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Effect of Heat Treatment on the Defect Structure of Tie Rod End

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Abstract

Tie rod end is the key part of ST2 brake shoes stack adjuster. During heat treatment, the part with defect is prone to have stress concentration. In this paper, the temperature field and stress field of tie rod end part with defect is studied by using numerical method, and the effect of the defect structure is considered. The results show that the temperature field and stress field of the end part under high temperature are distributed in layers, and the temperature is relatively low when the thickness of the part is larger, and the high stress area of the part is concentrated on the change of the part geometry. At the same time, surface defect of part is prone to have stress concentration at the edges and vertices of the defect. The stress of the part defect under high temperature increases as the depth of the defect increasing, and decreases as the defect area increasing. For defects in different positions, when the defect is in the high stress area of the part, the stress concentration is much higher than the surface of the part. When there have double defects, the form of internal and external distribution is prone to produce large stress concentration. To reduce the stress concentration of tie rod end part, structure improvement is designed. The fillet of inner or outer surface can reduce the stress concentration. But fillet together of inner and outer surface is more effective.

Keywords

Tie Rod End; Numerical Simulation; Defect Structure; Stress Distribution.

1. Introduction

With the development of national railway construction, China's railway transport industry has also been rapid development, railway transport capacity has been greatly developed, the subsequent braking of freight trains has become a very important issue, and the brake regulator is one of the key components [1-3]. The basic structure of the automatic brake shoe clearance adjuster is actually equivalent to cutting the pull rod into two sections and putting them together. One section is made into a screw, and the other section is made into a hollow rod with a frame. In the middle, the adjusting nut is used to connect. When the adjusting nut is turned, the pull rod will be stretched or shortened. The pre compressed spring is installed before and after the adjusting nut, and the screw and adjusting nut are made into "multi head non self locking thread", and the spring pushes the nut to rotate forward or backward. When the clearance between the brake shoe and the brake shoe is within the normal range, the clearance between the brake shoe and the brake shoe will be automatically increased when the clearance between the brake shoe and the brake shoe will be automatically increased to the normal range. ST series brake regulators are widely used in railway freight trains in China, including ST2-250 and st1-600. Among them, the ST2-250 brake regulator is the main brake regulator for new railway freight trains in China, and its typical installation method is to install between the front and rear brake levers [4-7]. The main function of the brake regulator is to compensate for the wheels and brake shoes through the extension or shortening of the brake regulator, control the gap of the brake shoes, maintain the normal stroke of the brake cylinder piston, and ensure the safety of train operation. However, in the operation of the vehicle, the brake regulator is prone

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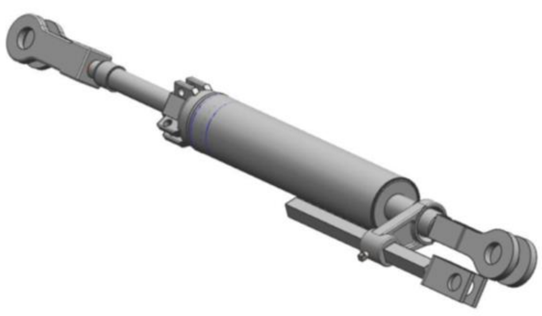
to failure in its adjustment function. Among the vulnerable parts of the brake regulator, the end of the tie rod is one of them.

Since the 1970s and 1980s, with the rapid development of computer technology, computer as a powerful tool has been widely used in various engineering fields, including quenching field. As a computer aided process planning method, numerical simulation of quenching process can optimize the design process, reduce the reject rate and greatly improve the work efficiency. Although the computer simulation technology of quenching process has made some progress in recent years, it shows great advantages.

