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Electric Resistance Welding of Dissimilar Pipes

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Abstract. Numerous studies have shown that corrosion of the casing outer side is one of the factors that has a negative impact on the accident rate of the casing string and is the reason of loss of tightness and various failures and complications in the well. The article describes a method of electric resistance welding of dissimilar steel bonding, which allows to increase the corrosion resistance of casing strings in elevator sections with an increased exterior aggressiveness. The developed technology solutions for welding conditions are presented. Metallographic studies of welded joints and recommendations for technological welding conditions are given.

1. Introduction

Corrosion is a common cause of oil field equipment and flow string failures [6, 12]. Corrosion damage to casing pipes often occurs due to loss of cement integrity under the influence of groundwater. Despite many research works to improve the quality of casing cementing [9], damage cannot be avoided.

The choice of corrosion-resistant materials can reduce the possibility of corrosion damage, but it is not always economically justified [18]. Since the corrosive media at different levels of the casing string is different, it may technically and economically be feasible to setup the casing pipe from dissimilar materials, that means to use low-alloyed and corrosion-resistant pipes in one string [3, 10].

One of the main requirements for pipe steel is a combination of strength and plastic properties, high rate of impact elasticity, fatigue resistance and corrosion resistance. DSS provides a good combination of mechanical properties along with high corrosion resistance of these steels (table 1) [4, 15, 17]. Among austenite and ferrite corrosion-resistant steels, duplex steels (DSS) stand out for their higher strength, toughness, corrosion resistance and heat conductivity. [1].

Joining pipes made of dissimilar materials by electric resistance welding is one of the advance research directions, since it allows to stop using sophisticated thread connections. A proper connection is ensured at high current densities, minimal heating time, while the development of a coarse-grained structure is excluded and the decontamination and oxide phase and overheated metal disposal from the welding area is provided [7, 19]. However the process of electric resistance welding has difficulties with a decrease in the stress-strain properties of connections, especially plasticity [8], nonsymmetrical strain conditions, which complicate the substitution of oxide films from the joint and the development of high-quality connections [7], with the generation of hardening texture at a high rate cooling.

While crystallizing duplex steel weld pool there is a risk that the ferrite content will be about 65%, which reduces the toughness and corrosion resistance of the weld. Consequently while predicting the

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behavior of a welded joint, it is necessary to know about the distribution of ferrite and austenite over the entire section of the welded joint and in the heat-affected area. [14, 16].

Therefore, the object of the work is to study the possibility of building up a casing string from dissimilar steels (low-alloy and duplex steel), connected by electric resistance welding. For this purpose the structure of the material in the weld area as well as stress-strain properties and corrosion resistance were investigated.

2. Methods and materials

To get a weld joint we used duplex 2205 corrosion resistant duplex steel and 09G2S low alloyed steel (Table 1).

Table 1. S31803 (duplex 2205) [20] and 09G2S [11] steel chemical composition.

S31803(duplex 2205)		09G2S	
C, %	0,03	C, %	0,12
Cr, %	21,0 - 23,0	Cr, %	0,3
Ni, %	4,5 - 6,5	Ni, %	0,3
Mn, %	2	Mn, %	1,3-1,7
Si, %	1	Si, %	0,5-0,8
Mo, %	2,50 - 3,50	Cu, %	0,3
N, %	0,08 - 0,20	N, %	0,008
P, %	0,03	P, %	0,035
S, %	0,02	S, %	0,04
F_{PREN}	31 - 38	As, %	0,08

For the study electric resistance welding was considered for five samples of pipes of duplex and low-alloy steel with different welding conditions (Table 2). In these welding conditions, the parts were compressed, followed by the electric current transmission, which led to the heating of the metal. As a result, interatomic bonds were set between the excited atoms located on the surfaces to be connected, that means a welded joint was formed.

Table 2. Welding conditions.

