Research on Residual Stress of Cr12 Surface Layer after Rolling Processing

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Abstract. In normal temperature, the effect of rolling motion and extrusion stress will lead to the occurrence of subgrain size refinement, changes of the dislocations and phase transition caused by plasticity, which will change the mechanical properties of the workpiece’s material on the surface layer and directly affect the fatigue strength and service life of the workpiece. In this paper, the residual stress of Cr12 after rolling processing by different rolling pass and contact stress are studied through experiments. Through the analysis of the test results, it is shown that: with the increase of rolling pass, the residual stress on the workpiece surface layer increase continuously, after rolling 3 passes, the residual stress will no longer continue to increase and remain stable. When the contact stress is less than 717 MPa, the residual stress increase obviously, and when it reaches 717 MPa, the residual stress keep relatively stable state with the increase of contact stress. In the depth direction, the residual stress decreases with the depth, and the maximum residual stress may appear at a certain depth from the surface.

1. Introduction

Fatigue failure of key parts in mechanical equipment will occur after a long period of work, especially under the action of alternating load. Fatigue failure of parts will become an important safety hazard, which will not only reduce the production efficiency of equipment, bring economic losses, but also threaten the personal safety of workers around. Therefore, researchers in related fields have been devoting themselves to the study of surface strengthening.

The mechanical properties of the workpiece can be effectively changed by rolling processing, so as to achieve the purpose of surface hardening. In the process of rolling processing (Figure 1), a rolling tool with high hardness and smooth surface is used to exert a certain load on the surface of the workpiece, and there is a relative rolling motion between the workpiece and the rolling tool. When the load is large enough, the surface of the workpiece will produce elastic and plastic deformation, resulting in dislocation configuration change and phase change. At the same time, the rolling layer will appear sub grain refinement and formation of gradient nanocrystalline layer [1-5]. Rolling processing can effectively reduce the roughness of the workpiece surface, produce work hardening phenomenon and introduce residual compressive stress on the workpiece surface [6-8], which can effectively prevent the occurrence of fatigue failure and improve the fatigue strength and fatigue life of the parts [9-11].

There are many technological parameters affecting the effect of rolling processing, and the effect of each technological parameter on the rolling processing effect is also slightly different [12-13]. In this paper, the influence of contact stress and rolling passes on the residual stress after rolling processing is analysed.
2. Test Process

2.1. Test Materials and Equipment

The test material is Cr12 (2.00%-2.30% C; 11.50%-13.00% Cr; 0-0.40% Si; 0-0.40% Mn; 0-0.03% S; 0-0.03% P; 0-1.00% Co; 0-0.25% Ni; 0-0.30% Cu) and the material is processed into a workpiece with a diameter of 40 mm and a length of 300 mm. The workpiece has been modulated and the surface of the workpiece has been processed by turning. After treatment, and the residual stress is 108 MPa, which is the tensile residual stress.

The experimental device is an independently developed surface rolling device for shaft parts based on C616 lathe (Figure 2), which includes mechanical part and hydraulic part. The device is symmetrical structure. The contact roller (GCr15, φ35 mm) exerts force on the workpiece from both sides. The contact line length between the roller and the workpiece is 4 mm, and the hydraulic system provides the force for the rolling processing. The relationship between the force and the hydraulic system is shown as follows:

\[ F = P \times S \]  \hspace{1cm} (1)

Where \( F \) represents the force between the contact roller and the workpiece, where \( P \) represents the internal pressure of the hydraulic system, where \( S \) represents the cross-sectional area of the hydraulic cylinder (707 mm²). According to the Hertz contact formula, the maximum contact stress \( \sigma_H \) between the contact roller and the workpiece under different forces is as follows:

\[ \sigma_H = \sqrt{\frac{F}{\pi b \left( \frac{1}{r_1} + \frac{1}{r_2} \right)} \left( \frac{1}{1-\mu_1} \right) \left( \frac{1}{1-\mu_2} \right) E_1 + E_2} \]  \hspace{1cm} (2)

Where \( b \) represents the contact line length, where \( r_1 \) and \( r_2 \) represents the workpiece diameter and the contact roller diameter. Where \( \mu_1 \) and \( \mu_2 \) represent the poisson's ratio of the workpiece and the roller (\( \mu_1=\mu_2=0.3 \)), where \( E_1 \) and \( E_2 \) represent the modulus of elasticity of the workpiece and roller (\( E_1=E_2=2.1 \times 10^5 \) MPa). Bring the above data into the upper expression:

\[ \sigma_H = 32.05 \times \sqrt{F} \]  \hspace{1cm} (3)
1 base, 2 workpiece, 3 roller, 4 bracket, 5 fixed seat, 6 hydraulic cylinder.