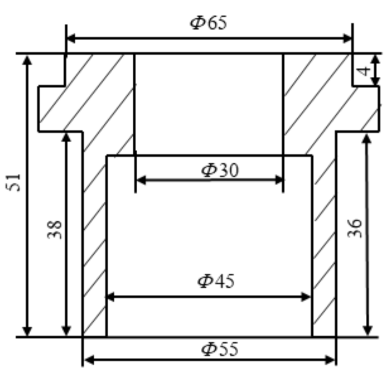
In the process of heat treatment, the thermal stress and phase transformation stress are formed because of the uneven temperature distribution in the parts and the non-uniform structure transformation process [8]. The existence of these stresses will directly affect the tensile properties and service life of the tie rod end, and affect the safety of the freight train operation. If the heat treatment is not correct, the structure and property of the parts cannot reach the predetermined requirements, and even excessive deformation or cracking will be produced. The actual production shows that cracks and defects often appear in the end of tie rod after heat treatment, which seriously affect the performance of parts [9-10]. Because heat treatment is a very complex process, which is affected by many factors, and the influencing factors interact and restrict each other, the traditional method cannot completely and accurately analyze or predict the temperature field and stress field of the heat treatment process. Numerical simulation can combine the physical phenomena of heat treatment process with the geometric model of parts. It reflects the temperature field and stress field dynamically in the process of heat treatment, so the numerical simulation technology of heat treatment has been widely used in recent research [11-12]. In order to study the law of temperature and stress in the heat treatment process of the tie rod end, the temperature field and stress field of the part with defects are studied by using numerical simulation method, and the effect factors of defect structure are considered. The law of defect on the end of pull rod is obtained, and further understands the failure reason and mechanism. According to the results, the structure of the part is modified to reduce the stress concentration, it provides a theoretical reference for the heat treatment process and subsequent design of the tie rod end.

2. Finite element model

During heat treatment, due to the effect of thermal expansion on the part of the tie rod end under high temperature, the part itself will generate stress. Taking into account the geometric shape of the part and the nonlinearity of the material, the general finite element software is used in this paper to analysis the stress of the tie rod end under high temperature. Use UG's modeling tools to build 3D solid model of parts. The dimension of the part is shown in Fig.1.



(a) Brake shoes stack adjuster



(b) Diagram of tie rod end size

Fig. 1 Dimensions of the parts

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The material of tie rod end parts is common 45 steel. Its density and temperature difference change very little and can be treated as a constant, which is taken as 7833kg/m^3, yield strength is 355MPa, Poisson's ratio is 0.3, and elastic modulus is 206GPa. In the analysis process, the non-linear property of the material's physical parameters needs to be considered. Since the thermophysical properties are parameters of temperature and the composition of the phase change, and the temperature changes greatly during the heat treatment process, it is obviously unreasonable to regard the thermophysical properties of the material as fixed. The specific heat capacity and thermal conductivity of the material Should be a function of temperature. The specific heat capacity, thermal conductivity and temperature change of 45 steel are shown in Table 1 according to the reference. Where T is the temperature (℃), C_p is the specific heat capacity of the material (J/kg·℃), is the thermal conductivity of the material (W/m·℃), and the thermal expansion coefficient of the 45 steel material is 11.59e-6.

Table 1. The relationship between the specific heat, thermal conductivity and temperature of 45 steel

T	100	200	300	400	500	600	700	755	800	900	1000
C_p	480	498	524	560	615	700	854	1064	806	637	602
λ	43.53	40.44	38.13	36.02	34.16	31.98	28.66	25.14	26.49	25.92	24.02

In this paper, the defect is simplified as a cube and located on the surface of the part. The initial size of the defect is 2mm×1mm×1mm. The inner surface of the defect is a uniform plane without other burrs or cracks. In addition, other surfaces of the tie rod end are smooth. Coupled temperature-displacement is used for analysis. The eight-node C3D8T elements are employed for modelling the tie rod end. At the same time, the mesh is refined at the defect location. The finite element mesh of the model is shown in Fig.2.

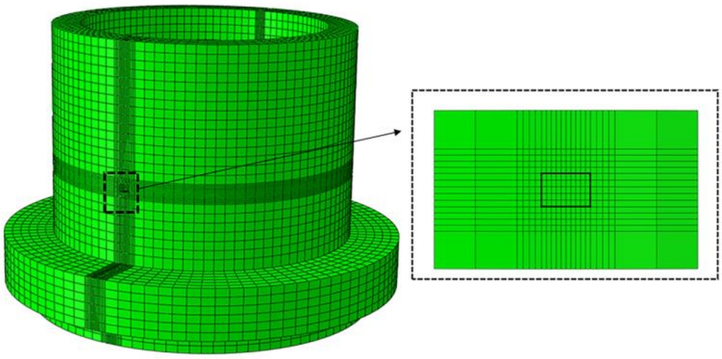

Fig. 2 Finite element model

Based on the actual working conditions, a normal constraint is imposed on the bottom of the model to limit the displacement and rotation of the surface in the vertical direction. During the heating process, the temperature gradually increased from room temperature to 820°C, and the heating process lasted for 10 minutes, after which the model was subjected to a heat preservation process for a total of 1 h, and the temperature load was applied to all external surfaces of the model.