№	I, A·c	j, A/mm^2	t_w, s	U, V	p_{oc1}, bar	p_{oc2}, bar	Δoc, mm	IF, A·c
1	1845	3,33	5,58	24,1	122,2	120,2	4,95	53,3
2	1733	3,13	5,28	26,1	131,6	123,8	3,58	50,7
3	1948	3,52	5,77	25,1	127,9	123	4,86	54,8
4	1467	2,65	4,48	25,6	129,9	122	2,7	44,5
5	1701	3,07	5,28	28,6	136,6	124,8	4,07	50,7

Where j – current density, t_w – welding time, U – welding voltage, p_{oc1}- p_{oc2} – welding pressure, Δoc – welding value, IF – coil current [9].

The sample was a pipe with an external diameter of 48 mm, a wall thickness of 4 mm and a height of 90 to 100 mm (Figure 1). The distance from the current lead to the pipe joint was 50 mm.

After that a metallographic sample was cut in the longitudinal direction to study the heat-affected zone and the welded joint. The studies were carried out using an optical microscope (×500). Hardness measurements were performed by the Vickers method with a load of 180 g ($HV_{0,18}$).

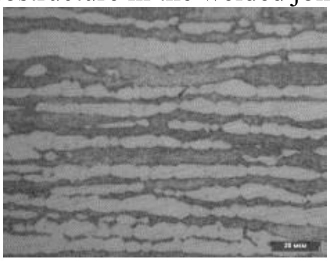
a

b

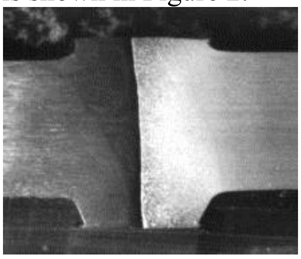
Figure 1. Test item: a – general view, b – dimensions.

3. Research results

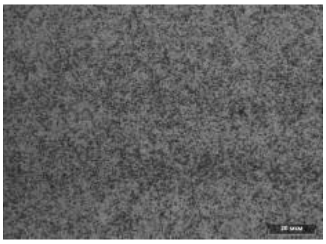
The microstructure in the welded joint is shown in Figure 2.



1) DSS microstructure



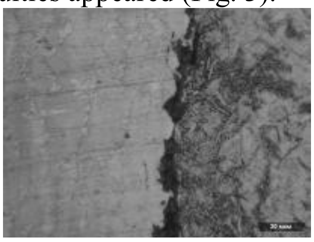
2) The welded joint macrophotograph



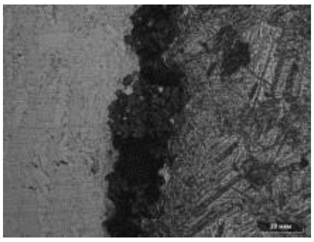
3) 09G2S microstructure

Figure 2. The metal structure of the welded joint of the sample №3.

During the compression of the parts towards the inner and outer walls of the pipe, the non-liquid metal spread out (Fig. 2). When the welded joint was formed, a line of separation of two metals with discontinuities appeared (Fig. 3).



1



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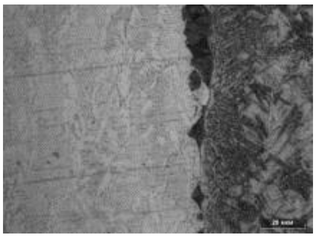

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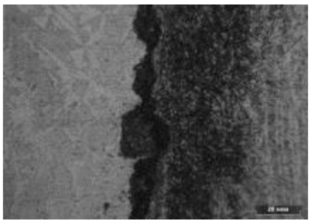

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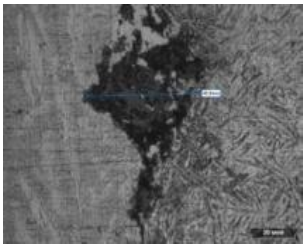


5

Figure 3. Discontinuities of different modes in the welded joint: 1-5, ×500.

