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Research on the Microstructure and Mechanical Properties of the Weld Zone in Q345E Steel Gas Compressor Pipeline

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Abstract

Hot wire TIG welding and H10MnSiNiA welding rod was used to weld Q345E seamless steel gas compressor pipe in the article. The microstructure, impact strength and bending strength of weld zone for Q345E steel gas compressor pipeline and the affection of heat treatment were studied. The results show that the weld metal with welding shielded flux was well formed, flaw detection was qualified. The weld microstructure is composed of lath ferrite, a small amount of lamellar pearlite and granular bainite. The lower temperature treatment at 230°C don't change the microstructure morphology of the weld. The impact strength of hot wire TIG welding is 350-390J/cm^2 , which is superior to that of traditional TIG welding. The original bending strength of Q345E seamless steel pipe welded with hot wire TIG is 1000MPa. No crack has been observed on the surfaces of bending samples, revealing good bending strength, impact strength and the plasticity of the weld of hot wire TIG welding Q345E seamless steel pipe.

Keywords

Q345E seamless steel pipe, Hot wire TIG welding, Welding microstructure, Heat treatment, Gas compressor.

1. INTRODUCTION

Natural gas compressor is one of the indispensable equipment in the natural gas industry, holding a crucial position throughout the process of natural gas production, transportation, and processing. Natural gas processing usually requires liquefaction, recompression and separation, all of which require the support of natural gas compressors. The complex structure of natural gas compressor is largely composed of welded parts and the diverse range of pipeline materials, including high-quality carbon steel, low alloy steel, and stainless steel. The weld seams must exhibit high performance, especially in terms of impact and bending resistance.

Zhao Taiyuan et al [1-4] studied the welding process of compressor pipeline with Q345E seamless steel pipe, Chen Yanqing et al [5] studied the self-protective flux-cored wire semi-automatic welding X65, X70 and X80 pipeline steel; Yang Gang et al [6] developed a stainless-steel pipeline back without argon self-protective tungsten tig welding flux-cored wire HTYA316L (W); Luo Bao et al [7] studied the self-protective flux-cored wire YR-321L welding 06Cr18Ni11Ti stainless steel. However, there is limited research on hot wire welding of Q345E steel for natural gas compressor pipeline [8]. Therefore, this paper focuses on Q345E steel for natural gas compressor pipeline, using H10MnSiNiA welding rod and hot wire TIG welding to weld the Q345E seamless steel pipe. The aim is to study the microstructure and performance characteristics of the weld seam, as well as the effects of heat treatment to improve the productivity and reliability of welding applications involving Q345E steel for natural gas compressor pipelines.

2. MATERIALS AND TESTS

2.1. Test materials

The chemical composition of Q345E seamless steel used in this paper is shown in Table.1. The wall thickness of the seamless steel pipe is 13 mm, and the outer diameter of the pipe is 168 mm. The welding wire used is DHQ60-5, composed of H10MnSiNiA with a diameter of 1.2 mm. The chemical composition of the welding wire and the mechanical properties of the deposited metal are shown in Tables 2-3. The automatic welding equipment is the pipe clamp welding system (KB370, Kunshan Huaheng Welding Co. Ltd.). Hot wire TIG welding (as illustrated in Fig.1) is adopted for the Q345E seamless steel pipe, involving preheating the wire with a 20A current prior to welding.

Table 1. Chemical composition of Q345E steel (mass fraction, %)

composition	C	Si	Mn	S	P	Cr	Ni	Mo	V	Nb	Cu
mass fraction	0.12~ 0.18	0.20~ 0.50	1.20~ 1.70	≤ 0.010	≤ 0.025	≤ 0.30	≤ 0.50	≤ 0.10	≤ 0.15	≤0.07	—

Table 2. Chemical composition of welding wire - DHQ60-5 (mass fraction, %)

composition	C	Mn	Si	Cr	Ni	Cu	Mo	S	P	others
mass fraction	0.08	1.05	0.54	0.06	0.94	0.14	0.10	0.010	0.012	≤0.50

Table 3. Mechanical properties of the clad metal of the welding rod used for Q345E steel[8]

tensile strength δb(MPa)	yield strength δs (MPa)	elongation δ5 (%)	impact value KV2(J)
≥550	≥470	≥24	≥27

2.2. Test method

A Y-type bevel with an angle of 60° is used in the test. The welding layer of weld path is shown in Fig.1. A multi-layer multi-channel welding technique is adopted, as shown in Table.4. The process involves 1 layer in the base layer, 3 layers in the filling layer, and then 1 layer in the capping layer.