3. Parameter effect analysis

3.1. Defect depth effect

The defect structure affects the geometric size of the defect in the whole part, so it is necessary to study the effect of the defect structure size on the part. Fig.3 shows the stress distribution

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around the entire defect structure when the defect is about 24mm away from the top (in the middle of the part), under different defect depths (the defect depth varies from 0.5mm to 2mm). Consider the stress changes at four positions A, B, C, and D on the outer surface of the defect. It can be seen from the figure that because the surface of the part is curved, the stress is concentrated at the apexes around the defect. The maximum stress is at two points A and B, that is, two points above the outer surface of the defect. On the outside of the defect structure, there is a transition zone where the stress decreases rapidly, and the stress changes on the inner surfaces of the defect are not obvious. The stress distribution at the two points A and B on the defect surface is basically the same, and the stress distribution at the two points C and D is basically the same. In addition, the maximum stress of the defect increases with the increasing of the defect depth, and the growth rate does not change linearly, but the amount of change is more obvious. When the depth is 0.5mm, the maximum stress is 20.23MPa, and when the depth is 2mm, the maximum stress is 31.5MPa, an increase of 55.7%. Therefore, in actual production, the normal use ability of tie rod end parts with large defects should be considered.

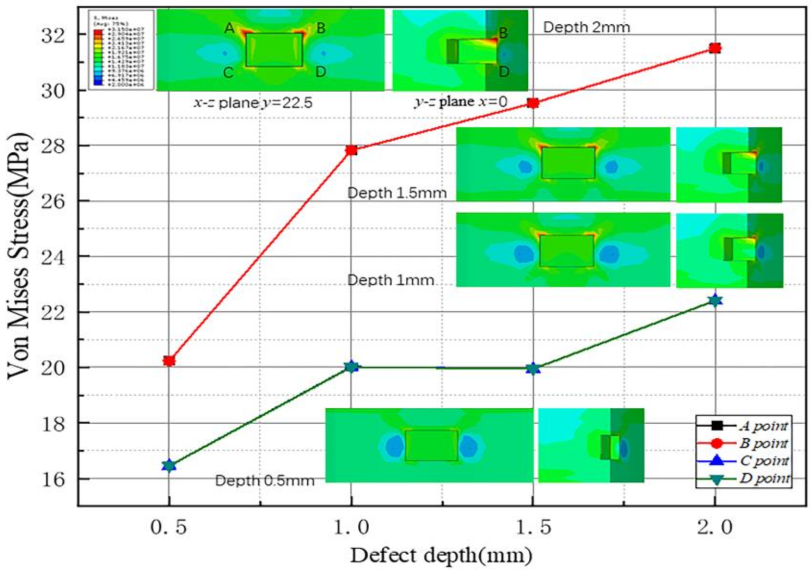

Fig. 3 The stress distribution with different defect depths

3.2. Defect area effect

Different defect areas will cause the complexity of the surface structure of the entire tie rod end part, which makes the surface stress distribution of the part more complicated. Fig.4 shows the stress distribution around the entire defect structure with different defect areas (the defect length varies from 0.5mm to 2.5mm) when the defect is about 24mm from the top and the defect depth is 1mm. Consider the stress changes at four positions A, B, C, and D on the inner side of the defect, where A and C are on the outside of the defect, B and D are on the inside of the defect. Although the stress is concentrated on the vertices around the defect, the stresses at points A and C on the outer surface are greater than points B and D, and the maximum stress is still point A, which is above the outer surface of the defect. The stresses at points A and C decrease as the defect area increasing, and the change is more obvious. When the defect area is 0.5 mm^2, the maximum stress at point A is 36.91 MPa, and the maximum stress at point C is 35.46 MPa. When the defect area is 2.5mm^2, the stresses at points A and C are reduced by 28.2% and 45.8%, respectively. In addition, the changes of stresses at points B and D are not obvious as the area increasing. Therefore, the parts with small defect areas are more likely to have stress concentration under the action of high temperature. If there are some initial cracks, the crack propagate may occurs, which should be paid attention to in actual production.

