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DAMAGE MECHANISM OF PIPING WELDED JOINTS MADE FROM AUSTENITIC STEEL FOR THE TYPE RBMK REACTOR

G.Karzov, B.Timofeev, A.Gorbakony, V.Petrov, T.Chernaenko
Central Research Institute of Structural Materials "Prometey", St.Petersburg, Russia

Abstract: In the process of operation of RBMK reactors the damages were taking place on welded piping, produced from austenitic stainless steel of the type 08X18H10T. The inspection of damaged sections in piping has shown that in most cases crack-like defects are of corrosion and mechanical character. The paper considers in details the reasons of damages appearance and their development for this type of welded joints of downcomers (325x16 mm, which were fabricated from austenitic stainless steel using TIG and MAW welding methods.

Keywords: Austenitic steel; Welded joint; Intergranular stress corrosion cracking; Piping.

1. The Essence of Paper

A number of Russian NPPs numerous cases of crack-like damages were revealed near welded joints in piping (downcomers (325x16 mm), manufactured from the stabilized austenitic steel 08X18H10T, after their operation for 50-100 thousand hours at various units. As it has been determined by X-ray inspection, ultrasonic testing and metallographic examination these cracks initiated from concentrators at the inner surface of tubes in the vicinity of the fusion line of weld root with base metal. Cracks were also propagating along the heat affected zone (HAZ), i.e. within the narrow zone (0.3-1.0 mm) near the weld fusion line. Sometimes a crack departed in weld, but here did not receive a further development and again returned to HAZ. The fracture surface of these cracks is similar to the intergranular corrosion fracture (further defined as intergranular stress corrosion cracking - ISCC) [1, 2]. The same fracture modes were observed in welded joints of instabilized austenitic steels applied at NPPs in western countries [3, 4] and it resulted in their replacement. Thus, ISCC of welded joints was found out both in steels without stabilizing additions of titanium and niobium combining carbon and in steels with these stabilizing additions. In the latter case ISCC can be revealed only a prolonged operation time.

The aim of the present research is to clarify the nature of ISCC, to determine its mechanism, to develop recommendation for the prevention of such failure. The present report is the review of investigations performed at the Institute. Earlier [2] it was shown that ISCC of welded joints fabricated from 08X18H10T steel depended on three main factors:

- level of acting stresses in the structure;
- purity of circulating water in the circuit on the oxygen content in it;
- sensibilization degree of HAZ metal of welded joints.

2. The Investigated Materials

For the stated above piping production one usually applies seamless pipes from austenitic steel of the type 08X18H10T. In this case it is recommended to use tubes with the carbon content in metal not more than 0.08% and titanium - not less than 0.4%. All tubes should be heat treated and tested on resistance to ICC according to GOST 6032-89 with a provocating heating.

Two welding methods were used for the production of these pipe-lines (MAW and TIG). Electric arc manual welding was performed with EA-400/10Y or EA-400/10T electrodes (OST 5.9370-81). Manual welding and automatic nonconsumable electrode arc welding (TIG) were performed with Sv-04X19H11M3 wire (GOST 2246-70).

The investigations of downcomers welded joints mechanical properties were carried out both in as-welded conditions and after a prolonged operation. The test results showed the degradation of welded joints properties after 120 thousand hours service did not practically occur. The degradation is observed only in local areas (directly at the tip of propagating crack in HAZ of welded joint) and can be detected using special test methods, for example slow strain rate testing (SSRT).

