PECULIARITIES OF TECHNOLOGY OF WELDING PIPELINES OF DISSIMILAR STEELS IN NUCLEAR POWER ENGINEERING*

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The main factors promoting corrosion cracking of welded joints of pipelines from dissimilar steels are analyzed. Welding consumables and technologies allowing improvement of welded joint resistance to local corrosion damages are proposed.

Keywords: *arc welding, pipelines, austenite and carbon steels, dissimilar welded joints, structure of welded joints, brittle interlayers*

In the pipelines of the second circuit of power units of nuclear power stations the welded joints of pipes of dissimilar steels (austenite and low-alloyed) are mostly subjected to corrosion fracture [1]. During repair of a pipeline the site welding is usually not applied. Instead of a removed defect area a specially manufactured insert is welded-in, which has also a limited life.

The investigations carried out earlier showed that corrosion cracking and fracture of mentioned joints is caused by heterogeneity of metal of welded joints, presence of brittle and weakened interlayers, stressed state and hydrogen embrittlement of metal.

The main factors influencing the life of welded joints of dissimilar steels are their chemical and structural heterogeneity in the places of joining of austenite and pearlite steels due to mixing of these metals in a weld pool and diffusion of different elements, especially carbon.

In mentioned areas of a welded joint the formation of alloyed martensite with sufficiently high carbon content is possible. It is characterised by high hardness and also low plasticity.

The residual stresses in similar and dissimilar welded joints are considerably differed after performance of heat treatment. During cooling in the process of tempering of dissimilar welded joints the new residual stresses occur due to different thermal expansion of steels.

Tensile stresses arise in an austenite part of welded joint. In welding of butts of pipes of dissimilar steels the stresses at the inner surface of austenite pipe are tensile and in the pipe of a perlite steel — compression. During evaluation of stressed state of the joint it is necessary to take into account the structural stresses. In martensite interlayers they can much exceed the residual stresses.

The main factor influencing the serviceability of dissimilar welded joints is hydrogen. The combination of three factors (diffusion-mobile hydrogen, martensite structure and stressed state) can result in delayed fracture of the welded joint [2]. Here the local defects and microcracks are formed on the grain boundaries of former austenite grains. The development of delayed fracture process can result in a rapid intercrystalline corrosion cracking of the welded joint.

The increase in life of dissimilar welded joints can be achieved as a result of development of different technological measures providing minimal penetration

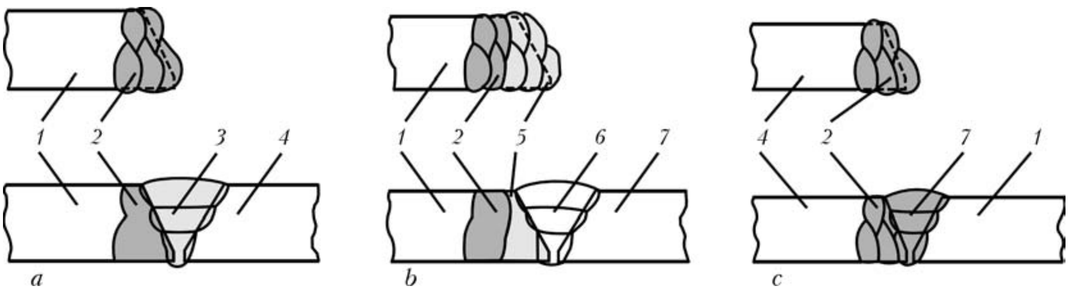

Figure 1. Schemes of first (*a*), second (*b*) and third (*c*) technologic variants of welded joints of dissimilar steels: *1* — base metal (steel 20); *2* — hard-facing of Armco-iron; *3* — weld made using filler metal Sv-10Kh16N25AM6; *4* — base metal (steel 08Kh18N10T); *5* — hard-facing of filler metal Sv-10Kh16N25AM6; *6* — weld made using filler metal Sv-04Kh19N11M3; *7* — weld made using Armco-iron as a filler metal

