Research on the influence of heat treatment temperature on bearing capacity of high steel grade pipeline during in-service welding

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Abstract. During the welding of in-service pipeline, natural gas is continuously transported in the pipeline, which maintains a high gas pressure. Therefore, the welding process is completed under strong cooling conditions, and welding delay crack is easy to occur. Preheating before welding and heat treatment after welding can effectively control the hardened microstructure, reduce the residual stress and ensure the welding quality. In this study, the influence of heating temperature on the bearing capacity of high steel grade pipe during in-service welding repair was studied. The high temperature tensile test was used to simulate the bearing capacity of the pipe under heating and high temperature environment. It is found that when the heating temperature is below 400°C, the pipe strength remains at the original level. With the increase of heating temperature, when the test temperature is higher than 400°C, the yield strength and tensile strength of the pipe decrease significantly. When the test temperature is 450°C, the yield strength and tensile strength of the material decrease by 15.8% and 11.1%, respectively, compared with the normal temperature, which are lower than the pipe standard requirements. Therefore, it is suggested that when the heat treatment temperature is higher than 400°C during in-service welding repair, it is necessary to consider reducing the pipeline pressure. At the same time, the box furnace heat treatment method was adopted to heat treat the pipe, and the tensile properties of the pipe after heat treatment were tested to analyze the bearing capacity of the pipe after heat treatment. It is found that when the heating temperature is higher than 700°C, the tensile properties of high grade pipeline steel pipe decrease sharply. It is suggested that when the heat treatment temperature is higher than 700°C, the risk assessment of the service safety of the heat treated pipeline should be carried out.

1 Introduction

In-service welding repair is one of the main repair methods in pipeline defects and leakage repair work. It can not only ensure the continuous pipeline transportation, but also reduce the degree of environmental damage, shorten the repair cycle and reduce the repair cost [1-2]. It has broad development prospects. At present, the in-service welding repair technology is faced with two technical difficulties, namely, burn-through and hydrogen-induced cracks [3-6]. Among them, burn-through mainly considers that the welding arc is instantaneously loaded on the pipe metal in the welding process, and the increases instantaneously. When the inner wall temperature of the pipe reaches 982 °C, the local strength loss of the pipe metal will occur. Hydrogen-induced cracks mainly consider the continuous transmission of natural gas in the pipeline during the welding of the in-service pipeline, so the welding process is completed under strong cooling conditions, which is easy to produce welding delayed cracks. Preheating before welding and heat treatment after welding can

effectively control the hardened structure, reduce the residual stress and ensure the welding quality. However, at present, the mainstream technology of pipeline steel production is to prepare high strength and toughness steel through low-carbon micro-alloying combined with thermo-mechanical control process. In practical application, when the heat treatment temperature is not controlled, the mechanical tensile properties of the pipe will change [7-10]. Therefore, it is necessary to study the influence of heat treatment temperature on the bearing capacity of high-grade pipeline during welding of in-service pipelines.

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2 Mechanical tensile properties of high grade steel pipes at high temperature

2.1 Test Materials and Methods

The test material was taken from φ1016mm×12.8mmX80 steel tube, and the chemical composition is shown in Table 1. The transverse rod-shaped specimen was taken at the pipe body for high temperature tensile test. The diameter of the gauge section of the specimen was 6.25mm, and the length of the gauge section was 25mm. The test equipment is CMT5105 material testing machine, and the test standard is ASTM E21-09.

Table 1. Chemical composition of test steel tubes (Wt×100%)

com posi tion	C	S i	M n	P	S	C r	M o	Ni	N b	V	T i	C u
cont ent	0. 4 9	0 1 9	1 . 8	0. 00 72	0. 00 23	0 . 3 1	0 . 2 4	0. 00 84	0. 0 8	0. 00 63	0. 0 2	0. 0 2

2.2 Test result

High temperature tensile test results are shown in Figure 1. When the test temperature is below 400°C, the strength index of the material fluctuates slightly. With the increase of test temperature, when the test temperature is higher than 400°C, the yield strength and tensile strength of the material decrease significantly. When the test temperature is 450°C, the yield strength of the material is 533MPa, the tensile strength is 618MPa, compared with the room temperature tensile properties decreased by 15.8% and 11.1%, the value is lower than the standard requirements. Therefore, it is suggested that when the post-weld heat treatment temperature is higher than 400°C, the depressurization treatment should be considered or the risk of in-service welding should be evaluated.

