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THE QUALITY ANALYSIS OF MULTI-STEP FORMING THE HIGHER D/t CYLINDER

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In order to solve the problem of large springback in higher D/t cylinder stamping, the method of hydroforming following drawing is adopted in this paper. It can reduce the residual stress of the cylinder after heat treatment. The effects of the stretching height, hydraulic pressure and blank holder force on the cylinder quality are investigated using the finite element software dynaform, and the optimal process parameters are obtained. In case that the stretching height, blank holder force and hydraulic pressure are relatively 55 mm, 12,5 MPa and 20 KN, the rate of wall thickness variation and springback are obviously reduced. The research results lay a theoretical foundation for improving the plastic deformation of thin-walled cylinder.

Key words: plastic deformation, hydroforming, sheet, the cylinder, stretching height

INTRODUCTION

Higher D/t thin-walled cylinder parts are common in large-scale aero engine casings, the materials of which are mainly chosen as aluminum alloys, nickel alloys, and titanium alloys [1]. The traditional methods including electrolytic processing and stamping are mainly adopted to form the higher D/t thin-walled cylinder. Due to the large size of the cylinder parts, just using electrochemical machining may result in low material utiliza-tion and low forming efficiency. In order to improve the formability of large stamping part, some scholars have conducted relevant researches. Lang et al. improved the quality of irregular aluminum alloy tube formed from heat medium by optimizing medium temperature and the loading path of hydraulic pressure [2].

In this paper, the higher D/t cylinder is formed by firstly stamping and then hydro-forming. A multistep finite element model is established by using dynaform software [3]. The effects of stretching height on the wall thickness deviation, formability and the springback after hydroforming are analyzed. Under the premise of guaranteeing the devia-tion of wall thickness, the process parameters of stretching height, hydraulic pressure and blank holder force are selected as research object. The springback is used as an index to measure the final formability. Finally, a set of optimal process parameters was obtained by single factor analysis, and the springback of the cylinder part is obviously reduced.

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RESEARCH OBJECT

The higher D/t thin-walled cylinder is selected as the research object (Figure 1), which is formed by stamping and clipping. Since the cut-off bottom hole uses wire cutting technology, the final size of the cylindrical part has little influence. Thus, this paper only studies the forming stage of the stamping drawing.

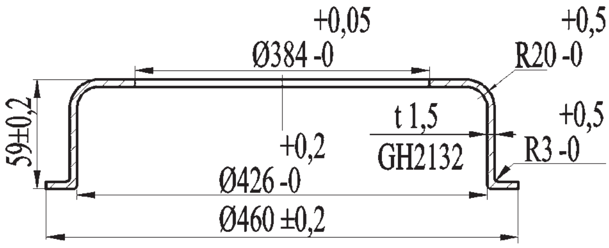


Figure 1 The size of higher D/t thin-walled cylinder

MODEL ESTABLISHMENT
Mechanical model of blank stamping

In order to analyze the stress and strain on each part during the forming of cylinder, the model is divided into 5 parts, as shown in Figure. 2 [4]. Among them, P_{cr} is called as critical fluid pressure; F_Q represents the blank holder force; R_p is the punch radius; R_b is the sheet radius; R_d is the die radius; R is the diameter of any point on the sheet; r_p is the punch radius; r_d is the die radius.

When the cylinder is formed by stamping, only the thicknesses of both the flange and the circular arc transition position are obvious. The flange position is subject to radical tensile stress σ_1, tangential compressive stress σ_3 and compression σ_2 in the thickness direction, where an elongation strain ε_2 is generated, resulting in an increase in wall thickness. The corners of the punch

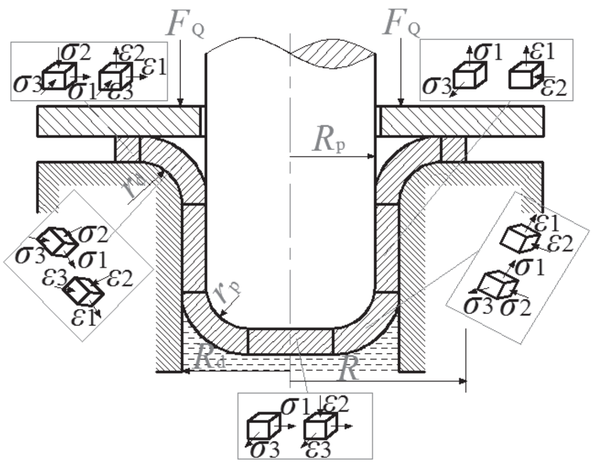


Figure 2 Mechanical model of sheet stamping

and the die have been bent due to additional compressive stress σ_2 in the thickness direc-tion, which causes the reduction of blank thickness. In the area slightly above the arc transition position between the side wall and cylinder bottom, the material is between the punch and die at the beginning of drawing. Moreover, the material to be transferred is less; the degree of deformation is small; the degree of cold hardening is low; and the material is thinned there. Since the cross-sectional area of the transmission force is reduced, it is often the place where the strength of the entire drawn part is the thinnest, and it is the "dangerous fracture surface" in the drawing process.