3. Level of Acting Stresses

In the process of operation the stresses from internal pressure, supports weight as well as forces from the self-compensation of temperature transport of tubes, drum-separator and suction manifold are superimposed on residual stresses of piping stated (post welding heat treatment was not carried out). Residual welding stresses at inner surface along the fusion line near weld root in (325x16 mm piping welded joint are tensile and equal to (0.3-0.4)YS. The stresses distribution through wall thickness the level of residual tensile stresses along weld fusion line at a depth of 2 mm from inner surface increases after welding to the value (0.6-0.7)YS in comparison with the value of residual stresses on inner surface near weld root. At a depth of 2-3 mm some reduction of reduction of residual streesses (0.3YS) is observed, and at a depth of 3-4 mm the second peak of residual stresses growth can be seen, which is by 1.5-2 times less, than the first one. Beginning with 4 mm wall thickness of tube welded joint (and further) the reduction of residual stresses is taking place, and starting with 7 mm tube wall thickness the residual tensile stresses change to compressive ones. But the decrease of stresses is going on till the wall thickness 12 mm. At such depth the compressive residual stresses are equal to 0.3YS.. And as a result of it the tensile residual stresses appear again, at this depth, and they are decreasing practically to zero as moving to outer surface of tube welded joint. After the power unit start-up the epyre of summary stresses throuugh thickness of welded joint remains invariable in its form, but in its stress value it increases by 2.0-2.5 times.

In the straining cycle the level of maximum axial tensile stress (with consideration of residual stresses) exceeds considerably the yield strength in the regimes start-stop. The distribution of normal stress on the fusion line in as-welded condition, after start and stop is given in Ref.2. By this, most high stresses are generating in weld root in the process of hydraulic tests (HT), which exceed stresses under normal operating conditions (NOC) by 1.5-2.0 times. Thus it is seen that the stress level in welded joint through its wall thickness is favourable for intercrystalline corrosion cracking process. Besides, due to a great margin of elastic energy in the circuit of multiple forced circulation the reduced distribution of stresses changes not much with the generation of first cracks in piping welded joints.

4. Water Chemistry Regime

In connection with the fact that dissimilar metallic materials (Zr-based alloys, corrosion resistant steels of the type 08X18H10T, chromium alloyed and carbon steels) contact each other in boiling reactors it was accepted constant neutron water chemistry regime. It was motivated by the fact that a decreased content of chlorides is necessary for a reliable operation of equipment and piping, manufactured from corrosion resistant austenitic steels. As to Zr-based alloys the alkaline regime is inpermissible because of the corrosion cracking of these alloys [7].

In the process of NPP operation the control of the following indexes of water-chemistry regime is carried out: conductivity, Cl- content, Fe, Cu, hardness of water, pH. The average index of water quality in the circuit of multiple forced circulation at NPPs, which were examined by our specialists, were maintained within the normative values. The oxygen content in circulating water is not a normalized index, but as the NPP operation experience shows in the process of water radiolysis oxygen and hydrogen are going out to a large amount with a steam phase. Using samples of circulating water, taken in various periods of NPP operation, it has been determined that oxygen content in water of the circuit of multiple forced circulation in the stationary regime is usually equal to 0.03-0.05 mg/kg. However in the process of planned repairs or reactor stop for other reasons the oxygen content in circulating water increases sufficiently. During a prolonged stop the oxygen content in water can reach 8 mg/kg.

The metallographical studies of welded joints of (325x16 mm tubes showed that the thermal attack of welding on HAZ of 08X18H10T steel was associated with solution and carbides formation as well as with grain growth. By this, intercrystalline cracks are forming and propagating along the adjacent to the fusion line recrystallized zone with the width 0.2-0.6 mm, and in case of its absence the crack growth ceased. Therefore, the influence of technological factors has been estimated in accordance with the criteria stated above. The sensibilization has been determined metallographically on the base of etching ability of boundaries, containing chains of fine-dispersed carbides, precipitated on them.

The investigations were carried out on specimens of weldments before and after their operation and also on specimens of experimental welded joints. On specimens made from weldments after their operation crack-like defects are locating along weld root at the distance to 0.5 mm from the fusion line at a depth of 5-6 mm. They are growing from the inner surface of tube and look as branching intercrystalline cracks. Throughout extent metal failed on a brittle mode. It has been made a supposition that cracks generate as a result of corrosion cracking on intercrystalline mode for which the necessary conditions are as follows: the stress level - above the yield strength, oxygen concentration in water - within the range 0.1-8 mg/kg (the latter is characteristic of a period of maintenance and units putting into operation) and sensibilization of grain boundaries (i.e. chromium concentration reduction on grain boundaries as a result of Me23C6 carbides formation).

