Study on the Improvement of the Thick Wall Cylinder Pressure Bearing Capacity Based on Autofrettage Technology

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Abstract: In order to improve the pressure bearing capacity of thick wall cylinder pressure vessel, the feasibility of autofrettage technology to improve the pressure bearing capacity of thick wall pressure vessel was analyzed by finite element software ANASYS, pressure bearing capacity of original thick wall cylinder and self enhancement treatments thick wall cylinder was comparative analyzed. The results show that: self enhancement technology has a significant effect on improving the bearing capacity of the thick wall cylindrical vessel, and it plays a guiding role in the design process of a thick wall cylinder pressure vessel.

Keywords: Autofrettage technology; Thick wall cylinder; Anasys

1. Introduction

Because of the special working condition of underground coal mine production, the electrical equipments used underground coal mine requires the flameproof property strictly, according to the requirements in GB3836.2-2010 Explosive atmospheres Part 2: Equipment protection by flameproof enclosures “d” [1-3],while hydraulic pressure test is the critical test for the verification of the strength of flameproof enclosure, the hydraulic pressure is 1.5MPa.

Autofrettage is an effective way to improve the carrying capacity of pressure and fatigue life of thick wall vessel[4-6], the main method is that plastic deformation zone is formed on the inner surface of the container in a certain area during processing, the favorable remnant stress field is produced. If the autofrettage technology can be introduced to the mine flameproof enclosure machining process, pressure bearing capacity of thick wall pressure vessel and safety will be improved and thecost will be reduced.

2. Modeling and Theoretic Analyzing

As Figure 1 shows the steel thick wall cylinder enclosure of flameproof bolt connector of 8Tmine electric locomotive, with inner diameter r1=90mm, external diameter r2=100mm, autofrettage pressure acts on inner surface p=28MPa,during the water press testing, applied load p1=1.5MPa, no axial pressure, axial length regarded as infinite, the thick wall material is Q235, material's yield limitσs=235MPa.

In actual production the processautofrettage pressure is high pressure hydraulic.

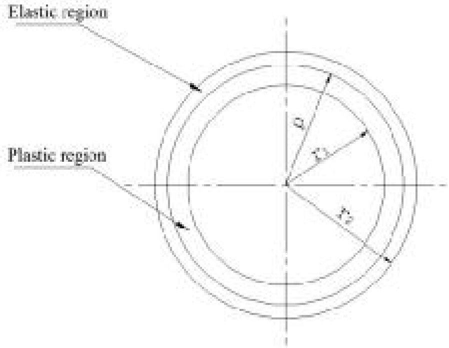

Figure 1. Physical model schematic diagram

According to the theory of elastic-plastic mechanics, under the autofrettage pressure, cylinder has already yielded based on von mises yield condition[6-7], the interface radius of the elastic region and the plastic region can be calculated from formula 1:

$$r = \frac{2}{\sqrt{3}} s_s \left(\ln \frac{r}{r_1} + \frac{r_2^2 - r^2}{2r_2^2} \right) \tag{1}$$

Put data to formula 1, we can get that ρ=0.95mm. When loading, stress distribution of thick wall cylinder was:

Elastic region (ρ≤r≤r2)：

$$\begin{cases} s_r = -\dfrac{s_s}{\sqrt{3}}\dfrac{r^2}{r_2^2}\left(\dfrac{r_2^2}{r^2}-1\right) \\ s_t = \dfrac{s_s}{\sqrt{3}}\dfrac{r^2}{r_2^2}\left(\dfrac{r_2^2}{r^2}+1\right) \end{cases} \quad (2)$$

(2)Plastic region ($r_1 \le r \le \rho$):

$$\begin{cases} s_r = \dfrac{2s_s}{\sqrt{3}}\ln\dfrac{r}{r_1} - p \\ s_t = \dfrac{2s_s}{\sqrt{3}}\left(\ln\dfrac{r}{r_1}+1\right) - p \end{cases} \quad (3)$$

Put data to formula2 and formula3, when $r=r_1$, $r=\rho$, $r=r_2$, the corresponding shear stress s_t will be243.5MPa,258MPa,245MPa.After unloading, residual stress distribution on thick wall cylinder:

(1) Elastic region ($\rho \le r \le r_2$):

$$\begin{cases} s_r = -\dfrac{s_s}{\sqrt{3}}\dfrac{r^2}{r_2^2}\left(\dfrac{r_2^2}{r^2}-1\right) + \dfrac{pr_1^2}{r_2^2-r_1^2}\left(\dfrac{r_2^2}{r^2}-1\right) \\ s_t = \dfrac{s_s}{\sqrt{3}}\dfrac{r^2}{r_2^2}\left(\dfrac{r_2^2}{r^2}+1\right) - \dfrac{pr_1^2}{r_2^2-r_1^2}\left(\dfrac{r_2^2}{r^2}+1\right) \end{cases} \quad (4)$$

(2) Plastic region ($r_1 \le r \le \rho$):

$$\begin{cases} s_r = \dfrac{2s_s}{\sqrt{3}}\ln\dfrac{r}{r_1} - p + \dfrac{pr_1^2}{r_2^2-r_1^2}\left(\dfrac{r_2^2}{r^2}-1\right) \\ s_t = \dfrac{2s_s}{\sqrt{3}}\left(\ln\dfrac{r}{r_1}+1\right) - p - \dfrac{pr_1^2}{r_2^2-r_1^2}\left(\dfrac{r_2^2}{r^2}+1\right) \end{cases} \quad (5)$$

Put data to formula4 and formula5,when $r=r_1$, $r=\rho$,$r=r_2$,the corresponding residual shear stress σ_t will be-22.28MPa,8.16MPa,7.12MPa. We can see that, residual stress distribution of autofrettaged thick wall cylinder deduced from the classical elastic-plastic mechanics theory. The following facts are shown: exists residual compressional stress on inner surface, exists residual tensile stress in elastic-plastic contact-zone and outside the zone. Whether residual stress produced by autofrettage technology is beneficial for improvement of the pressure bearing capacity of thick wall pressure vessel can be analyzed with the help of finite element software ANASYS.