Figure 1. High temperature tensile test results

3 Mechanical tensile properties of high grade steel pipe after heat treatment

3.1 Test Materials and Methods

Four kinds of steel grade pipeline steel plates with different wall thicknesses were selected for heat treatment test. The chemical composition of the test material is shown in table 2. The heat treatment process is as follows: the test plate is heated to 300°C, 500°C, 600°C, 700°C, 900°C, 950°C, 1000°C and 1050°C respectively by box resistance furnace, and the furnace is cooled to room temperature after holding 55 minutes.

Table 2. Chemical composition of test steel tubes (Wt×100%)

n o .	st ee l g r a d e	Thic knes s mm										
			C	Si	M n	P	S	C r	N i	M o	N b	V
1	X	43	0. 04 9	0. 7 7	1. 5 7	0. 00 7	0.0 3	/	0. 2 1	0. 2 3	0. 04 5	0. 02 5
2	X	40	0. 06 6	0. 2 2	1. 5 3	0. 01 2	0.0 2	/	0. 2 2	0. 2 2	0. 03 7	0. 02 0
3	X	36	0. 06 3	0. 6 6	1. 9 9	0. 01 1	0.0 5	0.	0. 2 9	0. 1 9	0. 04 1	/
4	X	45	0. 1 1	2. 7 2	1. 2 2	0. 01 5	0.0 3	0.	0. 3 1	0. 0 5	0. 02 4	0. 04 0

The rod-like tensile samples were taken at the center of the wall thickness of the raw material and the heat-treated test block, respectively. The diameter of the gauge section was 12.7mm and the length of the gauge section was 50mm. The tensile test was carried out on the UH-F500 KNI tensile testing machine according to ASTM A370-2012a standard.

3.2 Test result

The yield strength of pipeline steel after heat treatment is shown in Fig. 2. After heat treatment at 300°C – 700°C, the yield strength of pipeline steel increases slightly, which is mainly related to the precipitation strengthening of steel after heat treatment. In the temperature range of 700°C – 900°C, the material enters the temperature range of ferrite and austenite, and the original TMCP controlled rolling structure changes to form partial recrystallized structure. The yield strength decreases with the increase of heat treatment temperature. When the heat treatment temperature was higher than 900°C, the buckling strength of the material increased with the increase of heat treatment temperature. The grain grew up and the yield strength began to increase after all the austenitized microstructure was cooled by air, making the two-phase region at 900 °C the lowest point of yield strength. The yield strength of sample 1 decreased by 94MPa, that of

sample 2 decreased by 161MPa, that of sample 3 decreased by 212MPa, and that of sample 4 decreased by 191MPa. The higher the raw material strength was, the greater the yield strength decreased. When the heat treatment temperature rises to 1050°C, the yield strength of No.2, No.3 and No.4 materials increases rapidly due to the further growth of grains.

Figure 2. Yield strength of pipeline steel after heat treatment

The tensile strength of the pipeline steel after heat treatment is shown in figure 2. When the heating temperature is not higher than 500°C, the change of the tensile strength of the material is not obvious. With the further improvement of the heating temperature, the tensile strength of the pipeline steel decreases first and then increases, and reaches the lowest value in the temperature range of 900°C ~ 950°C. The tensile strength of sample 1 is reduced by 194MPa compared with the measured value of raw materials, sample 2 is reduced by 148MPa, sample 3 is reduced by 155MPa, and sample 4 is reduced by 191MPa.

By comparing the mechanical tensile properties, it is suggested that when the heat treatment temperature is higher than 700°C, the service safety of the pipeline after heat treatment should be evaluated.

Fig 3 Tensile strength of pipeline steel after heat treatment

4 Conclusion

(1) The high temperature tensile test was used to simulate the bearing capacity of the pipeline under high temperature heating environment. It was found that the strength of the pipe maintained at the original level when the heating temperature was below 400°C. With the increase of heating temperature, when the test temperature was higher than 400°C, the yield strength and tensile strength of the pipe decreased significantly. When the test temperature was 450°C, the yield strength and tensile strength of the material decreased by 15.8% and 11.1% compared with those at room temperature, respectively, which were lower than the requirements of the pipe standard. It is suggested that the pipeline pressure should be reduced when the heat treatment temperature is higher than 400°C.

(2) The box furnace heat treatment method was used to heat the pipe, and the tensile properties of the pipe after heat treatment were tested. It was found that when the heating temperature was higher than 700°C, the tensile properties of high grade pipeline steel pipe decreased sharply. It is suggested that when the heat treatment temperature is higher than 700°C, the service safety of the pipeline after heat treatment should be evaluated.

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