OPTIMAL DESIGN OF STAINLESS STEEL DRAWING DIE BY CYBER-PHYSICAL INTEGRATION

BY

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SYNOPSIS：

Computer Aided Engineering is used in virtual modeling, analysis, design, and optimization. This scientific method can effectively speed up the product development, avoid excessive trial and error, and thereby reducing research costs and achieving expected results. In this study, we build a cold drawing CAE model by DEFORM-3D, and using this model to analyze the deformation behavior of the UNS S17400 material between different mold design. By the simulation results, we found that the deformation distribution on the mold is the key to reduce the heat generation during the cold drawing process. The square drawing bar is chosen for the testing target. From the optimized design, the drawn bar temperature significantly drops down from 190 to 170C. The dropped value was up to 10%. The optimal design reduced the wear effectively and improved the life of the die.

Keywords：CAE, Drawing, Square bar, life of the die

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Introduction

During the producing process of the cold-drawing square or hexagonal bar, the uneven amount of deformation, and the partial large surface reduction rate often cause the surface to be scratched due to the failure of the cold-drawing oil. When the defects occur, it also causes damage to the die and reduces its service life. In the previous producing process, we faced a bottleneck in the UNS S17400 cold drawing square bar. Therefore, this paper expects to use the DEFORM-3D simulation software and try to define the physical quantities and limit values which cause the surface defects of the cold-drawing bar. Finally, we expected to break through the bottleneck of S17400 by designing the new geometric of the die.

Literature Review

Kim et al[1] found that the stress of the cold-drawing would increase with the friction coefficient and the surface reduction rate by the metal cold-drawing. It also found that if the taper of the die is too small, the contact area between the workspace and the die increase. It causes the friction increasing. If the trapper is too large, the shear deformation increase. All of the above would increase the stress of the cold drawing. Therefore, the trapper of the die has an optimal range. There was the smallest tensile stress of the cold drawing in this range. Avitzur[2] found that when the trapper entrance has the inappropriate design, it will make defects. When the trapper increases continuously, the scratches occur in process. Vega et al[3] compared the entrance taper of the die with different surface reduction rate by the failure criterion. It is found that the workspace will have defects in the center after the cold-drawing. Yuan-Chuan, Hsu[4] found that the load of the die, speed and temperature are the factors of affecting wear by the analysis of die wear in hot extrusion. The largest wear locates at the junction of the taper and the outlet of the extrusion die. The results of this study can be used as a reference for the geometric adjustment of the die. Ping-Hsun, Tsai[5] compared the conical die with the curved die in the research. It is found that no matter wear or the load of the die, the curved die is less. Che-Fu, Liu[6] analyzed the stress distribution and deformation to adjust the geometric of the design by asymmetric profiles. Avoid the defects which occur at the location where deformation is concentrated. Yi-Chi, Chen[7] said that the distribution of the cold-drawing oil on the extreme pressure and high temperature would affect the lubricating, cooling, cleaning and anti-corrosion significantly.

From the literature review, if the die and the area reduction rate are not matched properly, and the cold-drawing oil is in the high temperature and high pressure, the defect would occur in the cold-drawing process. It also said that the curved design can distribute the deformation resistance efficiently and increase the life of the die. It is an important factor to design the die.

Experimental

Cold-drawing is a method of metal forming process, which is forcing the bar to pass through the die to forming. For the cold-drawing square bar at present, we use the high area reduction rate in the first pass to achieve pre-forming, and the finished product size is achieved in the subsequent passes. The cold-drawing with high area reduction is efficient, but it also causes rapid wear of the die and easily causes scratches on the surface of the bar. This study is based on the S17400 square bar as the producing process and going for three steps. First step：collect the S17400 square bar production parameter. Second step：establish the cold drawing CAE model and adjust the parameter. Third step：design a new die. In order to make the cold drawing simulation meets the actual production, the measurement value of the actual production is used as the parameter adjustment benchmark of the CAE model. The model is used to design the die and modify the production parameter finally.

First step：collect the S17400 square bar production parameter. We compared S17400 and 300 series stainless steel mechanical properties as shown in Table(1). S17400 with high strength and poor toughness will let cold drawing more difficult than 300 series stainless steel.

