difference of the deep-hole cylindrical parts reaches 1.23 mm. The double-process hot extrusion can greatly reduce the influence of eccentricity on the deep hole cylindrical parts, make the wall thickness distribution more uniform, and the wall thickness difference is 0.38 mm. At the same time, the double-process hot extrusion reduces the forming force by 900 T and improves the feasibility of the process.

## Introduction

Deep hole cylindrical components are widely used in fields such as automobile manufacturing, electronic communication, etc. Previously, the manufacturing of deep hole cylindrical components used forging processes, combined with cutting treatment, which could meet the needs of early small-scale experiments. However, this method produces large amounts of waste material and affects the mechanical properties of the product, making it unsuitable for mass production [1,2]. Although the use of casting processes reduces cutting and improves material utilization, the structure of the deep hole cylindrical components produced by casting is loose, and the products cannot meet design requirements [3,4].

Compared to forging and casting, the backward extrusion process can improve the organizational properties of materials during the forming process, refine grains, and enhance their strength and plasticity; it achieves high processing precision and improves material utilization [5,6]; it reduces production costs and is suitable for batch production [7]. However, when producing deep hole cylindrical components by backward extrusion, eccentricity problems can easily occur. Especially when the cylindrical component is longer, the more serious the eccentricity problem becomes, leading to reduced material utilization; cutting of machining metal flow lines; and the long-term biased load on the mold affecting its service life [8], thus deep hole cylindrical components require multi-process backward extrusion forming. Factors causing forging eccentricity during backward extrusion forming include uneven blank temperature, mold position eccentricity, and inaccurate blank positioning, etc. The mold position and blank positioning can be adjusted by improving machining and mold assembly precision, so most eccentricity problems with deep hole cylindrical components in actual production are due to uneven temperature. During the forming process, the blank does not receive continuous heating, and there is a temperature difference between the punch and the die, with the mold also working on the blank. There is heat transfer during contact with the blank, leading to uneven reduction and distribution of its own temperature, especially in the circumferential direction of the blank, where there is a significant temperature distribution difference. This results in different metal deformation resistance at different parts, with the metal on the higher temperature side having better fluidity and lower deformation resistance [9]. Furthermore, due to the long design of the punch, it is prone to deformation during the forming process due to uneven force, leaning towards the higher temperature side of the blank, thus causing eccentricity issues. This article proposes a dual-process thermal extrusion forming process for typical products, which can effectively suppress the generation of eccentricity problems during the manufacturing process of deep hole cylindrical components.

With the help of finite element analysis software, the effects of different parameters can be efficiently analyzed, reducing trial-and-error costs, optimizing process paths, and minimizing the impact of eccentricity problems of deep hole cylindrical components [10].

**Establishment of finite element model**

Introduction of typical deep hole cylindrical parts product. The typical product studied in this article, as shown in Fig.1, is an irregular-shaped deep cylindrical component with a bottom.

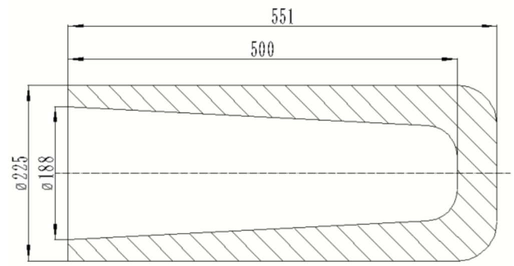


*Fig.1. Drawing of forgings with bottom barrel.*

Fig. 1 depicts a forging of a cylindrical component with a base. Its material is AISI-1045, with a maximum outer diameter of φ225 mm, a maximum inner diameter of φ188 mm, and a minimum wall thickness of 18.5 mm. The inner and outer shapes are similar, with the bottom being slightly thicker. It features an internal blind hole with a depth of 500 mm and a total length of the product is 551 mm.

Establishment of the geometric model. In the 3D software, the blank and the mold are modeled to generate 3D object format files. Entering the pre-processing module of the finite element analysis software, import the mold models for each process, and the blank, punch, and die form a complete model. The blank is set as a plastic body. Since the uneven temperature distribution of the blank will cause bending elastic deformation of the punch, the punch is set as an elastic body. The die is surrounded by a pre-tightening sleeve on the outside, with very little deformation, hence it is set as a rigid body.

