

Research on Coiled Tubing Butt Welding Process and Properties of Welded Joint

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1. Introduction

Coiled tubing technology is an advanced technique with great application prospect in Oil and Gas Exploration and production. With the development in past decades, coiled tubing changed from shot tubing butted together to one string with length of thousands meter, its material changed from normal carbon steel to high strength low alloyed steel, the grade covered 385~770MPa, and special purpose coiled tubing were also developed, such as titanium alloy and composite materials[1].

The working condition of coiled tubing is complicated, high strength, high plasticity and high corrosion resistance is demanded for its welded joint. Coiled tubing experienced three times welding during fabrication and utilization, i.e.

butt welding of plate, tube forming welding and butt welding of coiled tubing on site, gas tungsten arc welding (GTAW) welding method is usually used [2-5]. For butt welding on site, GTAW technological fixture and welding procedure are developed; the mechanical and corrosion properties of welded joint are researched in this paper.

2. Experiment Materials and Methods

CT80 and X52 grade coiled tubing were butt welded respectively, the dimension of which is $\Phi 33 \times 3.18\text{mm}$ and $\Phi 50.8 \times 4.44\text{mm}$. Automatic out-of position welding GTAW process was used; filling wire is specially developed for coiled tubing welding. The composition is listed in Table1, and mechanical properties are listed in Table2.

Table1 Composition of coiled tubing and filling wire

Tubing and wire	C	Si	Mn	P	S	Cu	Ni	Cr	Mo	Ti	Nb
CT 80	0.12	0.355	0.93	0.012	0.001	0.2	0.18	0.48			
X52	0.07	0.20	0.68	0.011	0.001	0.18	0.13	0.26	0.15	0.02	0.01
Filling wire	0.018	0.24	0.74	0.012	0.006		0.86	0.31		0.01	

Table2 Strength of coiled tubing and filling wire

Tubing and wire	$R_{10.5}$ [MPa]	R_m [MPa]	A_t [%]
CT 80	599	663	28
X52	488	575	40
Filling wire	688	720	21

EWA408 welding power and TOA77 automatic arc welding device was used for welding. HXD-1000ZMC was used to test the hardness HV300. Strength, bending and flattening properties of welded joint was measured with CSS-44000 UTM Universal Testing Machine. Microstructure is analyzed with JEOL JSM-6390A SEM. Corrosion properties are tested with M2273.

3. Results and Discussions

3.1 Welding procedure

Butt groove is machined to "V" shape, as shown in Fig.1, b , α and δ is 0, $75\sim 90^\circ$ and $0.5\sim 1\text{mm}$ respectively, special welding fixture was used to hold the joint together. Welding sequence consists of 3~4 layers welding. Filling wire is filled with speed of $90\sim 100\text{mm/min}$. Inter-pass temperature is controlled below 60°C .

To get uniform weld formation the internal flash of ERW seam weld is removed, its ovality and curvature is adjusted. The welding parameters were optimized according to weld formation and mechanical properties. Circumferential weld is divided into five parts, welding current is about $65\sim 74\text{A}$, voltage is about $8.6\sim 9.0\text{V}$, and welding speed is about $65\sim 80\text{mm/min}$.

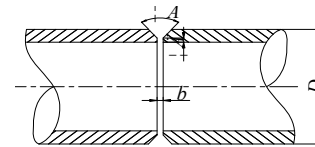


Fig.1 Butt welding groove

3.2 Mechanical properties

Coiled tubing is usually rolled with thermo mechanical control process (TMCP), and microstructure is always composed of ferrite and bainite, grain is very fine and usually under 12 grain-size classification, which is very sensitive to welding thermo. For welded joint, HAZ size is about 4-6mm, as shown in Fig.2. Through microstructure analysis, HAZ can be divided into coarse grain zone, normalized and tempered zone.

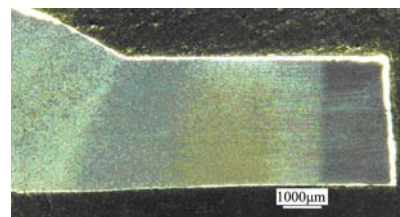


Fig.2 Macrograph of welded joint

Strength of welded joint was listed in Table 3. All

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strength of welded joint is decreased; CT80 and X52 joint decreased about 9% and 14% respectively, fracture starts from HAZ, which means softening existed. Hardness distribution along welded joint is shown in Fig.3, about HV218 for weld and base metal, but a softening zone is located in tempered zone, about 3-5mm distance from fusion line, and the hardness decline is about 15%, which is also the fracture location in tension test. So it can be derived that softening zone decreased the strength of welded joint.

Table 3 Strength (R_m) decrease of welded joints

Grade	Tubing [MPa]	Joint [MPa]	Decrease [%]	Water Cooling
CT80	663	606	9	N
X52	575	495	14	N
X52	594	581	2	Y

In order to reduce the influence of softening, water cooling is introduced into welding process, aimed at increasing cooling speed of HAZ and decreasing its residence time at high temperature. Hardness distribution of X52 welded joint is shown in Fig.3, the softening zone is located in area 5mm apart from weld center for no water cooling process, but no softening for water cooling process. Strength test results in Table2 also reveal the strength of welded joint with water cooling process is higher, and the strength descending range is only 2%.

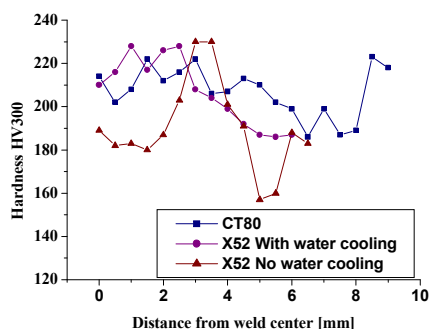


Fig.3 Hardness distribution

The deformability of welded joint was tested with flattening and bending method. In flattening, welded joint can be flattened to make the opposite side contact together, but no crack is observed in the specimen, as shown in Fig.4. In bending experiment, the punching head diameter is $\Phi 10$ mm, and no crack formed on bending surface, as shown in Fig.5. Results show welded joint has good deformability.



Fig.4 Specimen after flattening test

3.3 Corrosion resistance

Working condition of oil well acidizing treatment is

simulated in lab. The simulation solution is 28% HCl, corrosion time is 4h, and temperature is 100°C. Changing of specimen is shown in Fig.6. Coiled tubing was corroded uniformly; cover layer of weld is almost peeled off. The average corrosion rate of welded joint is about 0.00115689 g/(mm²·h), obviously it is more higher for weld. Composition of filling wire and tubing is different, as listed in Table 1, C content of filling wire is greater than tubing, but Cr content is lower, which induces different corrosion resistance. Corrosion potential for weld and tubing is -625.1mV and -672.5mV respectively, and corrosion current is 0.59A and 0.25A, which means better corrosion resistance for tubing, and couple corrosion will be established between weld and tubing. In couple corrosion, weld act as anode and tubing as cathode. Additionally, the dimension of weld is relatively small to tubing, so small anode and large cathode situation leads faster corrosion for weld.



Fig.5 Specimen after bending test



Fig.6 Changing of specimen in corrosion experiment

4. Conclusions

Automatic GTAW welding process of coiled tubing was developed; with the process ideal weld shape can be achieved. Softening area always exist in HAZ, which induces strength decrease for welded joint. With water cooling process, softening can be eliminated and strength decrease is only 2%. The welded joint also shows good bending and flattening deformability. Because of the composition difference between tubing metal and welding wire, couple corrosion formed in 28% HCl solution, which induces faster corrosion rate to the weld, and its cover layer is almost peeled off.

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