**Figure 2.** The schematic diagram (a) and physical diagram (b) of the rolling device

### 2.2. Test Parameters

In this paper, a two-factor test is designed. The test variables are contact stress and rolling pass, in which the set contact stress is 555 MPa, 717 MPa, 848 MPa and 1013 MPa (i.e. the force is 300 N, 500 N, 700 N and 1000 N respectively), the rolling pass are 1, 2, 3, 5 and 8 passes, and the rotational speed is fixed at 44 r/min for rolling test.

### 2.3. Detection Device

The residual stress of the workpiece was measured by iXRD stress analyzer (Figure 3). In the course of measurement, Cr target is used, the working voltage in X-ray tube is 20 kV, the working current is 4 mA, the exposure time is 1 s, the number of exposures is 10, the diameter of collimator is 1mm. In the process of measurement, for the region under the same rolling parameters, random measurements are made five times, and the average value is taken as the test result under the rolling parameters.

![iXRD stress analyser](image)

**Figure 3.** iXRD stress analyser

### 3. Analysis of Test Results

After rolling, the residual stress on the workpiece surface is transformed from tensile residual stress to compressive residual stress. The results of residual stress on the workpiece surface under different test parameters are shown in Table 1.
Table 1. Residual stress value of workpiece surface layer

| Test variables | Contact stress (MPa) | Rolling pass | Residual stress (MPa) |
|----------------|---------------------|--------------|----------------------|
|                | 1                   | -47          |                      |
|                | 2                   | -88          |                      |
| 555            | 3                   | -111         |                      |
|                | 5                   | -135         |                      |
|                | 8                   | -141         |                      |
|                | 1                   | -134         |                      |
|                | 2                   | -159         |                      |
| 717            | 3                   | -176         |                      |
|                | 5                   | -191         |                      |
|                | 8                   | -205         |                      |
|                | 1                   | -138         |                      |
|                | 2                   | -161         |                      |
| 848            | 3                   | -181         |                      |
|                | 5                   | -203         |                      |
|                | 8                   | -203         |                      |
|                | 1                   | -144         |                      |
|                | 2                   | -167         |                      |
| 1013           | 3                   | -180         |                      |
|                | 5                   | -209         |                      |
|                | 8                   | -207         |                      |

3.1. Effect of Test Parameters on Residual Stress
From Table 2, the variation trend of surface residual stress with the increase of rolling passes and contact stresses can be plotted, as shown in Figure 4. As can be seen from Figure 4: the variation of residual stress with rolling pass under different contact stresses is the same. With the increase of rolling pass, the value of residual stress increases first and then changes smoothly. Specifically, the residual stress increases obviously with the increase of rolling passes within 3 passes, and tends to be stable and basically unchanged when the rolling passes reach 3 passes; the variation law of residual stress with contact stress is basically the same as that with rolling passes. Specifically, when the contact stress is less than 717 MPa, the residual stress value increases obviously with the increase of the contact stress; when the contact stress reaches 717 MPa, the residual stress value basically keeps stable and no longer increases significantly.

3.2. The Trend of Residual Stress in Depth Direction
The workpiece was cut into 5 mm×5 mm×10 mm block specimen by wire-electrode cutting. The surface of the specimen was corroded layer by layer with nitric acid solution, the residual stress on the surface of the specimen after corrosion was measured. After selecting the specimen, the change trend chart as shown in Figure 5 is obtained. From the figure, it can be seen that with the increase of depth, the residual stress value generally shows a downward trend, and the maximum residual stress value appears at a certain distance from the surface.
4. Conclusion

In this paper, the effect of rolling on the residual stress of Cr12 material surface is studied through experiments. The main conclusions are as follows:

(1) Two-factor rolling tests were designed by selecting different rolling pass and contact stresses, and the residual stresses of workpieces were measured under different test parameters. After rolling, the residual stress on the surface of the workpiece changes from tensile residual stress to residual compressive stress.

(2) With the increase of rolling pass, the residual stress increase first and then change smoothly. Before the 3 passes, the residual stress changed significantly, and after 3 passes, the change became stable. The influence of contact stress on residual stress is the same as that of rolling pass. Before the 717 MPa, the residual stress changed significantly, and after 717 MPa, the change became stable.

(3) Along the direction of specimen depth, the value of residual stress decreases with the increase of specimen depth, and the maximum value of residual stress appears at a certain distance from the specimen surface.
5. References

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