14th International Research/Expert Conference
”Trends in the Development of Machinery and Associated Technology”
TMT 2010, Mediterranean Cruise, 11-18 September 2010

EXPERIENCES IN WELDING OF MEMBRANE PANELS MADE OF 7CrMoVTiB 10-10 (T24) STEEL.

Janusz Adamiec, Adam Hernas
Silesian University of Technology
ul. Akademicka 2, Katowice
Poland

ABSTRACT
The paper contains a presentation of former technological experiences and basic problems appear during welding of membrane panels made of bainitic creep resisting steel T24 used to the boiler operating at supercritical parameters. The main objective of this paper was to verify the welding technology of thin-walled tubes and present the characteristics of toughness properties, cracking and microstructure Hot cracking of T24 welds is one of the main problems in joining of membrane panels. Despite a great number of research, which led to establishment of hot cracking criteria in industrial practice such kind of cracking is still a significant problem. Cracking of T24 joints are determined by linear energy of arc, which is function of welding parameters and welding speed, moreover about the susceptibility to cracking of weld decides the way of cooling joint, what influences on forming of martensitic next to bainitic microstructure. On the basis of the test results, despite of recommendations of steel manufacturer, it was found that there is necessary use the preheating and post welding heat treatment, even during submerged arc welding of thickness components.
Keywords: membrane panels, welding, creep resisting steel T24.

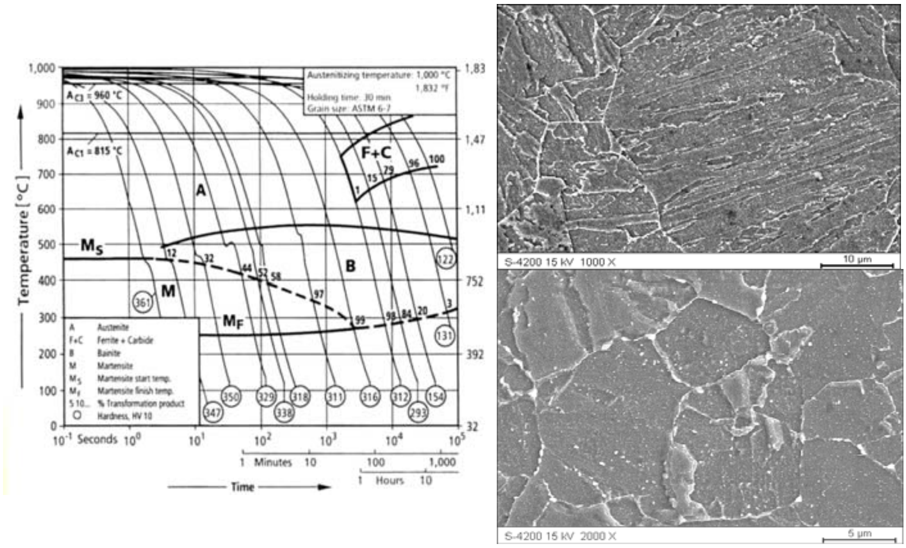
1. INTRODUCTION

The development of thermal power industry aimed at increasing the efficiency and reduction of harmful gas emission in line with the requirements laid down in EU directives, through increasing the parameters of steam in supercritical boilers, is conditioned on the availability of new engineering materials and relevant processing technologies. Tubular components of heat exchangers, mainly in superheaters, thick-walled tubes for fresh steam and membrane panels, the operating temperature of which exceeds 500°C, with steam pressure of 290 bar [1-4], are the critical components of boiler systems of modern power generation units. They are manufactured from low-alloy steel grades.

The mechanical properties, including creep resistance, of the 13CrMo4-4 or T11/T12 steel grades used so far for the membrane panels of boilers are insufficient. As it is the case of components of greater thickness range, the welded membrane panels have to be assembled without heat treatment [3-5].

In 1980-ties, two new groups of low-alloy steel grades were developed. In Sumitomo (Japan) the HCM2S grade with tungsten and niobium was developed, whereas in Europe (TP23), Manessman developed the 7CrMoVTiB 10-10 (TP24) grade [3,5]. The 7CrMoVTiB 10-10 steel is considered as suitable for welding with shielded electrode, submerged arc and TIG welding. The above steel was supposed to have not only greater creep resistance than that of the standard X10CrMo9-10 steel, but also favourable technical properties [4].

Austenite transformations in the 7CrMoVTiB 10-10 are close to those in the 10CrMo 9-10 (Fig. 1).



b)

Figure 1. CTPs graph for the 7CrMoVTiB 10-10 [7] steel and b) examples of martensitic and bainitic microstructure SEM.