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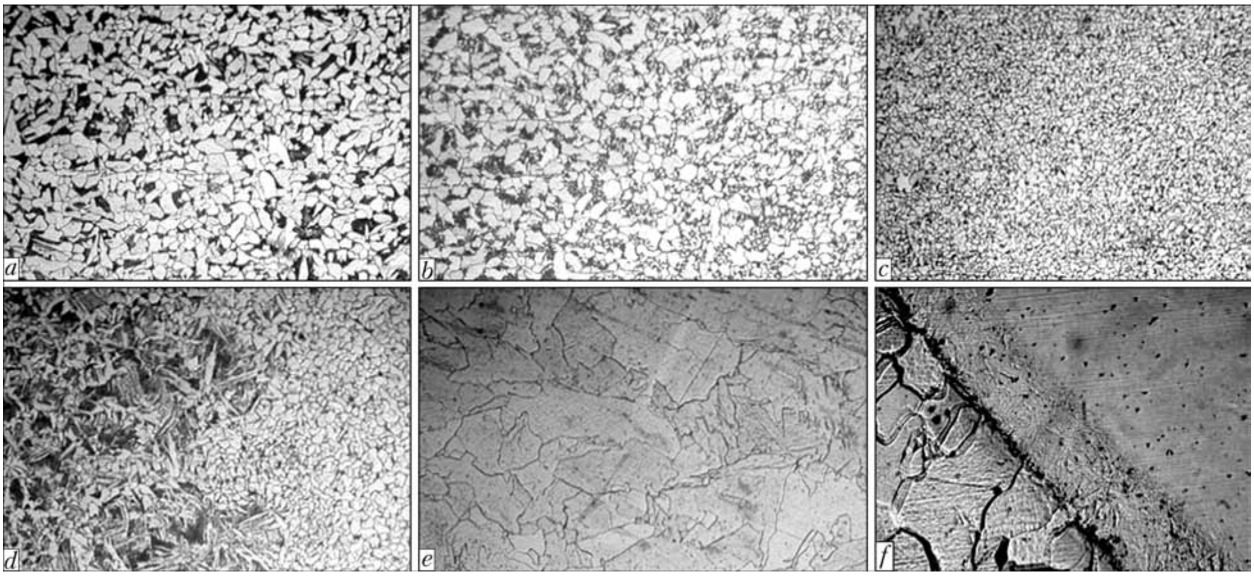

Figure 2. Microstructures (*a*–*e* — ×200; *f* — ×1000) of different zones in metal of welded joints of dissimilar steels: *a* — steel 20; *b* — steel 20, area of incomplete recrystallisation; *c* — steel 20, area of normalisation; *d* — zone of fusion of steel 20 with Armco-iron; *e* — hard-facing of Armco-iron; *f* — zone of fusion of deposited metal with austenite weld

of base metal and prevention of formation of brittle and decarbonized interlayers.

The analysis of existing domestic and foreign high-alloyed welding consumables showed that they do not allow complete prevention of formation of chemical and structural heterogeneity in dissimilar welded joints as well as formation of martensite and decarbonized interlayers.

To prevent formation of martensite interlayers it is necessary to exclude the possibility of mixing pearlite and austenite metals in welding. For this purpose it is possible to line the edge of pearlite steel with commercially pure iron (Armco-iron) with a low carbon content. During hard-facing the share of base metal should be small. In this case it is possible to prevent the formation of alloyed metal with carbon content of more than 0.05 %. In the iron with a low carbon content no hard martensite with a high density of dislocations is formed.

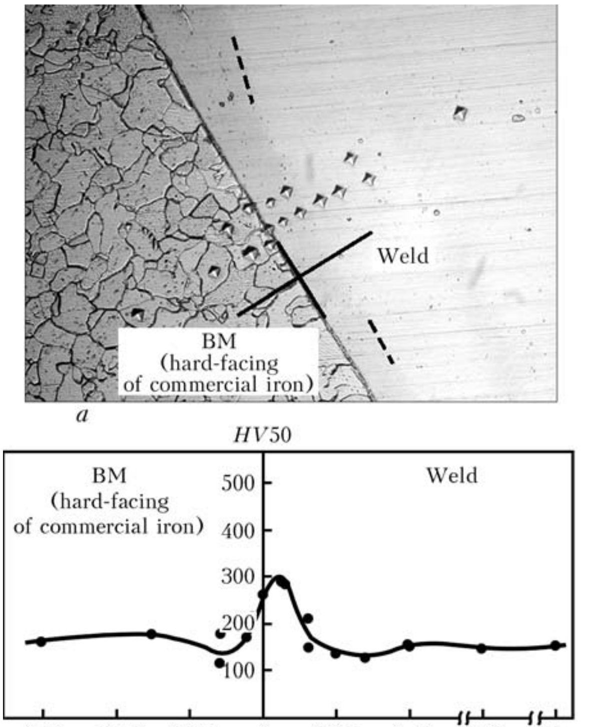

Figure 3. Microstructure (*a* — ×250) and change of microhardness (*b*) at the area of fusion of commercial iron layer deposited on steel 20 and weld metal made using wire Sv-10Kh16N25AM6

The universal method of decrease of diffusion movement of carbon is nickel adding to weld metal or lining of edges with this metal. Necessary concentration of nickel in a weld should be increased with increase of operating temperature of the welded joint.

In the work the following technological variants of welding dissimilar steels using interlayer of commercially pure iron are evaluated:

- preliminary argon arc hard-facing of two layers of Armco-iron on edge of steel 20 (Figure 1, *a*). After mechanical treatment of edges the welding of austenite steel using wire Sv-10Kh16N25AM6 was performed;
- argon arc hard-facing of Armco-iron layer, then two layers with filler wire Sv-10Kh16N25AM6 on the edge of steel 20. After mechanical treatment of edges the welding of joint was performed using filler wire Sv-04Kh19N11M3 (Figure 1, *b*);
- argon arc hard-facing of Armco-iron layer on the edge of steel 08Kh18N10T. After mechanical treatment of deposited edge the argon arc welding of a joint was performed using filler of commercial iron (Figure 1, *c*).

