Study on the Microstructure and Mechanical Properties of 20 Steel Strain Aging

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Abstract: The strain aging process in the prefabrication process of 20 steel high-pressure pipe was simulated. The microstructure, hardness and impact absorption energy of the 20 steel pipes in the process were studied, and the mechanism was explained. The study shows that normalizing before prefabricated and stress relief annealing after prefabricated can be better to ensure the performance of the elbow.

1. Introduction

High-pressure pipes are an important part of large-scale industrial installations in industries such as ammonia synthesis, oil hydrocracking and power generation. 20 Steel is one of the most widely used steel. In recent years, a number of failure cases even explosion about high pressure pipe caused by strain aging have occurred. According to the survey, the same risk factors as the accident pipeline exists in a large number of high pressure pipes in the fertilizer， energy and power enterprises. Therefore, it is very important to optimize the production process and improve the safety of the high-pressure pipes by studying the regular relationship between the influencing factors and the microstructure and mechanical properties.

Some material organization and performance changes were qualitative and quantitative tested, and a number of trends strain aging factors were summed up. A. Beukel presented theory of the effect of dynamic strain aging on mechanical properties[1]. T. Peng studied the brittle law of the X100 pipeline steel in the strain aging by using micro-analysis methods and mechanical properties test[2]. M. Li studied avoiding and eliminating strain aging embrittlement by heat treatment methods commonly used in engineering [3]. N. Han et al.[4] and M. Chemingui et al.[5] studied the effect of stretching and aging on the microstructure of 7050 aluminum alloy and Al-Zn-Mg alloy by optical microscopy, scanning electron microscopy and transmission electron microscopy. A. Vasilyev et al.[6] revealed that the strain aging behavior of ultra-low carbon bake hardened steels in industrial production was the pinning of the gap atoms to dislocations.

S. Serajzadeh et al.[7] argued that the static strain aging after hot rolling leaded to an increase in material yield strength and tensile strength. M. Chemingui et al.[5] tested the mechanical properties of Al-Zn-Mg alloy at 70°C and 135°C in two aging steps with hardness and tensile tests. M. Shahriary et al.[8] studied the effect of dynamic strain aging on room temperature mechanical properties of high martensite dual phase (HMDP) steel， and S. Luo et al. [9] studied the effect of dynamic strain aging on the microstructure and mechanical properties of a reactor pressure vessel steel. S Lou et al.[10] studied the elevated temperature mechanical properties and dynamic strain aging in pressure vessel quality steel plate.

The main contents of this paper are the evolution of microstructures and mechanical properties of 20 steel under various strain aging factors.

2. Test design

2.1Test material

Test material is Ø273×40 specifications of 20 steel pipes from a prefabricated factory without service. Material composition in Table 1 meets the relevant standards at home and abroad. The material is recorded as N85.

TABLE 1. THE CHEMICAL COMPOSITION OF 20 STEEL (W%)

Number	W_C	W_{Si}	W_{Mn}	W_P	W_S
N85	0.220	0.270	0.535	0.018	0.0039
GB6479	0.17-0.24	0.17-0.37	0.35-0.65	≦0.030	≦0.030
GB9948	0.17-0.23	0.17-0.37	0.35-0.65	≦0.030	≦0.020
GB5310G	0.17-0.23	0.17-0.37	0.35-0.65	≦0.025	≦0.015
AISI1020	0.18-0.23		0.30-0.60	≦0.04	≦0.05

2.2Heat treatment method and process

Industrial steel pipe treatment process was simulated. Prefabricated process was simulated with different strain and aging，normalizing before prefabricated and stress relief annealing after prefabricated.

Plastic deformation values are respectively 0%, 5%, 7%, 8% and 10% from small to large, along the steel pipe axis direction. The maximum deformation of the test is 10%. Heat treatment is shown in Table 2.

TABLE 2. HEAT TREATMENT

Heat treatment	Heating temperature	Holding time	Cooling method
Normalizing	910℃±10℃	3mm/min	Air cooling
Aging	250℃	1 hour	Air cooling
Stress relief annealing with high temperature	635℃±10℃	3mm/min	Furnace cooling to 350 ℃ then air cooling
Stress relief annealing with low temperature	590℃±10℃	3mm/min	Furnace cooling to 350 ℃ then air cooling

3. Test results and analysis

3.1Microstructure

1) *Normalizing microstructure*

Metallographic structure of normalizing N85 shown in Fig.1, the ferrite-pearlite is homogeneous. SEM structure shown in Fig.2, cementite layer is thin, and the gap is small.