Setting of simulation parameters. Select AISI-1045 for the blank material, and AISI-H13 for the punch and die materials. During finite element analysis, a non-uniform temperature field can be set to cause uneven deformation resistance in the blank during deformation. Different parts of the blank are set to different temperatures: the left side of the blank is 1000℃, the middle part is 1015 ℃, and the right side is 1030℃, as shown in Fig. 2. The temperature of the punch and die is set to 300℃, and the external environment is set to room temperature of 20℃.

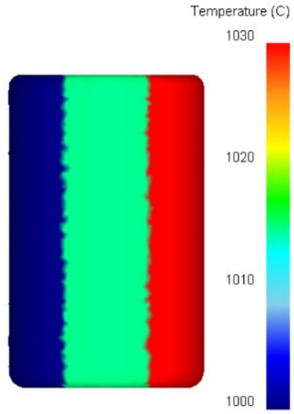


*Fig. 2. Temperature distribution of different parts of the blank.*

The change in the temperature of the blank during the backward extrusion process has a significant impact on the quality of the deep hole cylindrical components. It is necessary to define the heat exchange surface between the blank and the punch and die, and set an appropriate heat exchange coefficient. In actual production, there is also heat exchange during the transfer of the blank, so at the beginning of the simulation, the blank is not in contact with the mold for a period of time. The blank, being the main object of study, is divided into a dense grid. When dividing the grid for the punch and die, the grid needs to be refined at local details to better fit reality. When setting boundary conditions, the degrees of freedom in the actual motion direction are released, the movement speed of the blank is set to 0mm·s^-1, and the punch is set to a downward speed of 50 mm·s^-1. After setting up and checking for errors, the analysis is carried out using finite element software.

**Simulation results analysis**

Analysis of single-process thermal extrusion process. The overall forming effect of the forging is good, with the lowest temperature at the end of forging being 702℃ as shown in Fig. 3.

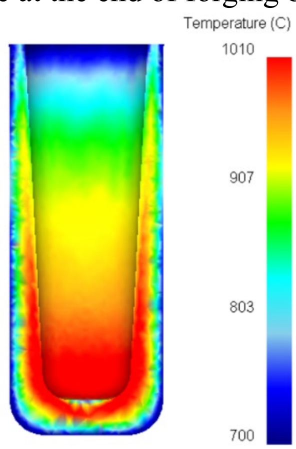


*Fig. 3. Final forging temperature distribution of single process hot extrusion.*

Using this scheme, the forging is at a reasonable extrusion temperature. The forming force, as shown in Fig. 4, peaks at 2570T. The forging forming force increases sharply after the end of the compound extrusion in the initial stage. The reason is that after the end of the compound extrusion, the lower end of the forging has been completely filled, the extrusion method changes from compound extrusion to backward extrusion, and the change in stress state leads to an increase in forming force. Moreover, the internal hole of the forging is a blind hole with a slope. As the extrusion continues, the projection area of the upper mold contact increases, with the projection area at the topmost end being the largest, thus requiring the greatest forming force. Therefore, it is

Materials Research Proceedings 44 (2024) 589-596 https://doi.org/10.21741/9781644903254-63

necessary to avoid using backward extrusion to form the upper end of the forging.

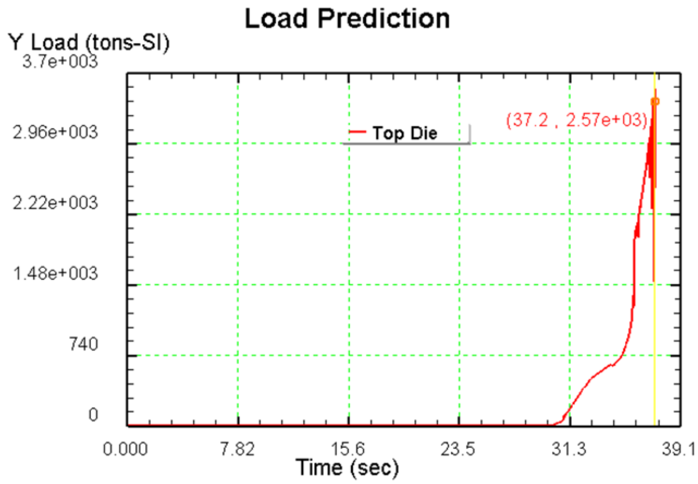


*Fig. 4. Single-process thermal extrusion forming force curve.*

The simulation results of the single-process thermal extrusion, as shown in Fig. 5, indicate that when there is a temperature difference of 30℃ on both sides of the blank, the wall thickness difference at 250 mm above the bottom surface is 1.23 mm.