For modes 2 and 4 discontinuities reach 20-25 microns, for mode 5 - 45 microns. Also, as we can see on Figure 4, there are drops of duplex steel metal on the inner surface of the pipe, which is the result of heating above the solidus during welding. Also some part of duplex steel flowed into low-alloyed steel, which also confirms the heating which exceeds the duplex steel solidus temperature.

Figure 4. Dropping metal duplex steel side (mode 5).

Low alloyed steel pipe grain in the welded joint is a martensite (Fig. 5, area 1), average hardness by mode was approximately 600 HV0,18. In the heat-affected area near the welded joint (Fig. 5, area 2), we have the banding of the low-alloy steel grain in martensite strips form, which are characterized by reduced hardness values), alternating with bainitic ones.

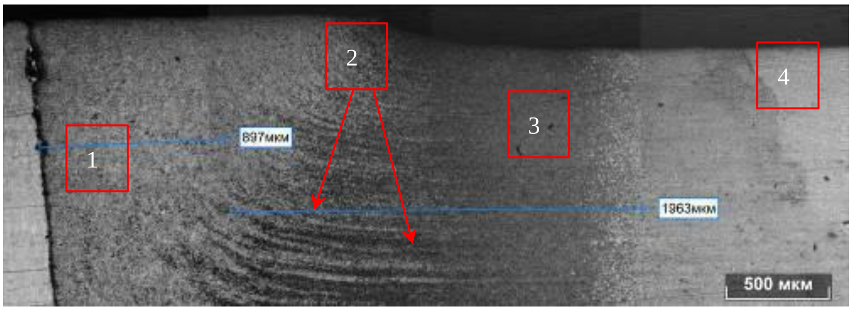
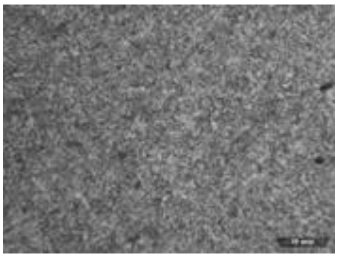


Figure 5. Panorama of the heat-affected zone of the welded joint low-alloyed steel side (mode 5), ×25.

Then there is the area 3, which has a bainite grain (Figure 6, area 3), the average hardness of the area by mode is about 390 $HV_{0,18}$. The base metal grain is sorbite (Fig. 6, area 4).

Area 3 grain



Area 4 grain

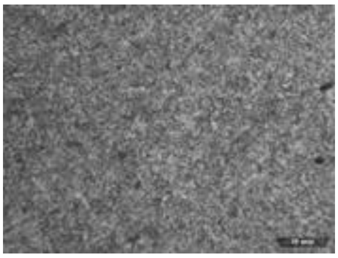
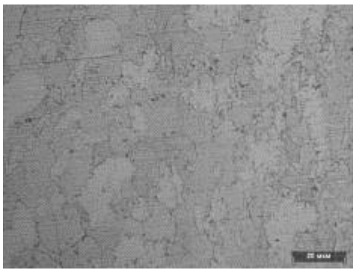


Figure 6. Low-alloyed steel grain in the welded joint, ×500.

The grain of a part of a duplex steel pipe in the welded joint area is a mixture of ferrite and austenite in an approximate ratio of 50/50 banded morphology (Fig. 7, dark areas are austenite, light areas are ferrite). Average hardness of area 3 (Fig. 7) for all welding conditions was ≈ 290 $HV_{0,18}$. In the heat-affected zone close to the welded joint (area 1), there is no banding of the grain, the average hardness of the area for all welding conditions is about 320 $HV_{0,18}$.

Microstructure close to welded joint



Base metal microstructure

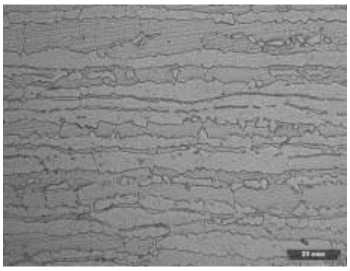


Figure 7. Duplex steel grain close to welded joint, ×500.