Steel serious	UNS S17400	AISI 303	AISI 316	AISI 304
Tensile Strength(MPa)	1038	584	514	603
Yield Strength(MPa)	819	246	210	294
Elongation rate(%)	16	47	51	60
Reduction Area rate(%)	61	52	80	74

Table(1)：Mechanical properties of S17400 and 300 series stainless steel

Table(2) is the test results with different parameters of S17400 cold-drawing. The test results are using the dies before optimizing. The record table includes die specifications, cold drawing speed, cold drawing surface quality and the temperature of the bars when exiting the die.

Input bar size	Cold drawing size(mm)	Reduction angle(°)	Speed(mm/s)	Surface quality	Temperature(℃)
Round Bar 33mm	H28.54	16	11	No scratch	100
	H28.54	16	11	No scratch	110
	H28.54	16	37	Scratch	130
	H31.75	18	40	Scratch	77
	H30.42	18	40	Scratch	101
	H32.15	20	40	Scratch	78

Table(2)：Parameters and measurement results of UNS S17400 cold drawing hexagonal bars before optimize design

The performance curve of the cold-drawing oil is shown in Figure 1. From Figure 1, when the temperature of the cold-drawing oil higher, the viscosity is lower. So, the drapeability and compression resistance will decrease when the temperature increase.

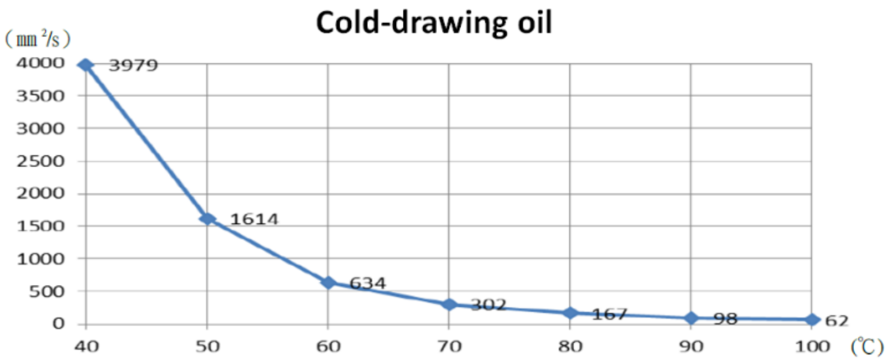
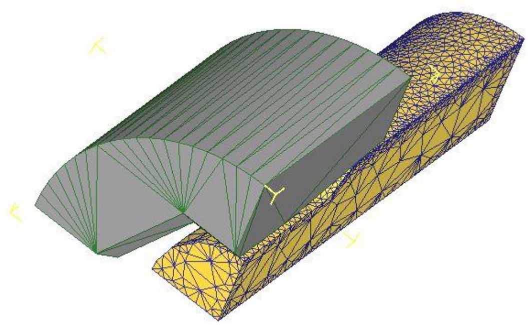


Figure 1：The relationship between viscosity and temperature of Cold-drawing oil

From the test results, the characteristics of the cold-drawing oil, and the conclusions of the literature review, it is shown that the surface scratches of S17400 are caused by the material contacted with the die when the failure of the film.

Second step：establish the cold drawing CAE model and adjust the parameter. According to the existed drawing dies, we build the 3D CAD model. In order to increase the computing efficiency, we used the quarter symmetry. The 3D CAD model is shown in Figure (2). We imported the geometry into DEFORM-3D for motion, deformation and temperature heat transfer simulation after completed the 3D model. We adjusted the CAE boundary conditions according to the actual measured temperature. So that the CAE model can meet the actual production results. Finally, completed the model of CAE cold drawing, and used the parameter for subsequent design. The CAE final boundary conditions are shown in Figure (3).