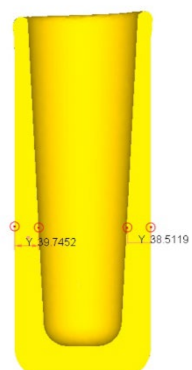


*Fig. 5. Wall thickness at the bottom surface starting height 250 mm of the single process hot extrusion forging.*

Analysis of double-process thermal extrusion process. In the single-process thermal extrusion, the forming force of the forging increases sharply after the initial compound extrusion ends, resulting in a high final forming force. This is because after the compound extrusion ends, the lower end of the forging is completely filled, and the extrusion method changes from compound extrusion to backward extrusion, causing the stress state to change and increase the forming force. In addition, the internal hole of the forging is a blind hole with a slope. As the extrusion continues, the projection area of contact of the upper mold becomes larger, with the largest projection area at the uppermost end, which requires the most significant forming force. Therefore, it is necessary to avoid using backward extrusion to form the upper end of the forging.

The double-process thermal extrusion scheme uses a first process compound extrusion to form the upper end of the forging, as shown in Fig. 6. By forming the upper end of the forging through a first process compound extrusion (the red box indicates the same part), the required forming force can be effectively reduced. Moreover, the punch needed for forming the upper end is thicker and shorter, which enhances rigidity. It can withstand the maximum forming force and also resist the biased load caused by temperature differences, lubrication, etc., effectively reducing the eccentricity of the forging. The second process uses a thinner punch to form a smaller inner hole.

Materials Research Proceedings 44 (2024) 589-596 https://doi.org/10.21741/9781644903254-63

The upper part extruded in the first process can guide the second process punch, ensuring the alignment of the punch and lateral support during the extrusion process.

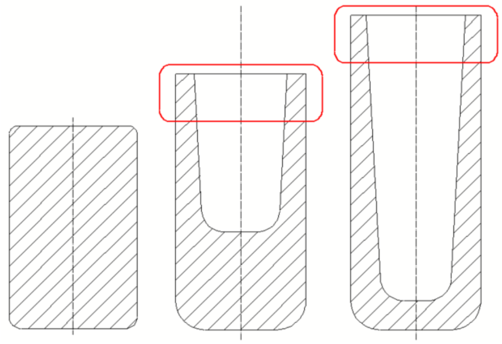

*Fig. 6. Double-process thermal extrusion process diagram Blank diagram (b) First process forging diagram (c) Second process forging diagram.*

The forging is well-formed, with no tendency for defects during the process, and the final forging temperature distribution is shown in Fig. 7.

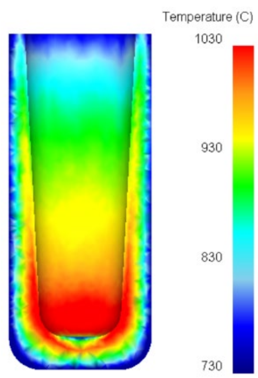


*Fig. 7. Double-process extrusion final forging temperature distribution map.*

The first 30 seconds of the simulation are for transfer time, with no extrusion force generated. The maximum forming force for the first extrusion is 1670T, and for the second extrusion, it is 1260T, with the maximum forming force for the double-process extrusion being 1670T. The double-process thermal extrusion forming force curve is shown in Fig. 8.

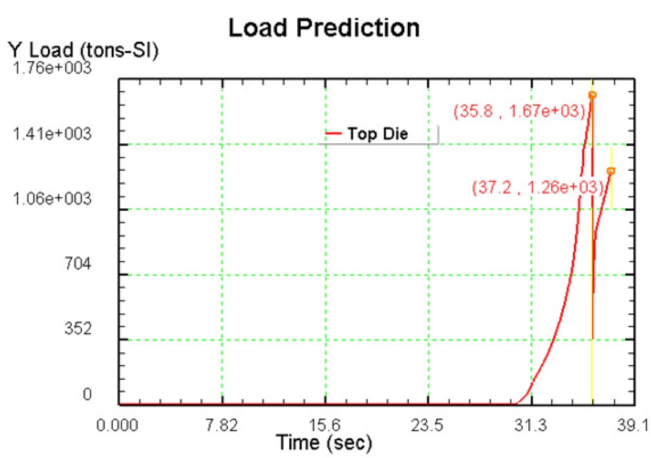


*Fig. 8. Double-process extrusion forming force curve.*

The overall forming effect of the forging is good, with reasonable metal flow and no tendency for defects. The lowest final forging temperature is 738℃, and the forging is at a reasonable extrusion temperature. The double-process scheme effectively reduces the extrusion forming force.