The welded joints of steels 20 and 08Kh18N10T, made according to different technological variants, were cut into transverse templates to perform mechanical and metallographic investigations.

The values of strength, bend angle and impact toughness, obtained as a result of investigations, satisfied the requirements set forth to welded joints of steels 20 and 08Kh18N10T.

Figure 2 shows microstructures of metal of characteristic areas of welded joint of dissimilar steels:

- area of complete recrystallization or normalization (Figure 2, *c*) where after phase recrystalization the metal acquired a fine-grain structure;
- area of overheating, where along with hard-facing of Armco-iron layer (Figure 2, *d*) the coarse structure of large areas of ferrite and pearlite (Widmanstaetten structure) was formed on steel 20. The deposit of Armco-iron near steel 20 has a fine-grain structure, and due to its mixing with base metal single pearlite areas were present in it;
- the metal of hard-facing of commercial iron (Figure 2, *e*) has a purely ferrite structure with a relatively coarse grain;
- area of fusion of Armco-iron layer with austenite weld metal (Figure 2, *f*), where coarse grains of ferrite and layer of Armco-iron melt, not mixed with weld metal, are seen.

Depending on conditions of mixing metal in weld pool the transition from Armco-iron can be abrupt or have a layer with a fine-dispersed structure. This is a metal formed as a result of incomplete melting of grain fragments of commercial iron and absence of mixing such melted metal with austenite weld metal (or deposited metal).

It is obviously that formation of such interlayers is influenced by higher temperature of technical iron melting (about 1530 °C as compared to 1380 °C in austenite metal) and narrow range of crystallization temperatures facilitating its rapid solidification at changes of temperatures in the process of welding and also difficulty of mixing with an austenite melt.

The joint metal at the transition area from the layer of commercial iron to the layer of deposited metal of the type Sv-10Kh16N25AM6 has a similar microstructure (Figure 3).

It is seen from results of measurements that in austenite weld metal or deposited metal at the area of changing composition in base metal (commercial iron) the microareas are formed with increased hardness, much lower than that of martensite due to different volume participation of melted unalloyed and surfaced high-alloyed metals. Due to non-uniform mixing of melts of iron and austenite metal, except areas with increased hardness, the microareas with hardness of austenite are formed.

The obtained results showed the following:

- in hard-facing of transient unalloyed carbon-free iron layer and next welding using the austenite weld the migration of carbon and formation of carbide interlayers, characteristic of the zone of fusion of steel 20 with austenite weld metal, were revealed;
- migration of carbon and formation of decarbonized interlayer in steel 20 does not occur at the area of its fusion with underlayer of commercial iron;
- at the areas of the commercial iron–deposited weld austenite metal fusion the microareas with variable hardness are formed due to additional alloying of iron melt by alloying elements and carbon of austenite wire.

The investigations of technological variant with hard-facing of Armco-iron layer on the edge of steel 08Kh18N10T and next argon arc welding of a joint with Armco-iron filler showed that at the area of fusion of the first hard-facing layer of Armco-iron on austenite steel no areas with high hardness of metal, characteristic of hardened structures, were formed. At this area of welded joint no redistribution of carbon and formation of carbide interlayers were observed.

The results of investigations of flat specimens showed that boundary of fusion of austenite and low carbon steel is more homogeneous if to perform hard-facing of low carbon steel on austenite and to fill a weld with ferrite metal. However filling of a weld with low carbon unalloyed metal leads to the decrease in strength of the welded joint.

Later to fill a weld, the Armco-iron, alloyed with a small amount of strengthening elements, was used as a filler material. As a whole, the values of mechanical properties of dissimilar welded joints performed according to suggested technology meet completely requirements regulated by PNAE G-7-010–89 for equipment of nuclear power stations.

CONCLUSIONS

1. In the course of preliminary corrosion tests of welded joints of dissimilar steels 20 and 08Kh18N10T it was established that their welded joints represent complex multi-electrode element with difference of potentials between base metals in a welded joint of up to 0.5 V in neutral medium of sodium chloride (pH 6.5–7.0), thus causing intensive fracture of metal in a fusion zone.

2. In the process of tests of welded joints at the loading of up to $0.9\sigma_y$ in boiling solution of mixture of calcium nitrite and nitrite of ammonium in the specimens welded both according to conventional technology, and also in hard-facing of commercial iron on the edges of steel 08Kh18N10T, corrosion cracking occurs. Under similar conditions of testing specimens with hard-facing of edges of carbon steel by Armco-iron the corrosion cracking was not observed.

3. The developed technology of welding of the second circuit pipelines of dissimilar steels is supposed to be certified at Khmelnitskaya nuclear power station.

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