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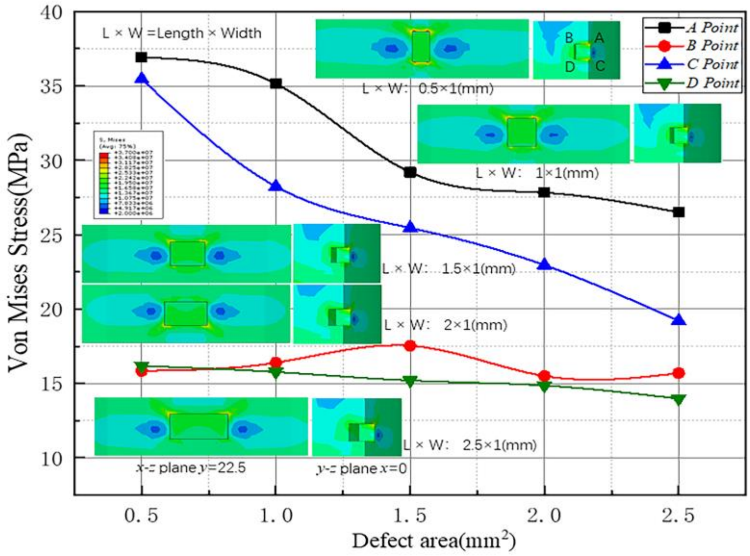

Fig. 4 The stress distribution with different defect areas

3.3. Defect position effect

The position of the defect also affects the overall geometric size of the part. If the position of the defect is at the geometric mutation position of the part, the stress distribution under high temperature becomes complicated. Fig.5 shows the stress distribution around the entire defect structure with the effect of different positions when the defect size is 2mm×1mm×1mm. There are four defective positions examined, among which positions 1, 2 and 3 are on the wall surface of the part, respectively 12mm, 24mm, and 36mm from the top surface, and position 4 is on the bottom step surface of the tie rod end part. In addition, A, B, C, D in the defect are the four vertices on one side of the defect. The stress at position 3 is the largest, the maximum stress reaches 115.47 MPa, followed by position 4, and the stress at position 1 is the smallest. Because in the Fig. 4, the position 3 is the high stress area of the entire part, and the defect stress is more obvious based on this situation. In addition, location 4 is close to the high stress area of the part, and the step surface structure of the part is more complex, which makes the internal stress of the defect more concentrated. For position 3, the maximum stress is point C, because this position is away from the center of the high-stress area of the part. The internal stress of defects at all positions are small at points B and D. Therefore, when the actual production defect exists in the sudden change position of the part surface, the strength of the this position should be considered.