To accurate determine the grain in different areas of welded joints, as well as to determine the dimensions of the heat-affected area at the weld boundary, the hardness of the welded joints was measured by metallographic study. The results of measuring the hardness of welded joints, carried out after welding, including the heat-affected area and welded joint metal are shown in Fig. 8.

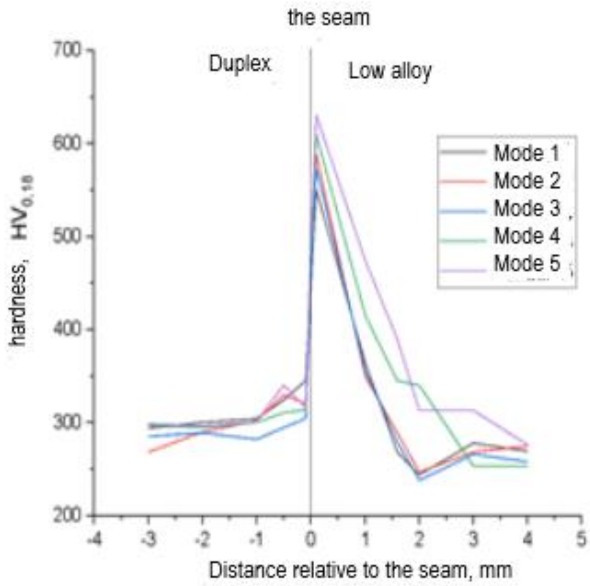


Figure 8. Distribution of hardness over the pipe section in the joint area.

According to NACE MR0175 the maximum permitted hardness value for the welded area must be 250 HV. These hardness values are unacceptable for H_2S media and the requirement is not met [20].

4. Discussion

Metallographic studies have shown that there are discontinuities in the joints, which affects the mechanical properties of the construction. There are areas of increased hardness in the welded joint area, which can also adversely affect the corrosion resistance of the pipe under voltage [20].

Hardening grains have also been found in the welded joint, which can adversely affect resistance to corrosion cracking, especially in a hydrogen sulfide environment.

For this welding method, there are low specific pressures, which are responsible for plastic deformation, which is the main activating factor in a welded joint development in the solid phase. Heating is also an activating factor, but its main function is to reduce the resistance to deformation and, as a result, to lighten plastic deformation. Although with a temperature increase, the concentration of vacancies increases, which intensifies the diffusion, which is an accompanying process, but rather important in the welded joint development in the solid phase. Due to relatively low specific pressures and increased contact resistances in comparison with classical electric resistance welding, local melting and drops splashing in the joint are observed (Figure 4) The use of heating to certain temperatures reduces the deformation resistance of the metal and forces diffusion processes. According to this the temperature increase contributes to all those processes that can provide a reliable welded joint, and the correct technology will ensure that hardening grains and discontinuities are avoided [2, 5].

So the welding technology requires modification of the welding conditions. The optimal parameters for the welding conditions are: higher welding current density and lower voltages [5, 13].

5. Conclusion

We have studied the result of electric resistance welding of dissimilar pipes - duplex and low-alloyed steel. The investigated technology allows us to use corrosion-resistant casing pipes in the well lift in those areas where their use is economically reasonable, but the technology has its own requirements and limitations, therefore the welding conditions should be carefully selected. To improve the welding, a higher welding current density, about 20-60 A / mm2, and lower voltages of 1.5-5 V are required.

In the material grain in the area of the welded joint on the low-alloyed steel side, hardening grains of the martensite and tempered martensite type with high values of hardness were noted, which is unacceptable in a hydrogen sulfide environment and can significantly reduce the corrosion resistance.

This technology requires further study for choosing the optimal welding conditions.

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