Analysis of the stress state of cylindrical workpieces during pipe end crimping with wall thinning

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Abstract. Workpieces with different cross sections in the orthogonal direction along the height can be produced by crimping of hollow cylindrical blanks. This operation is highly productive and makes it possible to obtain various types of connectors. This article discusses simultaneous crimping and thinning of the workpiece wall at the exit from the deformation zone. During crimping, the thickness of the workpiece grows in the deformable part. In view of this, significant stresses may arise in the deformation zone. Therefore, selection of process parameters that provide the best stress state of the products is relevant. This article presents a study of the stress state in the combined process of crimping with wall thinning.

1. Introduction

The article discusses the operation of crimping of a steel pipe blank in a cold state. Its major feature is that the wall of the workpiece at the exit from the deformation zone undergoes thinning, which is ensured by the size of the gap between the die and the mandrel [1-4]. This makes it possible to ensure large degrees of deformation and obtain a deformed element of the product with the best mechanical characteristics in the crimped part of the workpiece. Significant stresses arise during the forming. In some cases, the destruction of the workpiece material is possible due to the critical values of tensile stresses [5-7]. In view of this, the article discusses the combined crimping process with wall thinning in terms of discovering the influence of technological factors on the stress state of the workpiece.

2. Materials and methods

The study was carried out on the basis of computer simulation using DEFORM. To carry out research on the crimping process, DEFORM software was used together with the main provisions of the theory of plasticity of elastoplastic, incompressible and hardening materials. Stamping of pipe blanks from steel 1010 was carried out at a temperature of $-20 \, ^\circ\mathrm{C}$. Its properties are as follows: $\sigma_T = 210\, \text{MPa}$; $\sigma_S = 340\, \text{MPa}$. The pipe had a diameter $D_0 = 80 \, \text{mm}$. Workpiece wall thickness was $s = 5 \, \text{mm}$. Workpiece height was 120 mm. Elastoplastic rheological model of the blank was used. Workpiece wall thinning was determined by the gap between the mandrel and the die. The thinning coefficient in this case was $k_{th} = (D_0 - D_1)/(D_{die} - D_p) = 0.8 - 1$. During the simulation, various crimping coefficients $k_c = D_0 / D_{die} = 0.6 - 1$ and the taper angle of the tool $\alpha = 10 - 20^\circ$ were used.

Figure 1 shows a diagram of the forming.
3. Results and Discussion

Of greatest interest is the assessment of the stress state in the thinning zone and in the deformation zone [8, 10]. A number of computer experiments were performed to assess the stresses. In the course of the analysis of the results, the maximum absolute values of the compressive and tensile stresses were found. Figure 2 shows a diagram of the product after crimping with an illustration of the stress distribution during deformation at the characteristic stages.

Figure 2. To the assessment of stresses in the workpiece

Figure 2 shows that the stress state of the product during deformation is complex. Thus, at the first stages of deformation, zones of significant compressive stresses, which are transformed into tensile stresses during stamping, are observed along the inner surface of the crimped part of the workpiece. The maximum tensile stresses are concentrated before entering the deformation zone at the initial stages of the process (on the outer surface of the workpiece), and at the exit from the deformation zone at the final moment of deformation (along the workpiece wall). Thus, the zone in the wall formed after crimping, was selected to assess the influence of the technological parameters of the process on stresses.
The influence of the wall thinning coefficient, crimping coefficient, contact friction and the taper angle of the die on compressive and tensile stresses was analyzed. Figure 3 shows the dependence of the change in the maximum absolute value of tensile stresses on the thinning coefficient and the taper angle of the die.

![Figure 3](image)

**Figure 3.** $\sigma, \text{MPa}$ plotted versus $k_{th}$ ($k_{cr} = 0.8$; $\mu = 0.1$): 1 – $\alpha = 10^\circ$; 2 – $\alpha = 20^\circ$

Figure 3 shows that an increase in the thinning coefficient leads to a decrease in tensile stresses in the studied area for cases with the die taper angle $\alpha = 10^\circ$ by 40%, and for $\alpha = 20^\circ$ by 20%. An increase in the taper angle of the die leads to a decrease in tensile stresses.

Figure 4 shows the dependence of the change in the maximum absolute value of the compressive stresses on the thinning coefficient and the taper angle of the die.

![Figure 4](image)

**Figure 4.** $\sigma, \text{MPa}$ plotted versus $k_{th}$ ($k_{cr} = 0.8$; $\mu = 0.1$): 1 – $\alpha = 10^\circ$; 2 – $\alpha = 20^\circ$

Figure 4 shows that an increase in the thinning coefficient leads to an increase in compressive stresses in the analyzed volume of the workpiece, regardless of the taper angle of the tool by an average of 25%. An increase in the die taper angle leads to an increase in compressive stresses by 5%, but only for a larger value of the wall thinning coefficient.