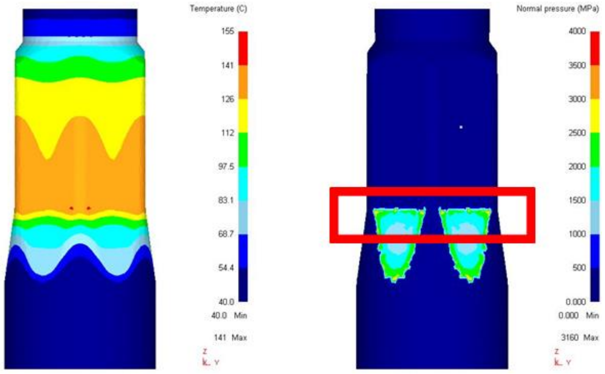


Figure(2)：Quarter model of geometry

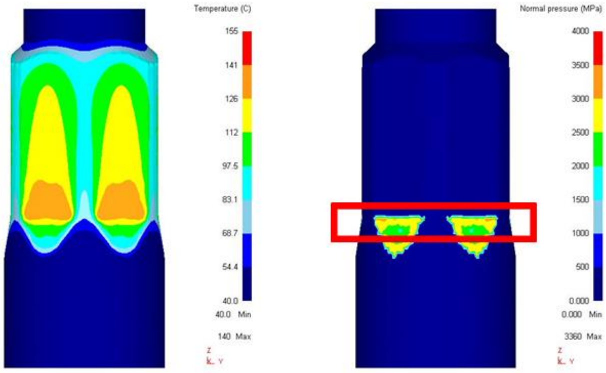
- Geometric Description
  - Die：Actual die size
  - Feeding：R33mm
- Material Description
  - Die：Rigid
  - Feeding：Plastomer
- Mesh Description
  - Encryption outside feeding
  - Bar：50000
- Boundary Condition：
  - Feeding：Port speed control
  - Speed：According to actual speed
  - Quarter symmetry
- Contact Relationship
  - Thermal conductivity：1N/s/mm/℃
  - Friction coefficient：0.05

Figure (3)：CAE boundary Condition setting

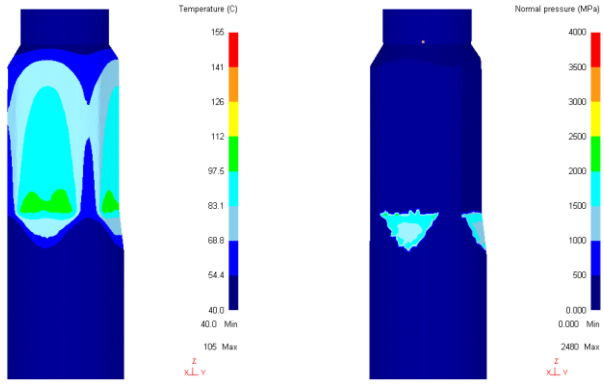
According to the analysis results of the CAE cold drawing model and the characteristics of the cold-drawing oil, it can be seen the red boxes in Figures (4)~(5). The deformation will cause the temperature higher than the 300 series stainless steel due to the S17400 with higher strength. In addition, it can be clearly seen that the different pressure on the contact surface when comparing the simulation results of two groups with scratches or not. Besides, we used the same parameter from figure(4) but only changed the material to AISI 303. As shown in Figure (6), the pressure of the bar entering the corner transition zone of the die was lower than Figures (4) and (5). It can be found that the mechanical strength of the bar affected the pressure generated by the cold-drawing process.



Figure(4)：Simulation results of non-scratch parameter



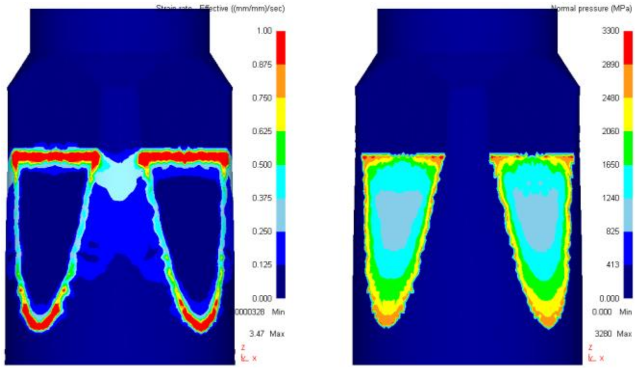
Figure(5)：Simulation results with scratch parameter



Figure(6)：Simulation results of S30300

It is shown that the scratch mechanism is also affected by the temperature which generated by drawing. In order to avoid scratches on the surface during cold-drawing, the temperature and pressure must be controlled within a safe range at the same time. The temperature can be mainly controlled by the area reduction rate and speed, and the pressure can be controlled by the contact area with the die.