According to the experience of a number of European welding contractors, the steel in question involves a series of problems as to its susceptibility to post-weld cracking.

2. MEMBRANE PANELS WELDING TESTS

The design of membrane panels of a boiler incorporates double sided tube-flat bar joint. The maximum length of a single panel ranges up to 24 m and width up to 2 m. Individual panels are most frequently joined with a butt weld with the use of electrode or submerged arc welding. The maximum hardness of such joint, as recommended by VGB regulations, is 350 HV. For submerged arc welding tests, tubes with a diameter of 44.5 mm and wall thickness of 7.1 mm were used, together with a flat bar of dimensions: 8.0 mm x 75.9 mm. Welding consumables recommended by Böhler were utilised: P24-UP welding wire in BB 305 flux [5]. The welding was performed with submerged arc method (121) with P24-UP wire (SZCrMo2VNb acc. to EN 12070), with BB 305 flux (SA AR 1 76 AC H5 acc. to EN 760) with a four-head Deuma welding unit. The welding speed applied was 0.8 – 1.0 m/min and the linear arc energy was 7.2 – 8.4 kJ/cm. The acceptance criteria for welded joints were based on strict requirements of PN-EN 5817 (class B) and VGB – R 501 H regulations. See figure 2 for the face of welds obtained and their cross sectional view.

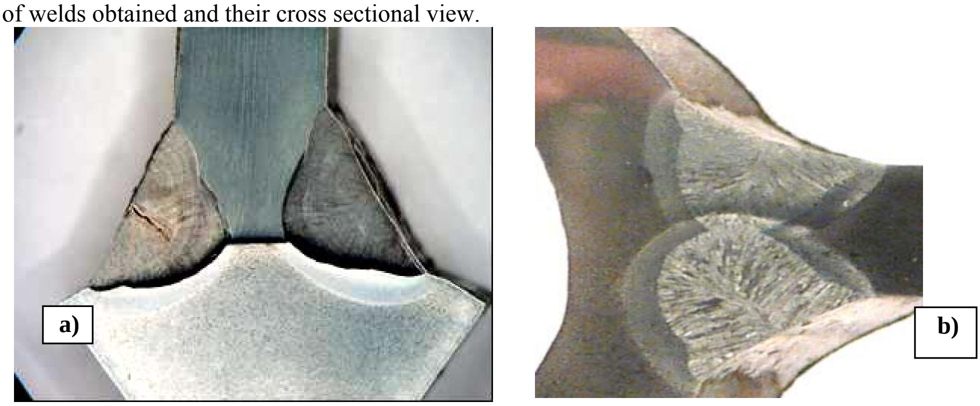


Figure 2. Hot crack in the joint after welding at the speed > 0.8 m/min d) the proper joint macrostructure after welding at a rate < 0.8 m/min.

Lateral cracks in the weld face were found, by visual and macro examination, in the welded joint (E_l = 7.2 kJ/cm, v_s =1.,0 m/min) (Fig. 2a) and in the sample no. 2 (E_l = 7.5 kJ/cm, v_s =0.,9 m/min). By examining the area of the crack surface in sample no. 1, the crack was found to be spreading throughout the entire weld and propagating to the heat action zone.
In visual and macro examination of the weld no. 3, the face was found correct, and no other shape variations or cracks were found (Fig. 2b). In macroscopic examination of the surface perpendicular to the welding direction, correct shape of the thorough penetration joint was found (Fig. 2b). That joint confirms to the geometrical criteria of PN EN 12952 and the requirements of VGB.
see Fig. 3 for hardness distribution in the joints being tested.