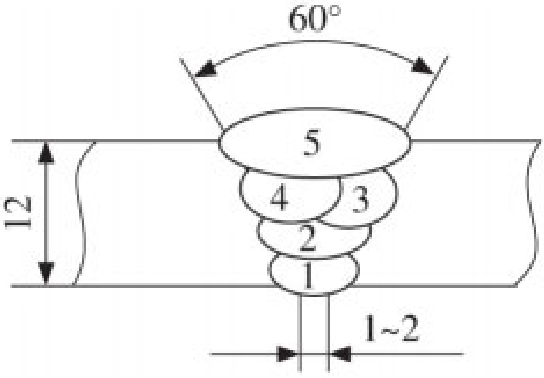

Figure 1. Diagram of welding method

Table 4. Welding process parameters of Q345E steel

layer	source polarity	hot wire current (A)	current (A)	yaw amplitude (mm)	welding speed (mm/min)	wire feed speed (mm/min)
1(base layer)	DC-	20	185	4.0	81	1000
2(filling layer)	DC-	20	210	6.0	65	1000
3(capping layer)	DC-	20	200	10.0	60	1000

2.3. Heat treatment process

In order to study the effects of heat treatment on the microstructure and properties of Q345E steel pipe hot wire welding weld seam, low-temperature tempering at 180℃, 200℃, 230℃, and high-temperature austenitization at 920℃ were applied. The high-temperature austenitization is conducted in a furnace. From 0 ℃ - 800 ℃, the heating speed is 10℃/min. From 800 ℃ - 920 ℃, the heating speed reduced to 3 ℃ / min. After reaching the required temperature of 920 ℃, open the furnace and then clamp the sample quickly into the furnace with tongs for insulation (half an hour). After that, the sample was air-cooled to room temperature. The microstructure and mechanical properties of the sample were then investigated and compared with those of weld seam sample in the original state.

2.4. Mechanical performance tests

According to the standard NB/T 47014-2011, 3 impact samples were intercepted in the weld area of the welded joint. The size of the impact sample is 5mm×10mm×55mm. A V-type bevel with an angle of 45° and a depth of 2.00±0.05mm was used. According to GB/T 229-2007, the impact test was carried out on ZBC2302-C pendulum impact tester on pendulum impact test machine.

According to NB/T 47014-2011, the welded joints are intercepted 2 face bending samples and 2 back bending samples. Bending test was carried out in the SHT4605-type 60 t microcomputer-controlled electro-hydraulic servo universal testing machine by following the standard GB/T 2653-2008. the results show that there is no cracks on the bending surface, as shown in Fig.2 (B, C), the weld seam has good plastic toughness, it suggests that the selection of welding materials and the welding process set is suitable for welding of Q345E seamless steel pipe.

3. RESULTS AND ANALYSIS

3.1. Appearance inspection and non-destructive testing of welded joints

After welding, the appearance inspection is carried out on the weld according to the standard of NB/T 47014-2011. The welded joints are well formed with no defects of non-penetrating weld, incomplete fusion, pore, sticky slag and crack, as shown in Fig 2. The highest residual height of the weld seam is 1.7 mm. It meets the requirement of no more than 3.0 mm as described in the standard GB/T 20801.5-2006.