The double-process thermal extrusion scheme uses a first process compound extrusion to form the upper end of the forging, with a thicker and shorter punch needed for forming the upper end, increasing rigidity. It can withstand the maximum forming force while also resisting the biased load caused by temperature differences, lubrication, etc., effectively reducing the eccentricity of the forging. The second process uses a thinner punch to form a smaller inner hole. The upper part extruded in the first process can guide the second process punch, ensuring the punch's alignment and lateral support during the extrusion process.

The simulation results of the double-process thermal extrusion, as shown in Fig. 9, indicate that when there is a temperature difference of 30℃ on both sides of the blank, the wall thickness difference at 250 mm above the bottom surface is 0.38 mm.

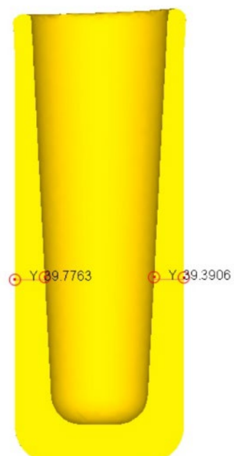


*Fig .9. Double-process thermal extrusion forging bottom surface raised 250mm wall thickness map.*

The double-process thermal extrusion process scheme can significantly reduce the eccentricity problem caused by the temperature difference in the blank compared to the single-process thermal extrusion scheme. Without considering other factors, when the temperature difference in the blank reaches 30℃, the double-process thermal extrusion can control the forging wall thickness difference within a very small range.

The temperature distribution of the forging in the process of extrusion is shown in Fig. 10.

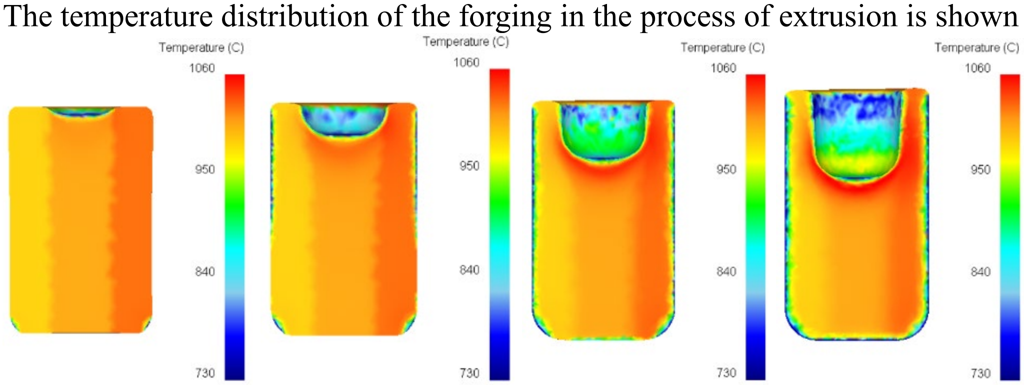


*Fig. 10. Temperature distribution of forgings in the middle step of the first process of double process hot extrusion.*

The temperature distribution of the forging in the second process of extrusion is shown in Fig. 11.

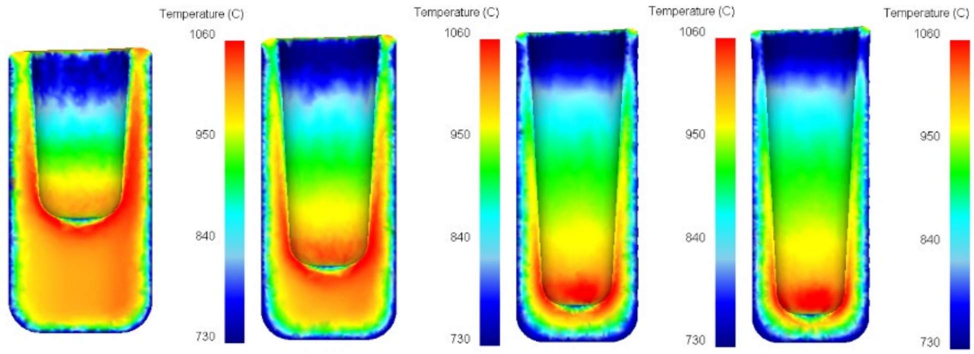


*Fig. 11. Temperature distribution diagram of the middle step of the second process of double process hot extrusion.*

During the first process of extrusion, there is a clear problem with the temperature distribution inside the blank, with the left side being cooler and the right side being hotter. During the second process of extrusion, due to the heat generated by the extrusion and the long period of heat exchange, the circumferential temperature distribution inside the forging is relatively uniform. During the first process, the side with the lower temperature has greater deformation resistance, and the punch at this time will be subjected to a force towards the right side, as shown in Fig. 12.