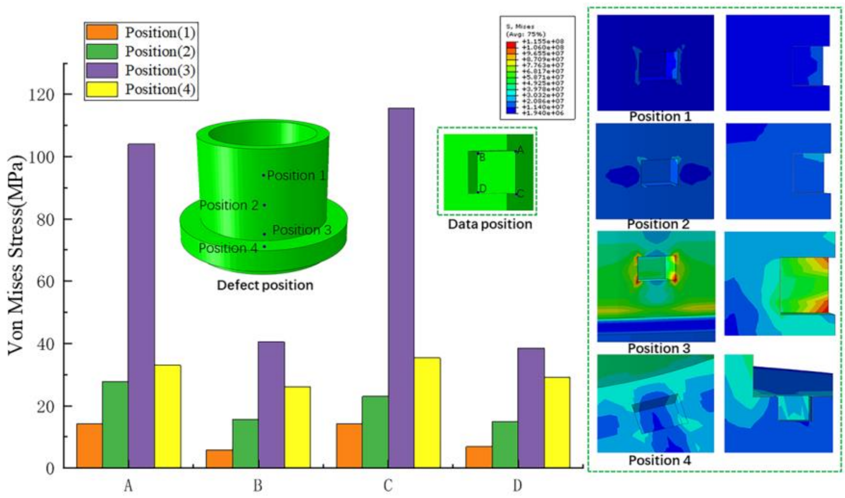

Fig. 5 The stress distribution with different defect positions

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3.4. Double defects effect

When two or more defects exist on the surface of the part at the same time, the stress distribution between the defects is more complicated. Fig.6 shows the stress distribution around the defect structure with the effect of different positions when there are double defects on the surface of the part, and the defect size is 2mm×1mm×1mm. There are 3 double defect positions, which are distributed inside and outside, distributed axially, and distributed circumferentially. Consider the stress at the apex of the defect as shown in the figure. When the double defects are distributed inside and outside, the overall stress of the internal defect is larger, and the maximum stress is at point a. The maximum stress area on the surface of the part is concentrated on the inner surface, the internal defect stress will be larger. When the double defects are distributed axially, the stress of the upper defect is smaller, but there is not much difference between the two defects. When the two defects are distributed in the circumferential direction, the stress distribution between the two defects is approximately symmetrical, and the maximum stress is located at the apex where the two defects are closer. When there are defects in the parts, it is easy to have a large stress concentration, and the practical application of this situation should be paid attention to.

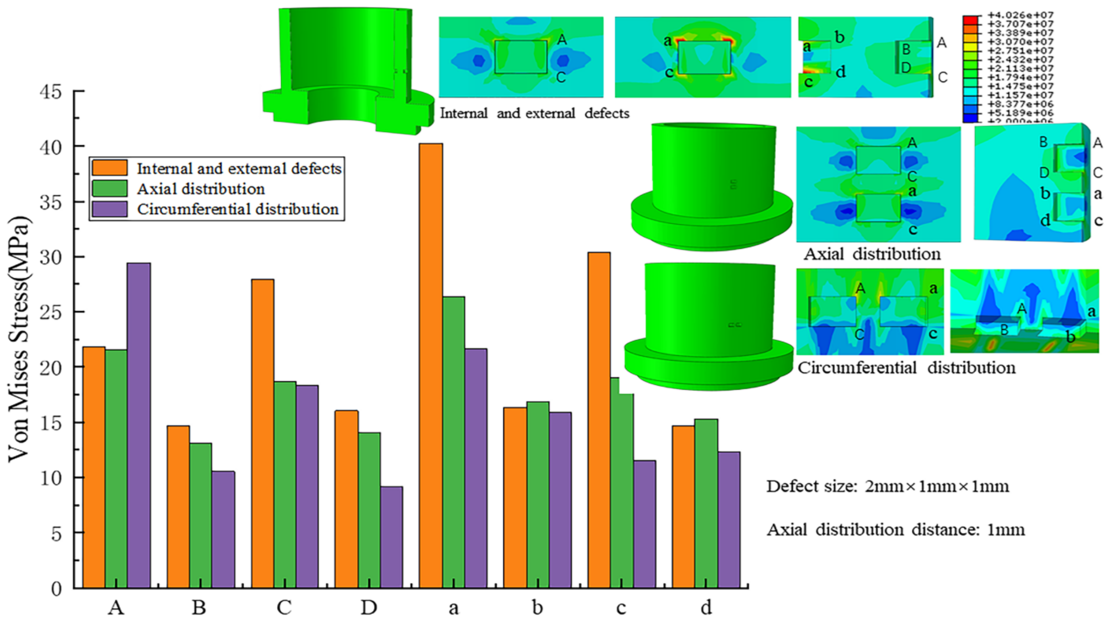

Fig. 6 The stress distribution with double defects

4. Conclusions

The tie rod end parts with defects are prone to stress concentration under high temperature load. Numerical model is established, the temperature field and stress field of the tie rod end parts with defects are studied in this paper, and the effect of the defect structure is considered which led to following conclusions:

(1) The temperature field and stress field of the tie rod end are distributed hierarchically. The high stress area is concentrated in the parts with abrupt change in geometry shape. At the same time, the stress concentration is formed at the edge and apex of the surface defect of the part.

(2) The stress of the defect of the tie rod end part under the high temperature increases with the increasing of the defect depth, and decreases with the increasing of the defect area.

(3) For defects at different positions, when the defect is in the high stress area of the part, it is easy to have stress concentration much larger than the surface of the part.

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(4) When the parts have double defects, the internal and external distribution of defects is prone to large stress concentration.

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