Third step：design a new die. It is known that the key factors affecting the quality of the cold-drawing are temperature and contact pressure from second step. Although the heat can be reduced by reducing the area reduction rate by adjust the feeding size, but the value of the area reduction rate would affect the sharp of the bar corner of the special-shaped rod. The adjustable range is constrained. Therefore, this study focuses on reduce the contact pressure and reduce the temperature by adjust geometric. So that it can reduce the risk of oil film failure and avoid the scratching. It can be found that the contact surface between the die and bar is triangular in Figure (7). The pressure and strain rate are concentrated at the bite point and the corner edge. Both decrease from the outside to the inside gradually. Therefore, the key to the design is how to disperse the contact pressure of deformation and avoid the pressure concentrating in a small area which cause the oil film failure.



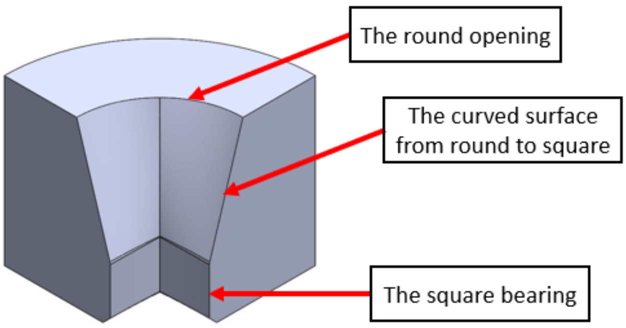
(a) (b)

Figure (7)：Simulation results of the past design from R37mm to S29.2mm

(a)：The distribution of the strain rate

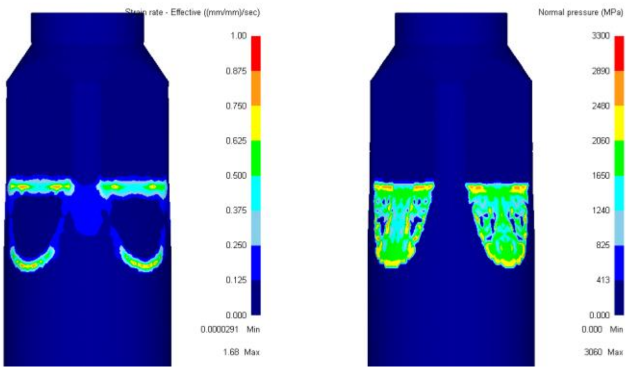
(b)：The distribution of the pressure

The analysis and ideas were integrated into the design and applied the concept of the curve to the die. So that the bar deformed from a round bar to a square bar gradually by increasing the contact area during the actual cold drawing process. By this means the bar can reduce the pressure at the entry point. The surface contour of the new design as shown in Figure (8), which can be drawn by stacking and extrusion in the Solidworks.



Figure(8)：Quarter model of new design

In order to validate the concept of the design, we have done the simulation. The simulation results as shown in Figure (9). The bar was much fit even the contact area reduced a lot. Comparing to the results of the past design, the new design distributed the local concentration effectively in the simulation. From the figure, the uniformity of the strain rate and the distribution of pressure had improved, and the overall value decreased. The maximum pressure was controlled below 3000MPa, which was within the assessed safety threshold.