Piping welded joints after operation do not evidence a tendency to ICC on AM GOST 6032-89 method. Thus, close to weld zone sensibilization appears sufficient for ISCC, but insufficient for ICC proceeding. The comparison of sensibilization degree after operation with that in as-welded condition shows that grain boundaries sensibilization occurs by welding (initial) and develops at low temperature (290oC) in the process of operation. Sensibilization during welding occurs as a result of close to weld zone heating to temperatures 1200-1300oC, due to a partial solution of titanium carbides and carbon fixing in solid solution, chromium carbides forming in the process of cooling after welding and repeated heatings within the temperature range 500-650oC. Repeated heatings take place by producing usual welding beads. A final sensibilization depends on initial one. The greater the initial sensibilization the more rapidly the sensibilization level is achieved, by which ISCC begins.

At the first moment after hydrotests and NPP putting in the regime the crack development, proceeding with a decreasing rate, is induced by a mutual action of tensile stresses and corrosion failure of metal depleted of Cr due to contact corrosion with oxygen depolarization. However, while operating in full power the oxygen amount in the circulating water decreases to 0.03-0.05 mg/kg and corrosion processes with oxygen depolarization cease. In this case pH in crack reduces to 3. By this, corrosion at the crack tip will proceed, but already with hydrogen depolarization causing the crack tip blunting, mentioned above. In order to resume the corrosion failure process with oxygen depolarization it is necessary to bring oxygen to the crack tip (and it takes place during hydrotests).

5. Sensibilization Degree of Austenitic Welded Joints

In connection with corrosion damages of welded joints in piping made from 08X18H10T steel of NPP with the type RBMK reactors it has been considered the influence of technological factors on close to weld zone microstructure. It has been assessed the effect of repeated passes, welding method and intermediate cooling of beads. The metallographical studies of welded joints of (325x16 mm tubes showed that the thermal attack of welding electric arc on close to weld zone of 08X18H10T steel was associated with solution and carbides formation as well as with crystalline cracks forming and propagating along the adjacent to the fusion line recrystallized zone having the width 0.2-0.6 mm, and in case of its absence the crack growth ceased. Therefore, the influence of technological factors has been estimated in accordance with the criteria stated above. The sensibilization has been determined metallographically on the base of etching ability of boundaries containing chains of fine-dispersed carbides, precipitated on them.

6. Conclusion

1. Formation and development of intercrystalline stress corrosion cracking (ISCC) of welded joints of piping (325x16 mm of the circuit of multiple forced circulation is a result of damages accumulation from the effect of three basic factors: mechanical, corrosion, metal structure.
2. The fraction of the mechanical factor is determined by the value of elastic energy margin, presence of tensile stresses, exceeding the yield strength; the fraction of corrosion factor - oxygen content in circulating water with concentration not less than 0.2 mg/kg; the sensibilization fraction of HAZ welded joints is determined by the correlation of grain areas and depleted of Cr zones of its near-boundary areas.
3. The rate of corrosion failure processes of near the weld zones at the inner surface of welded joints of tubes (325x16 mm achieves its saturation already with the oxygen content 0.2-0.3 mg/kg and a further oxygen content increase in circulating water influences slightly the duration of the incubation period of ISCC.
4. The process of ISCC cracks development is descrete. Each initiation of cracks growth takes place in the process of hydraulic tests. A trend of crack growth rate decrease is observed with the increase of its depth.
5. It is possible to suppress the nucleation and growth of ISCC cracks completely or partially by means of eliminating the influence of one of these factors. As it is practically impossible to suppress the influence of each factor, it is necessary to attain the release of all factors and that also can increase the incubation period of ISCC and reduce the rate of its development.

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