Figure 5 shows the dependence of the change in the maximum absolute value of tensile stresses on the compression coefficient and the friction coefficient.
Figure 5. σ, MPa plotted versus $k_{cr}$ ($k_{th} = 0.8; \alpha = 15^\circ$): 1 – μ = 0.05; 2 – μ = 0.1

Figure 5 shows that an increase in the crimping coefficient leads to a decrease in tensile stresses by 5 ... 10%. This dependence is practically linear. An increase in the contact friction coefficient leads to an increase in tensile stresses in the analyzed volume of the workpiece by 10%.

Figure 6 shows the dependence of the change in the absolute value of the maximum compressive stresses on the compression coefficient and the coefficient of friction.

Figure 6. σ, MPa plotted versus $k_{cr}$ ($k_{th} = 0.8; \alpha = 15^\circ$): 1 – μ = 0.05; 2 – μ = 0.1

Figure 6 shows that an increase in the crimping coefficient leads to a decrease in the compressive stresses in the considered volume of the workpiece by 30% for a lower value of the contact friction coefficient and almost by 2 times for a higher value of the contact friction coefficient. This dependence is practically linear. An increase in the contact friction coefficient leads to an increase in compressive stresses. Moreover, for high degrees of deformation, its effect is more noticeable.

Based on the simulation results, a statistical study of the influence of the studied technological parameters on stresses was carried out [9].

Table 1 shows the factor space of the process under study.
Table 1. Factor space for stress estimation.

| No. | Factor name        | Uncoded factor value | Factor code | \( X_i \) min \((X_i = -1)\) | \( X_i \) 0 \((X_i = 0)\) | \( X_i \) max \((X_i = +1)\) |
|-----|-------------------|----------------------|-------------|-----------------|-----------------|-----------------|
| 1   | Crimping coefficient \( k_c \) | \( X_1 \) | 0.8          | 0.85            | 0.9             |
| 2   | Thinning coefficient \( k_{th} \) | \( X_2 \) | 0.8          | 0.85            | 0.9             |
| 3   | Taper angle \( \alpha \) | 10° | 10          | 15             | 20              |

Table 2 presents the experiment planning matrix.

Table 2. Experiment planning matrix.

| No. of the experiment | \( X_0 \) | \( X_1 \) | \( X_2 \) | \( X_3 \) | Tensile stress | Compressive stress |
|-----------------------|----------|----------|----------|----------|---------------|-------------------|
| 1                     | +        | –        | –        | –        | 289           | 521               |
| 2                     | +        | +        | –        | –        | 188           | 487               |
| 3                     | +        | –        | +        | –        | 198           | 470               |
| 4                     | +        | +        | +        | –        | 157           | 300               |
| 5                     | +        | –        | –        | +        | 172           | 563               |
| 6                     | +        | +        | –        | +        | 167           | 501               |
| 7                     | +        | –        | +        | +        | 159           | 492               |
| 8                     | +        | +        | +        | +        | 161           | 320               |

According to the results of statistical studies, regression dependences for tensile stresses were obtained:

in coded units:

\[
Y = 186.38 - 18.13X_1 - 17.63X_2 - 21.26X_3 + 17.37X_{13} + 12.87X_{23}
\]

in uncoded units:

\[
\sigma = 1760 - 692k_c - 1124k_{th} - 75\alpha + 34.74k_c\alpha + 51.48k_{th}\alpha
\]

According to the results of statistical studies, regression dependences for compressive stresses were obtained:

in coded units:

\[
Y = 456.75 - 54.75X_1 - 61.25X_2 - 30.75X_{12}
\]

in uncoded units:

\[
\sigma = 2246 - 4860k_c - 3695k_{th} + 6150k_c k_{th}
\]

The obtained expressions make it possible to establish the values of the compressive and tensile stresses during the crimping with thinning in order to determine the critical values of the considered technological parameters. This can be useful for creating manufacturing techniques of adapters with selection of voltages precluding achieving critical process values.

Conclusion

Based on the simulation results in the DEFORM program environment, the stress state of the workpiece was analyzed during the combined crimping process with wall thinning at the exit from the plastic deformation zone. The zones of concentration of compressive and tensile stresses in the workpiece at different stages of deformation are determined, the influence of the wall thinning...
coefficient, crimping coefficient, contact friction and the taper angle of the die on the compressive and tensile stresses is revealed. Based on the results of statistical studies, regression dependences for tensile and compressive stresses are obtained, which make it possible to establish the approximate values of compressive and tensile stresses for different geometric parameters of the tool.

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