Finite element model establishment

The blank thickness is 1,5 mm and the material is GH2132. The mechanic para-meters are shown in Table 1. The constitutive equation at normal temperature is shown as equation (1). Punch, die and blank holder are all regarded as rigid bodies. The coefficient of friction between the blank and dies is 0,125. The gap between punch and die is 1,1 times thicker than the original blank; the gap between punch and blank holder is 1,2 times thicker; the speed of die closure is 2 mm·s^{-1}; the feed speed of punch is 5 mm·s^{-1}. The value of hydraulic pressure is shown in Figure. 3, under the premise of preventing the parts formability from wrinkling. The blank holder force is 2 000 KN. The finite element model is shown in Figure. 4.

$$\sigma = 283 + 1{,}67E5\cdot(\varepsilon)^{0{,}45} \quad (1)$$

Table 1 **Mechanical properties of GH2132**

Factor	Value
Young's Modulus/MPa	175 000
Poisson's ratio	0,3
Yield Strength/MPa	283
Tensile strength/MPa	637
R00	0,81
R45	0,36
R90	0,29

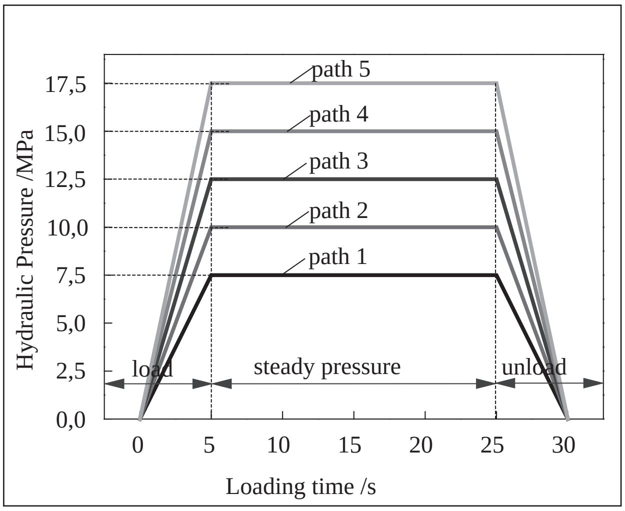


Figure 3 The loading path of hydraulic pressure in hydroforming

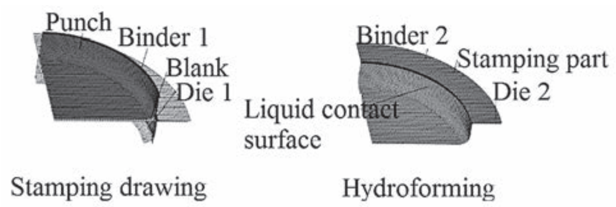


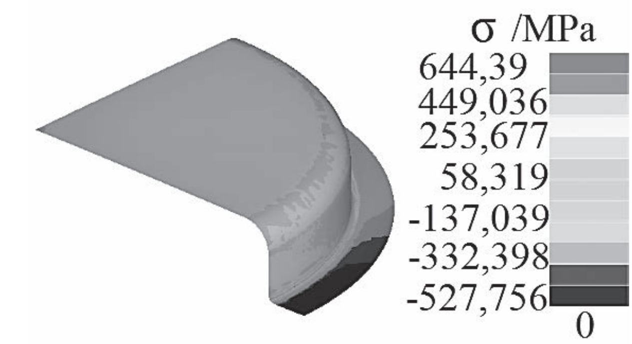
Figure 4 The finite element model of blank multi-step forming