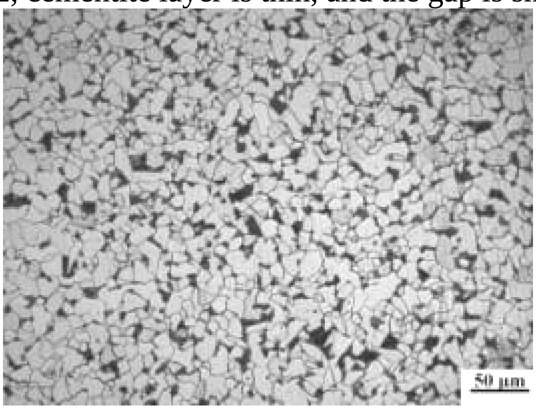

Figure 1. Normalizing metallographic of N85

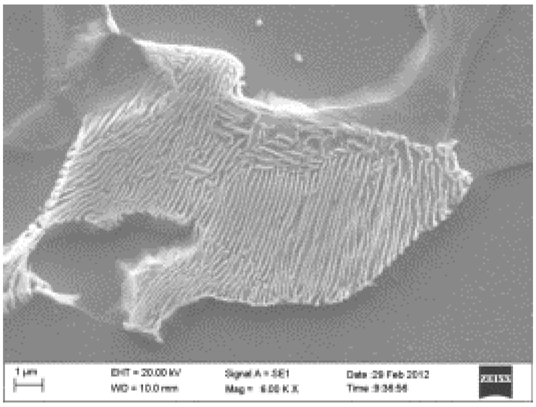

Figure 2. The pearlite of normalizing N85

2) *the microstructure with normalizing and plastic deformation*

They have no significant change which are in the OM structure and the SEM structure of N85 with 7% plastic deformation after normalizing and SEM microstructure with 10% strain aging after normalizing compared with the pearlite in the heat treatment.

3) *The pearlite with normalizing and different strain aging and stress relief annealing*

a) *The pearlite with stress relief annealing at different temperatures*

The microstructures of N85 with normalizing and 10% strain aging and 590°C and 635°C stress relief annealing respectively are shown in Fig.3 and Fig.4. The sheet cementite converts into pellets partly and almost all after 590℃ and 635℃stress relief annealing respectively. The pearlites in two processes both remain the original shape. The cementite does not diffuse into the eutectoid ferrite.

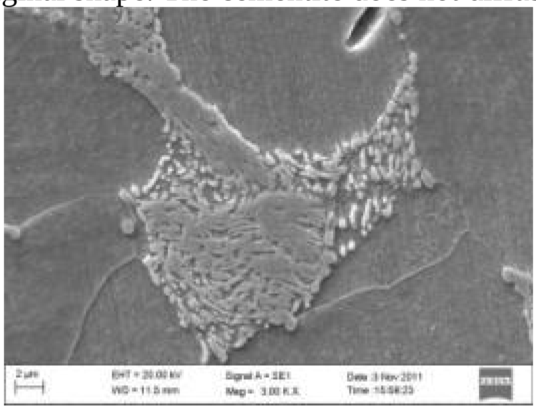

Figure 3. The 590℃ stress relief annealing microstructure with 10% strain aging after normalizing of N85 with SEM

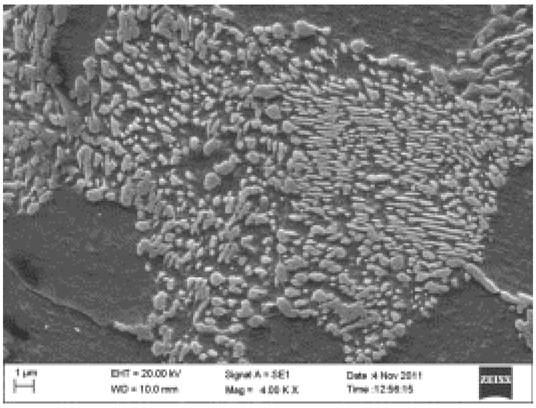

Figure 4. The 635℃ stress relief annealing microstructure with 10% strain aging after normalizing of N85 with SEM

The pearlite is a metastable structure. When annealing can reduce the driving force of the interface, the lamellar cementite is spontaneously transformed into granular form due to its large surface area and high interfacial energy. For the 20 steel with the same amount of cementite, the strength and hardness of granular pearlite is lower than that of lamellar pearlite, but the plasticity is better, the fracture strength and fatigue resistance are higher, and the ductile and brittle transition temperature is lower.

b) *The pearlite with normalizing and different strain aging and stress relief annealing*

The SEM structures of N85 with normalizing and 5%, 8% and 10% strain aging separately and stress annealing are shown in Fig.5, Fig.6 and Fig.4. There is a phenomenon of granulation phenomenon of cementite in pearlite, and the degree of granulation increases with plastic deformation.