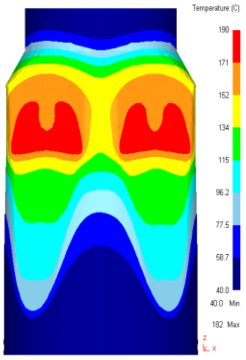
(b) (b)

Figure (9)：Simulation results of the new design from R37mm to S29mm

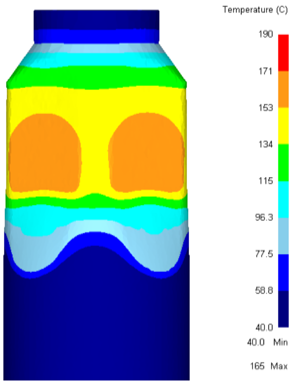
(a)：The distribution of the strain rate

(b)：The distribution of the pressure

Not only improved the pressure distribution, but also the heating of the material which generated by deformation decreased significantly. As the figure(10)~(11) show, it was also confirmed by the actual cold-drawing. The temperature reduced form 190℃ to 172℃. Although it is still 30℃ higher than 140℃ which is a recommended safety value to avoid oil film failure. Decreasing the contact pressure was benefit of increasing the lubricant viscosity and reducing the risk of scratching.



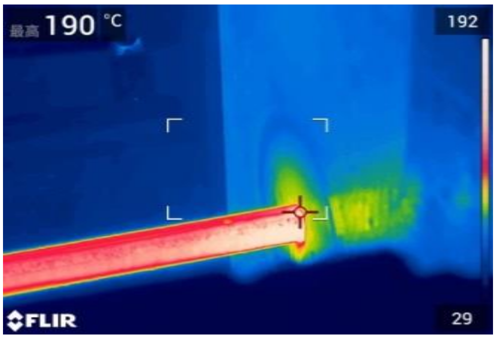
Figure(10)：The simulation temperature of the cold-drawing bar by the past design



Figure(11)：The simulation temperature of the cold drawing bar by the new design

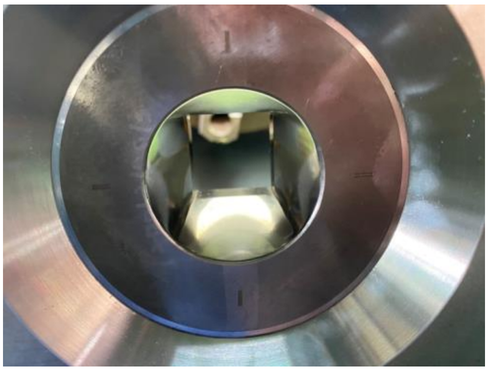
Result and Discussion

Compared the design before and after the optimize with S17400 steel. When using the past design and the R37mm feeding bar, the measured temperature was 190℃ as shown in the figure(12). The sharp of the bar corner was qualified, but surface scratches occurred during the test. Finally, the die was scrapped due to the sever wear and a lot of cracks in the inner hole after produced a few bars.

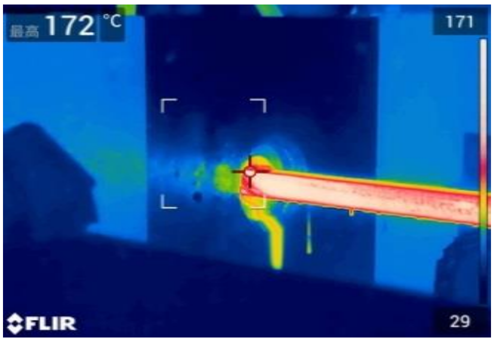


Figure(12)：The cold drawing temperature of the past design which measured by thermal imager

Figure(13) showed the new design. The feeding size of the bar was also R37mm. The sharp of the bar corner was better than the past design, and the temperature was 172℃ which is shown in the figure(14). The scratches and scratch depth decreased significantly. The surface of the die only had one tiny crack after producing more bars than the past design, and it can still produce in the future. The service life of the new design was expected more than twice of the past.



Figure(13)：The new design of die



Figure(14)：The cold drawing temperature of the new design which measured by thermal imager

Conclusion

This study makes the follow four conclusions and recommends：

1. According to the literature and actual test, the temperature generated from the cold-drawing deformation and the contact pressure are the key factors of the cold-drawing oil failure.
2. It is known form the simulation results that adjusting the design of the die can distribute the deformation of the forming process. Not only improve the quality of cold-drawing, but also improve the life of the die.
3. The new design of the die also can apply in other stainless steel grade. It can improve the life of die effectively.
4. Because the new die has a special curve structure in the inner hole, so the processing and the acceptance check are much complex than the past design. There would be worthy to discuss in the future.

Literature

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