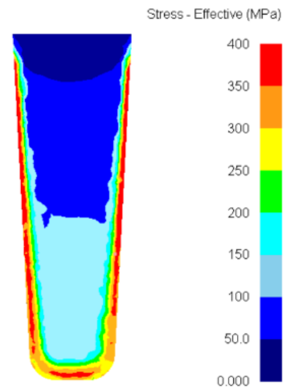


*Fig. 12. Double-process thermal extrusion first process punch equivalent stress map.*

In the stress field of the punch, it can be seen that the punch has a tendency to bend towards the right side due to the lateral force received, causing greater stress on the right side above. However, at this time the punch is shorter and has a larger diameter, which means its overall rigidity is strong, effectively preventing significant bending. In the second process of extrusion, since the temperature of the forging is more uniform, the punch receives less lateral force. Even if the punch is long and slender, it will not produce significant bending.

**Conclusion**

1) The uneven circumferential temperature change of the blank during the extrusion forming process is the main cause of eccentricity issues, affecting the wall thickness distribution of the formed parts. The double-process approach resolves the alignment problem with two differently designed punches and also improves the wall thickness distribution of the formed parts, increasing production efficiency.
2) The single-process thermal extrusion does not allocate the deformation volume reasonably, resulting in a large forming force. During the forming process, the uneven cooling of the blank's temperature and the long punch length, but insufficient strength, can easily cause eccentricity issues in the formed parts, affecting quality. The double-process extrusion scheme shows good forming effects with a smaller forming force, and the double-process setup can also reduce the eccentricity of the forging inner hole, improving forming quality.

## References

[1] C. Zhang, H.X Sun, J.X Zhang, Research on the molding process of deep hole cylindrical parts with bottom flanges, Hot Work. Tech. 51 (2022) 82-86. https://dx.doi.org/10.14158/j.cnki.1001-3814.20220080

[2] J.B Zhang, Y. Hao, K.W. Li, Influence of hot reverse extrusion punch structure on extrusion forming force of nitrogen spring cylinder, Forging Tech. 46 (2022) 109-115. https://dx.doi.org/10.13330/j.issn.1000-3940.2021.05.017

[3] X.H. Ye, Numerical simulation and experimental research on hot precision forging of press cylinder block, Anhui University of Technology, Maanshan, 2017. https://dx.doi.org/cdmd/j.cnki.2.1017.246907

[4] Y.H. Qiao, C. Song, Z.S. Wang, Casting process analysis of engine cylinder block, Hot Work. Tech. 43 (2014) 65-67. https://dx.doi.org/10.14158/j.cnki.1001-3814.2014.07.019

[5] L.L. Jia, S.Z. Zhang, Extrusion Process and Die, China Machine Press, Beijing, 2004.

[6] H.J. Choi, J.H. Choi, B.B. Hwang, The forming characteristics of radial–backward extrusion, J. Mater. Process. Tech. 113 (2001) 141-147. https://doi.org/10.1016/S0924-0136(01)00703-8

[7] S.J. Zhou, Study on precision isothermal forming process of typical structure of 7A04 aluminum alloy, Aerospace Manuf. Tech. 3 (2010) 34-37. https://dx.doi.org/sun htgy/j.cnki.0.2010-03-012

[8] F. Wang, C.W. Cui, F. Fang, Research on shrink forming process of 7A04 alloy cylinder, Hot Work. Tech. 40 (2011) 98-100. https://dx.doi.org/10.14158/j.cnki.1001-3814.2011.11.036

[9] C.C. Zhao, H.B. Hao, L.M. Hu, Influence of uneven billet temperature on quality of high-pressure gas cylinder back-extruding parts, Forg. Stamp. Tech. 44 (2019) 88-97. https://dx.doi.org/10.13330/j.issn.1000-3940.2019.06.013

[10] R.S. Sharma, V. Upadhyay, K.H. Raj, Neuro-fuzzy modeling of hot extrusion process, Indian J. Eng. Mater. Sci. 16 (2009) 86-92.