3.2Hardness evolution

4) *Hardness evolution of heat treatment and 10% strain aging and stress relief annealing*

The hardness of 20 steel with non-heat treatment cannot be higher than 156HBS in the 《GB/T699-2015 high-quality carbon structural steel》. The hardness of N85 with as-received or normalizing，10% plastic deformation, aging，stress relief annealing in turn are shown in Fig.7. The hardness of as-received N85 and normalized N85 meet with the requirements of GB/T699. The hardness of N85 with 10% plastic deformation after heat treatment increases a lot, more than 156HBS. The hardness after aging is further increased relative to plastic deformation, which is much higher than that of 156HBS. Then after stress relief annealing, the hardness decreases significantly, but still slightly higher than 156HBS.

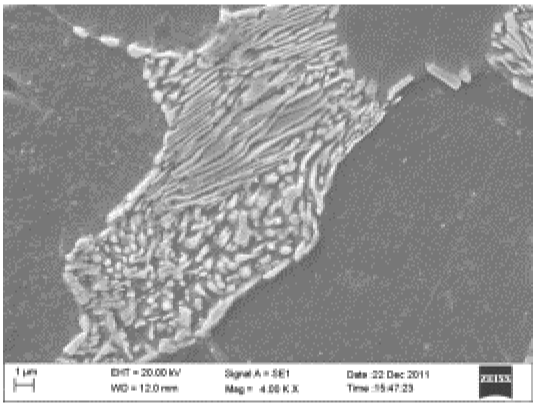

Figure 5. The stress relief annealing microstructure with 5% strain aging after normalizing of N85

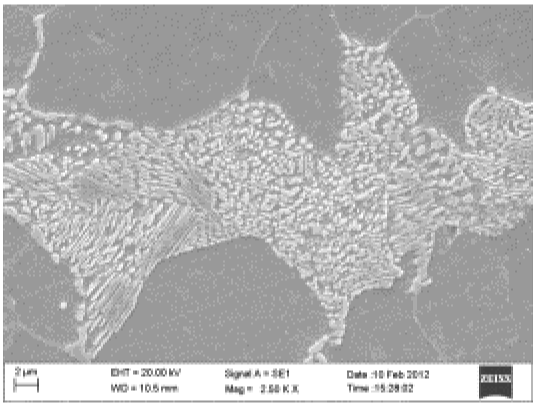

Figure 6. The stress relief annealing microstructure with 8% strain aging after normalizing of N85

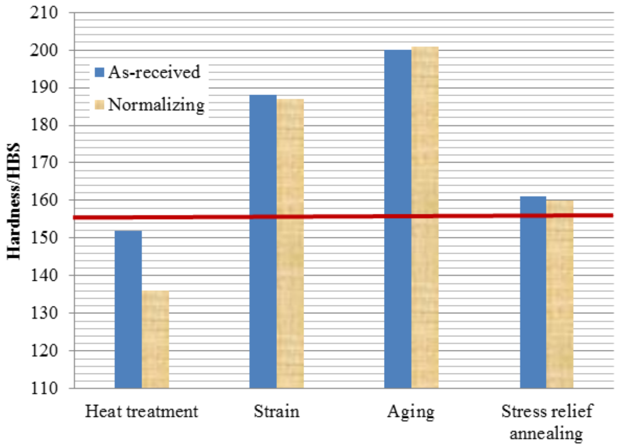

Figure 7. The N85 hardness changes at the process of at different heat treatment, 10% strain aging and stress relief annealing

5) The hardness with normalizing and different strain aging and stress relief annealing

The hardness of N85 with normalizing and 5% or 8% or 10% strain aging and stress relief annealing are shown in Fig.8. The hardness increases with increasing strain. The hardness with various strain after aging is higher than 156HBS. after stress relief annealing, the hardness with 5% strain is less than 156HBS, both 8% and 10% are still slightly higher than 156HBS.

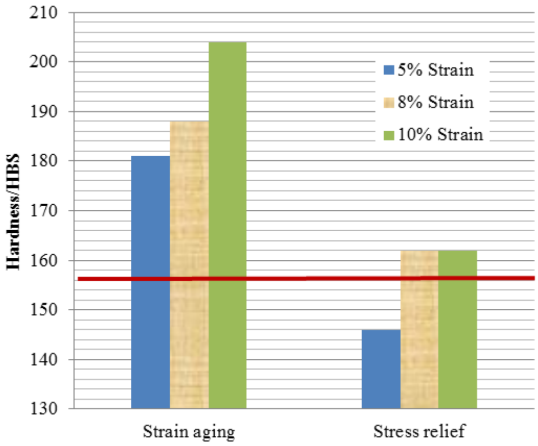

Figure 8. The hardness diagram of different stain aging and stress relief annealing

B. *Impact absorption energy*

《GB9948-2013 Seamless steel pipe for oil cracking》provides that the impact absorption energy of 20 steel is not less than 35J, while 《GB5310-2008 high pressure boiler seamless steel pipe》 provides the impact absorption energy is not less than 40J. The higher 40J is used as the criteria for impact absorption energy.