ANALYZE AND OPTIMIZE FORM-ABILITY OF THE HYDROFORMING PART

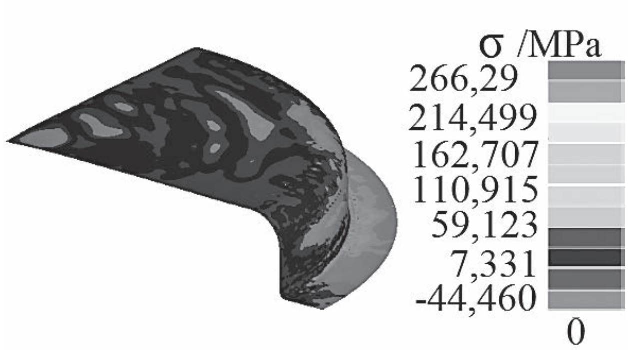
To explore the forming mechanism of the cylinder, the stress in different stages is analyzed. The stress distribution is shown in Figure. 5 and the wall thickness is shown in Figure. 6. The figure indicates that stress is increased both in bottom and in the edge in the final phase, which causes the wall thick-ness in the bottom decreasing. The edge is wrinkling because the blank holder force is insufficient. But the maximum rate of wall thickness change does not exceed 10 %. The stamping part is treated by heat treatment in the second stage and the residual stress inner is eliminated. The stamping part is treated by hydroforming in the third stage. Compared with the stamping forming phase, the overall stress of the stampings as well as the strain at each part are becoming smaller and the wall thickness remains almost unchanged. Due to the relatively uniform force applied during the hydraulic rectification of the tubular member, the springback caused by this is also small, so that the diameter accuracy of the opening portion of the tubular member is improved.

Effect of stretching height on the form-ability of hydroforming parts

The dimension of each step of the cylinder is shown in Figure. 7. The symbol *h* is defined as drawing height; *a* as the distance from the side of the stamping part to



a) last stage of the stamping



b) last stage of the hydroforming

Figure 5 Stress distribution in the XY plate during multi-step forming of the cylinder

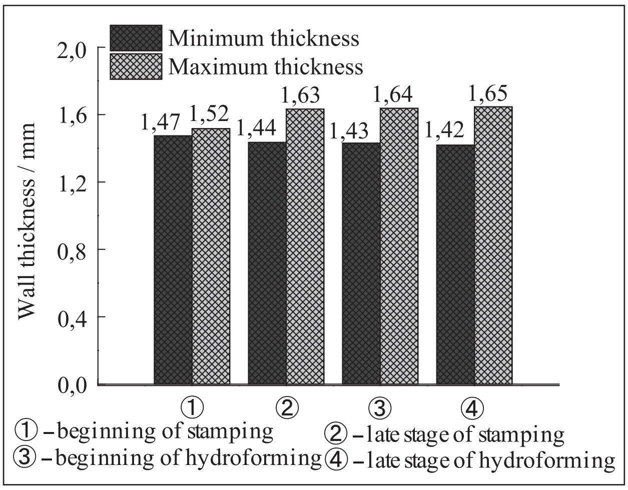


Figure 6 Thickness distribution during multi- step forming of the cylinder

the hydroforming part; *b* as the distance from the bottom of the stamping part to the bottom of the hydroforming part. Since the drawing height *h* has a significant influence on the wall thickness uniformity and springback of the stamped part, it is necessary to analyze the change of *h* reflect on the formability of stamping parts. The value of *a* is set to 1 mm, the value of F_Q is set to 20 KN. The loading path is mode 3. The value of h_s is set to 53 mm, 54 mm, 55 mm, 56 mm, 57 mm respectively, aiming to implement finite element analysis on this working condition. Finally, the curve of the maximum springback amount and wall thick-ness variation with *h* is shown in Figure. 8.

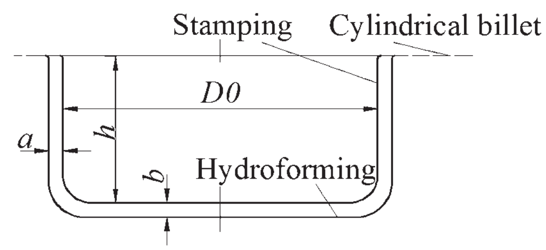


Figure 7 The dimension of each step of the cylinder

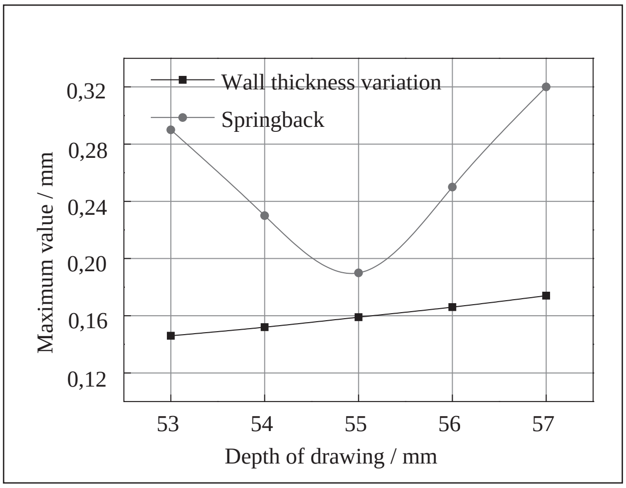


Figure 8 The effect of stretch height on the formability of hydroforming

As can be seen from Figure. 8, the max-imum springback of the cylinder part first decreases and then increases with increasing *h*. This is because the cylinder part is subjected to heat treatment after drawing and the springback amount of the stamped part is hydroforming. Depending on the amount of hydroforming, the stress at the side wall de-creases with increasing *h* within a certain value, but the stress will increase when *h* exceeds the certain value. So the springback will also increases. The greater the stretching height, the more the thickness decreases. The maximum rate of thickness change increases with the increase of *h*. In order to improve the formability of the cylinder, the height of the first stretch should be around 55 mm.