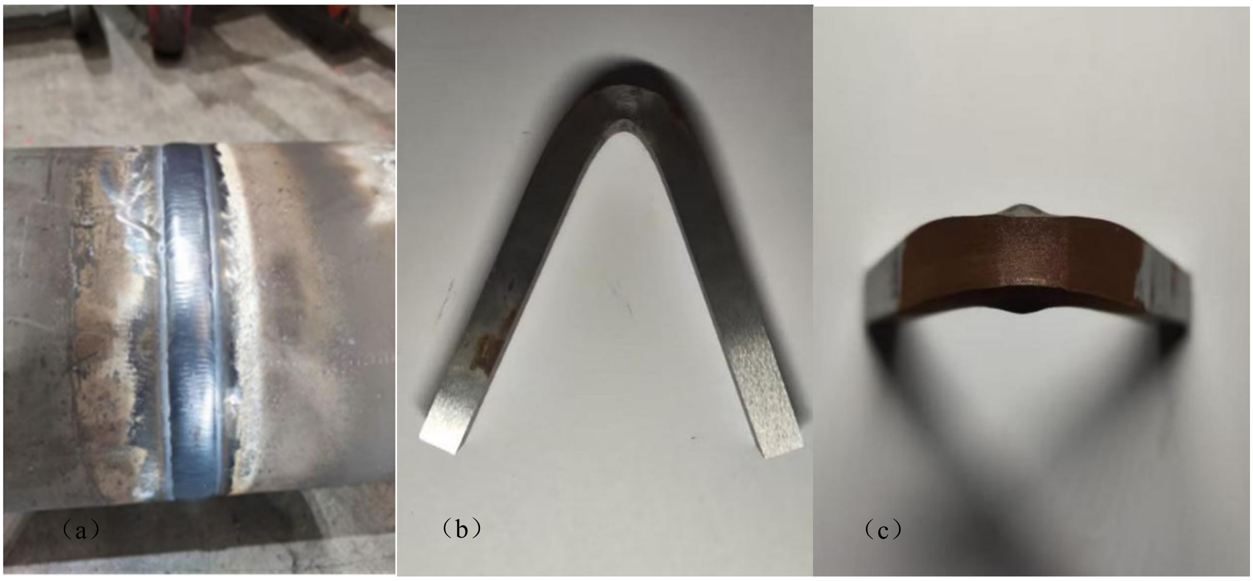

Figure 2. Appearance and orphology of Q345E steel pipe hot wire welding seam and bending weld seam: (a) appearance of weld seam; (b) back side morphology of bending weld seam; (c) front side morphology of bending weld seam

The welded joint is subjected to 100% ray flaw detection test according to the standard NB/T 47013-2015. Along the 120° circumference of the weld seam, a total of 3 photographs were taken by using vertical transillumination. To meet the weld quality standard of not less than Ⅱ level as described in GB / T 20801.5-2006, the test attempted to reached the I level of the standard.

3.2. .Microstructure analysis

The microstructure of welded joints was observed on the OLYMPUS GX-71F metallurgical microscope following the standard GB/T 13298-2015. Before the observation, the sample was grand, polished and etched. The etching solution is 4% nitric acid alcohol solution. Fig.3 shows the microstructure of original weld and of the weld conducted low-temperature tempering. For the sample in the figure, the microstructure of the weld area is composed of massive ferrite and pearlite as well as a small amount of bainite. As for the weld joint after low-temperature tempering, it shows the heat treatment has little effect on the microstructure and morphology. A small amount of widmanstatten structure is observed in the weld microstructure due to the high Mn content presented in the Q345E steel. Also, a small amount of granular bainite microstructure and feathery bainite were observed, as shown in the red circle in Fig. 3. These observations are in consistent with the results of previous research [9]. It has harmful effects on weld microstructure and performance. When the temperature reaches 920℃, reaustenitization has occurred, and the microstructure within the weld is mainly composed of ferrite and pearlite. The grains became larger and more isometric with similar sizes, as shown in Fig.3 (e).