1) Strain aging

The Charpy V-notch impact absorption energy at room temperature 5℃ of N85 with different heat treatment and strain aging is shown in Fig.9. The impact absorption energy of as-received N85 is less than 40J. It is more than 100 after normalizing, which is greatly improved after normalizing. The impact absorption energy drops sharply to less than 20J after strain aging at two kinds of state. 10% strain and aging at 250℃ for 1h make 20 steel completely brittle.

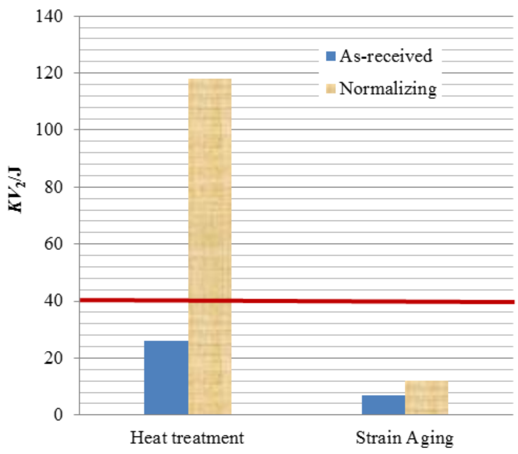

Figure 9. The impact absorbed energy of N85 with heat treatment and strain aging at 5℃

2) Stress relief annealing

Impact absorption energy of N85 with different treatment and 10% strain aging and stress relief annealing at room temperature 15℃ is shown in Fig.10. With stress relief annealing after 10% strain aging, the impact absorption energy decreases to meet the standard requirements.

The difference between the impact absorption energy of as-received N85 at 15℃ and 5℃ is very large. the impact absorption energy of 15℃ is higher than 40J , and it is lower than 40J at 5℃, which indicates that the as-received N85 occur ductile-brittle transition at room temperature. The Normalizing 20 steel reaches the standard requirement at both temperatures.

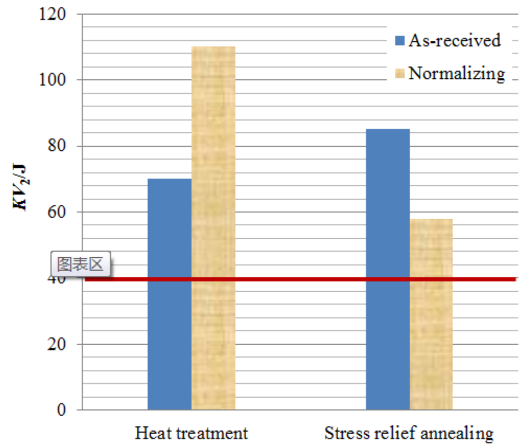

Figure 10. The impact absorbed energy of N85 with heat treatment and 10% strain aging combined with stress relief annealing at 15℃

3) The impact absorption energy with normalizing and different strain aging and stress annealing

The impact absorption energy of N85 with normalizing, different strain aging and stress relief annealing in turn is shown in Fig.11.

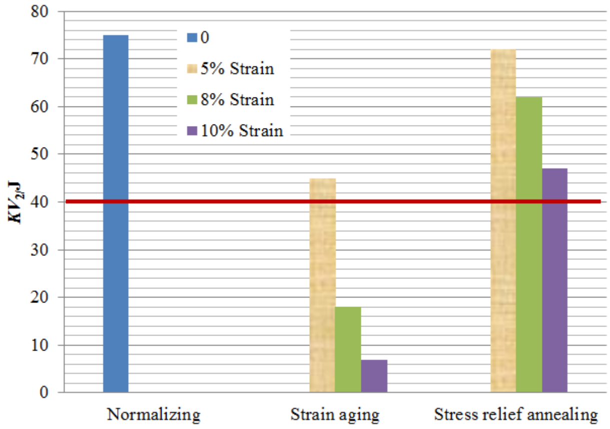

Figure 11. The impact absorption energy of different plastic deformation and heat treatments

The impact absorption energy with normalizing is higher. the impact absorption energy after the strain aging is much lower than that with normalizing. The greater the plastic deformation, the greater the impact absorption can be reduced. the impact absorption energy with Stress relief annealing increase to meet the standard requirements. The smaller the plastic deformation, the better the recovery is.

4. Conclusions

The microstructure of 20 steel with normalizing is fine and uniform. no significant changes is observed after strain after aging. to stress annealing after the trend of pelleting. There is a tendency to pelleting after stress relief annealing due to stretching.

Both the impact absorption energy and hardness are in the standard range with normalizing, which are lower than the standard requirements after strain aging. mechanical properties increase to meet the standard requirements after stress relief annealing.

According to the experimental results, it is suggested that the normalizing and stress relief annealing are carried out before and after 20 steel pipe is prefabricated separately.

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