Effect of hydraulic pressure on the formability of hydroforming parts

It is necessary to explore the effect of loading path on the formability of hydro-forming part. If $a = 1$ mm, $h = 57$ mm, $F_Q = 20$ KN, loading path uses the five conditions of methods 1, 2, 3, 4 and 5 for finite element analysis to obtain the liquid loading path for orthopedic parts. The effect of loading path on the thickness and springback is shown in Figure. 9.

Figure. 9 indicates that the maximum of springback increases with the increase of *h*. The maximum rate of thickness change flu-ctuates with the change of *h*, because the amount of stress depends on the amount of hydraulic press. The loading path in hydro-forming

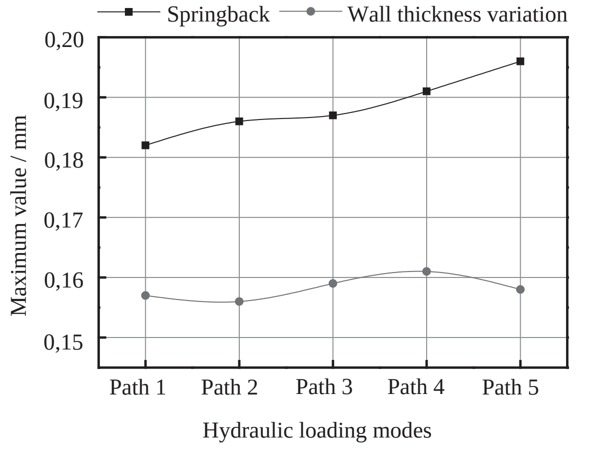


Figure 9 The effect of loading path on the formability of stamping

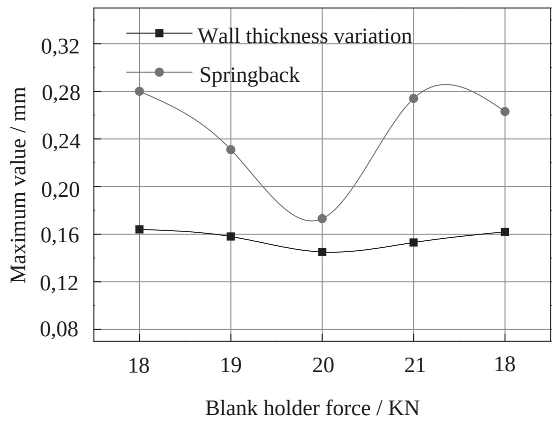


Figure 10 The effect of BHF on the formability of hydroforming part

should be set in path 3 within the allowable range of wall thickness deviation.

Effect of blank holder force on the formability of hydroforming part

Blank holder force (BHF) is the main factor that causes thinning and wrinkling of stamping parts. The value of *a* is set to 1 mm. The value of *h* is set to 57 mm. The value of F_Q is set to 18 KN, 19 KN, 20 KN, 21 KN, 22 KN, aiming to implement finite element analysis on above working condition. Finally, the effect of BHF on the formability of the cylinder is shown in Figure. 10.

From Figure. 10, it can be seen that the maximum springback amount of the cylinder part first decreases and then increases with the increase of the BHF. This is because when the BHF is too small, stress concentration occurs at the flange part during hydraulic reshaping. The flange thickness gradually increases because the larger blank holder force blocks the metal flow at the arc transition. The maximum wall thickness almost does not change with the increase of BHF. So the optimum BHF is 20 KN.

Process parameter optimization and simulation verification

According to the effect of each parameter on the orthopedic quality of stamped parts, a set of optimized process parameters was selected. The symbol *h* is set to 55 mm, loading path is set to path 3, F_Q is set to 20 KN. The results indicated that the maximum wall thickness rate of change after hydro-forming is 8,93 %, the maximum springback 0,156 mm.

CONCLUSION

A series of problems, such as the over-thinning of the wall thickness and the large amount of springback caused by the stamping of higher D/t cylinder parts, and the increase of the force due to the hydroforming of the cylinder part, have been improved in this paper by adopting the first hydraulic pressing after stamping. The regular of effect of the blank holder force, the loading path and the stretching height on the formability were obtained, which uses simulation and single factor analysis. The rate of wall thickness change and springback of the cylinder are insufficient, when the stretching height is 55 mm, hydraulic press is 12,5 MPa, and the blank holder force is 20 KN.

Acknowledgements

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Note: The responsible translator for the English language is Q. Q. Yan, Ningbo, China