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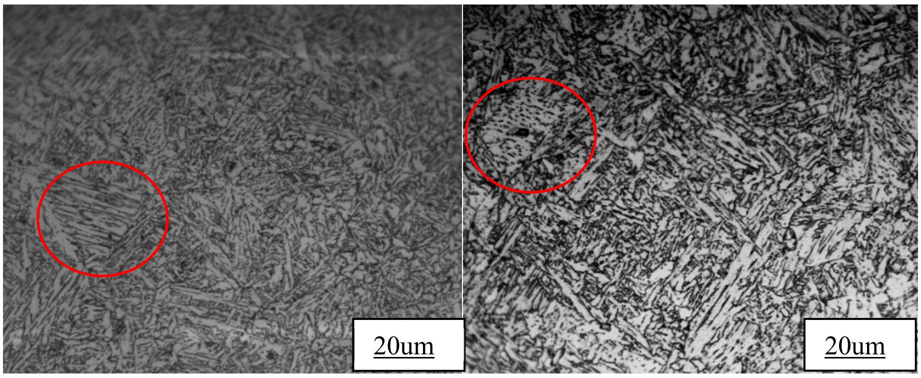
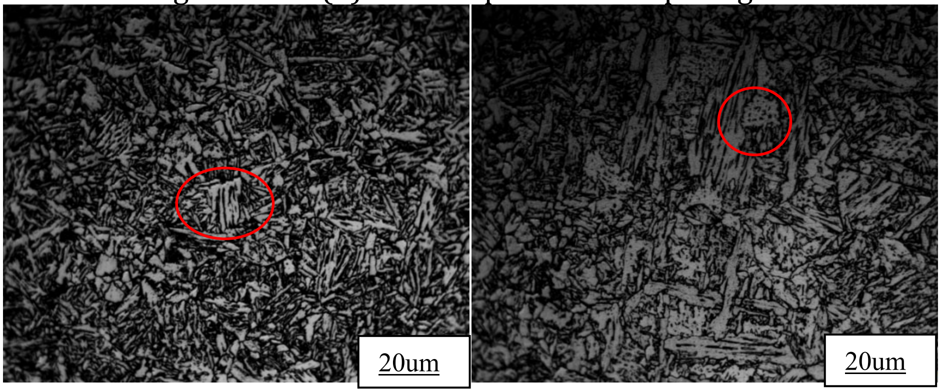
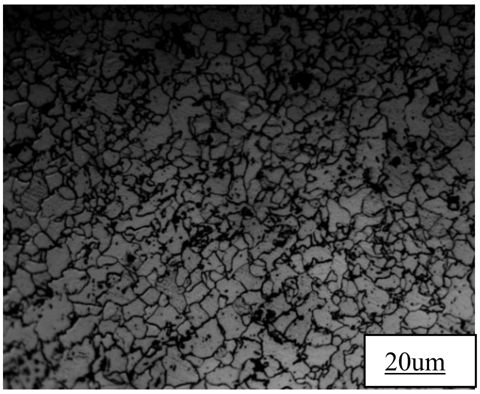


(a)weld seam of original state (b) low-temperature tempering weld seam at 180 °C

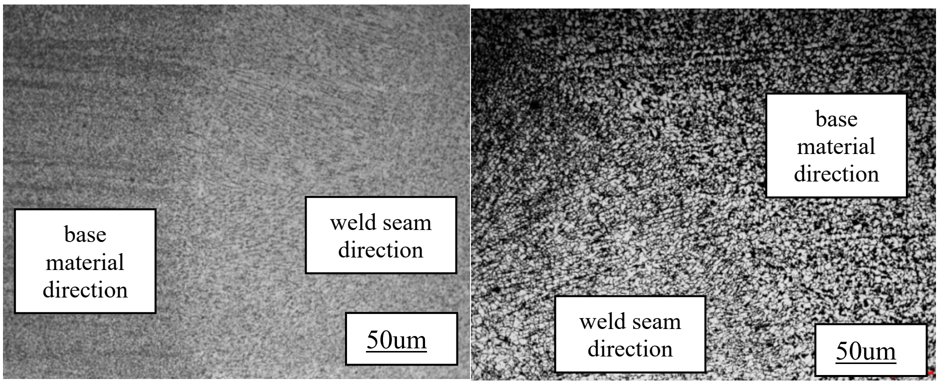


(c) low-temperature tempering weld seam at 200°C (d) low-temperature tempering weld seam at 230°C



(e)high temperature austenitized weld seam at 920°C

Figure 3. Microstructure characteristics of weld seam under different heat treatment states



(a) fusion line of original state (b) 920°C high-temperature austenitization fusion line

Figure 4. Microstructure and fusion line characteristics of the weld seam zone

Fig.4 is the microstructure and fusion line characteristics of the weld zone. At low-times, the weld microstructure of the original-state is obviously finer than that treated by 920℃ high-temperature austenitization. The microstructure in the fusion line on the left side of the base material of the original state shows equiaxed grains, and the right side of the weld zone is a columnar grain microstructure. During the welding, heat dissipation of the internal and external surface of Q345E steel is different due to the different cooling rate. Therefore, there is a great temperature gradient, resulting in columnar grains in the vicinity of the fusion line. Particularly, the columnar crystals form fast along the direction of the temperature gradient.