3. The Finite Element Simulation

3.1.Key Problem Description

We analyzed a quarter of the model on the basis of the principle of symmetry, imposed vertical symmetrical plane restriction. Founded the finite modelbased on figure 1as shown in Figure 2, apply vertical section constraint on the surface, quadrilateral mesh with 0.001 in side length was adopted, applied load on the inner surface of the cylinder. In order to validate that autofrettage technology is an effective way to improve the carrying capacity of pressure of thick wall vessel, applied load 1.5MPa in test 1; Load step character of ANSYS were employed to simulate the same model in test 2, at first, applied autofrettage pressure, and then unloading, at last, applied test pressure 1.5MPa, pressure curve are shown in Figure 3, at last analysis results were obtained[8].

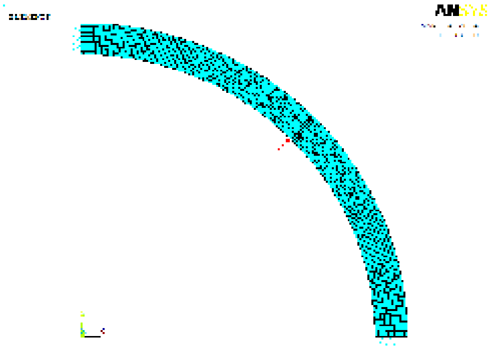

Figure 2. Finite element model

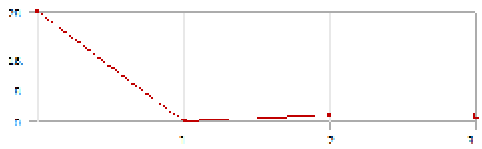

Figure3. Pressure curve in test 2

3.2. Result and Discussion

As Figure 4 shows the analysis result of test 1, the results indicate that, it increases gradually from inner surface to outer surface, the maximum force position is in the inner surface: 92.7MPa, the stress exerted on the outer surface is the minimal force75.8MPa.

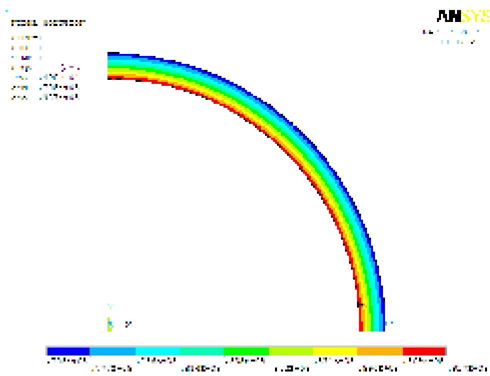

Figure 4. Von mises stress nephogram of untreated thick wall cylinder (test 1)

As Figure 5 shows the analysis result of test 2, the model applied autofrettage pressure at first, and then unloading, at last, applied test pressure 1.5MPa, the results indicate that, pressure distribution is more uniform, stress value tended to firstly decrease then increase along the radius direction, the maximum force position is in the inner surface: 23.9MPa, the stress exerted in the middle of the wall (elastic-plastic radius)is the minimal force3.26MPa.

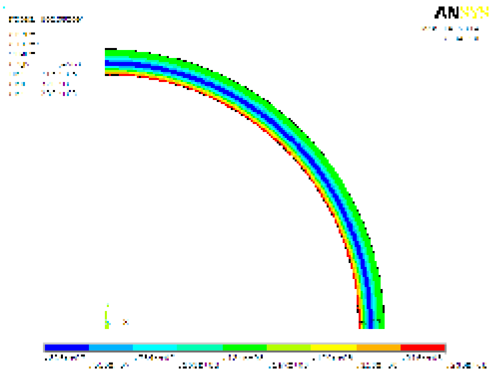

Figure 5. Von mises stress nephogram of self-enhancement treatment thick wall cylinder (Test 2)

We can see that from the results of test 1 and test 2, distribution of stress of untreated thick wall cylinder and self-enhancement treatment thick wall cylinder are completely different. Under the same load1.5MPa, the maximum force of untreated thick wall cylinder is 92.7MPa, meanwhile, the maximum force of self-enhancement treatment thick wall cylinder is 23.9MPa, which means, for the same thickwall cylinder, self-enhancement treatment one can carrying more capacity of pressure; what's more, the stress of self-enhancement treatment thick wall cylinder distribution has symmetry, and the stress distributes reasonably. Autofrettagetechnology has important significance for improving the carrying capacity of pressure and fatigue life of thick wall vessel.

4. Summary

This paper analyzed the model by means of elastic-plastic theory and finite element software ANASYS, proved that self-enhancement treatment can increase bearing capacity of circular flameproof enclosure, reduce thickness and the cost under the same loading. It plays a guiding role in the design process of a thick wall cylinder pressure vessel.

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