3.3. Mechanical properties of welded seam

Table.5 shows the impact energy of the impact sample of Q345E hot wire TIG welding. It was found that the impact energy is much higher than that of the reference standard (mechanical properties of the weld metal of the welding rod used in the Q345E steel [8] KV_2 (J) $\geqslant$ 27). Moreover, the post-weld heat treatment can improve the impact resistance performance, which increased from 140 J to 155 J.

Table 5. Impact energy of hot wire welded Q345E pipe

welding method	state	impact energy KV_2(J)			
		sample 1	sample 2	sample 3	average value (J)
hot wire TIG welding	original state	135	140	147	140.7
	180℃ low temperature tempering	152	156	158	155.3
	200℃ low temperature tempering	150	158	155	154.3
	230℃ low temperature tempering	146	156	158	153.3
	920℃ high temperature austenitizing	145	148	147	146.7

In order to explore the different effects of hot wire TIG welding and traditional TIG welding on the Q345E weld seam zone, the impact strength was tested. The results were shown in Table 6. The minimum impact strength of the weld seam zone of the hot wire TIG welding weld zone is 350J/cm^2, which is still higher than the maximum impact strength of the traditional TIG welding weld zone. It suggests a higher toughness of the hot wire TIG welding weld zone than the traditional TIG welding weld zone. This is likely a result of finer microstructure in the weld zone of hot wire TIG welding compared to that of the weld zone of traditional TIG welding.

The bending performance of hot wire welded Q345E pipe weld is shown in Table 7. The bending strength of sample is as high as 1000MPa. The sample surface after bending is intact without cracks, as shown in Fig.2 (b, c). It indicates that the bending performance, impact toughness and plasticity of the hot wire welded Q345E pipe weld are outstanding. The maximum bending force and bending strength of Q345E pipe weld is also slightly elevated after tempering and high temperature heat treatment. This is because the welding defects that may existed in the welding process is eliminated during the low-temperature tempering, resulting in higher flexural strength. The maximum force also becomes larger. After reaustenitization at high temperatures, the internal microstructure begins to reaustenitize and recrystallization. More internal pearlites were emerged and uniform equiaxed grains were formed. Therefore, the flexural strength of Q345E becomes greater.

Table 6. Comparison of impact strength between hot wire TIG welding and TIG welding

welding method	state	impact energy (J)	impact strength (J/cm^2)
hot wire TIG welding	original state	140.7	351.75
	180°C low temperature tempering	155.3	388.25
	200°C low temperature tempering	154.3	385.75
	230°C low temperature tempering	153.3	383.25
	920°C high temperature austenitizing	146.7	366.75
TIG welding	original state	109.7	274.25
	180°C low temperature tempering	102.3	255.75
	200°C low temperature tempering	108.3	270.75
	230°C low temperature tempering	106.3	265.75
	920°C high temperature austenitizing	92.0	230.00

Table 7. Bending properties of hot wire welded Q345E pipe

performance state	original state	180°C low temperature tempering	200°C low temperature tempering	230°C low temperature tempering	920°C high temperature austenitizing
maximum bending force(kN)	7.08	7.17	7.30	7.21	7.89
average bending strength(MPa)	1061.89	1075.65	1095.23	1080.88	1184.55

4. CONCLUSION

(1) Low-temperature tempering below 230°C has no effect on the weld microstructure. The weld microstructure is mainly composed of lath ferrite, a small amount of lamellar pearlite, granular bainite, and widmanstatten structure. After 920°C high-temperature austenitization, the microstructure of the weld seam formed by air cooling is dominantly composed of thicker equiaxed ferrite.

(2) Low-temperature tempering and re-temperature austenitization below 230°C can further improve the impact energy of the hot wire TIG welding Q345E seamless steel pipe weld seam. The impact energy of the original weld rised from 140J to 155J. The impact strength of the hot wire TIG weld seam zone (350-390 J/cm^2) is higher than that of the conventional TIG weld seam zone (230-275 J/cm^2).

(3) The quality of the weld seam of welded joint is excellent without defects of non-penetrating weld, incomplete fusion, pore, sticky slag and crack. It meets the requirements of weld seam quality as stipulated in standard GB/T 20801.5-2006.

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