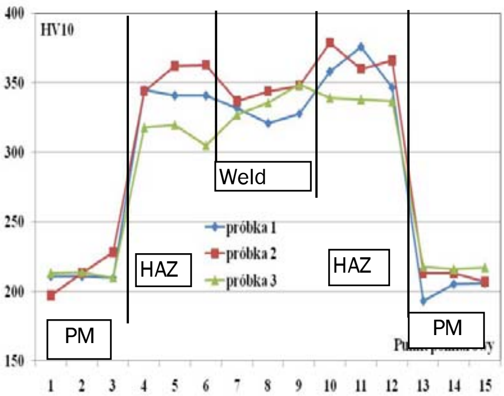


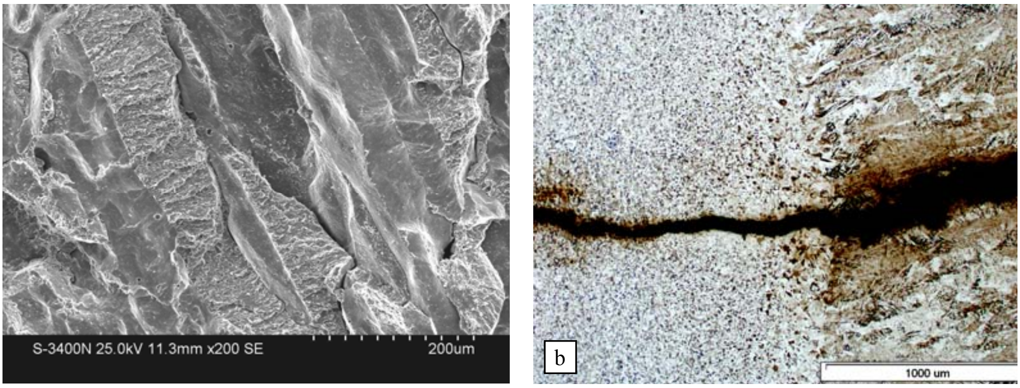
Figure 3. Hardness distribution in examined joints

Based on the hardness distributions joints achieved in the joints, it was found that for the joints no. 1 and 2, the values obtained exceeded the 350HV limit in the heat action zone (Fig. 3). In the joint no. 3, welded at the speed of 0.8 m/min, the hardest recorded weld yields 349HV, and in the heat action zone, the hardness remained within the rang of 305 HV to 339 HV. The hardness of the tube and flat material was within the range of 210 HV to 218 HV.

The breaking work of the material at the joint and HAZ, when the martensite dominated in the microstructure, was very low ; 12 – 27 J.

3. METALLOGRAPHIC EXAMINATION

The structures of double-sided joint of the tube and flat bar made of the 7CrMoVTiB 10-10 steel with submerged arc method, represent typical welding structures. The virgin material exhibits usually the bainitic or bainitic and ferritic structure. In many cases of as-delivered steel, the bainitic structure with a varied martensite contents is present (Fig.1b). In narrow heat affective zone, insignificant growth of grains close to the fusion penetration line was revealed. In the fusion penetration line, column crystals of bainitic and martensitic structure increase orthogonally to the crystallisation surface (Fig. 4b).
In the technical experiments carried out, the cracks revealed were progressing in the joint as intercrystalline cracks, and then, through the heat affective zone, they reached the parent material, on the side of both, the flat and the tube being welded. The analysis of the fracture surface indicates hot cracking condition (Fig.2a). This is proven by smooth crystallite surfaces, which are formed due to solidification of a thin layer of liquid on their surface during welding (Fig. 4a). Areas of brittle trans-crystalline fractures were also discovered on the crystallite boundaries.
The areas are formed within the high-temperature brittleness range, as a result of cracking of solidified and contacting joint crystals, as a result of welding stress and deformations (Fig. 4a). The cracks advance on the boundaries of weld crystals, which proves the lack of match between individual crystals. This leads to the formation of hot fracture crack grid. In the fusion penetration line, the transition of crack fracture, from the intercrystalline to mixed fracture, was clearly visible. In the heat action zone, numerous fracture cracks were found, mostly of intercrystalline trajectory, whereas the main crack has a strongly developed surface of mixed brittle trans and inter-crystalline character.



a)

Figure 4. a) Brittle weld cracking surfaces, b) cracking progression on the fusion penetration line – HAZ.

4. CONCLUSIONS

In visual examination of joints, cracks perpendicular to the welding directions in welds made at speeds above 0.8 m/min. (Fig. 2), were revealed. In the fractographic examination of crack fracture it was found that the cracks are of hot nature in the joint area, which advance along the boundaries of column crystals, forming a grid of fracture cracks (Fig. 4a). According to the tests carried out, cracking of joints is a result of heavy deformation of joints during welding, as well as of the presence of gases in the joint, which results from the welding speed being to high.

The analysis of the microstructure of the joint welded at the speed of ≤ m/min (joint 3), with linear arc energy 8.4 kJ/cm, revealed bainitic and martensitic structures in the joint and bainitic structures in the SWC and base material (Fig. 4b). The joint hardness did not exceed 350 HV (Fig.3). The NDT carried out did not reveal cracks on the joint surface. The examination scope was supplemented by geometry measurements of the fusion penetration surface, which proved the requirements of PN EN 12952 and of VGB – R 501 H to be met.

It is quite often the case that, despite the requirements for the 7CrMoVTiB 10-10 steel to EN 10216:2002/PR A2:2006 being met as certified, and correct welding technology in line with the WPS, hot or hydrogen cracks occur in the joint, together with microstructures of significant share of martensite which promote cracking. It is concluded that, if the material in the as-delivered state exhibits correct bainitic microstructure, then no such problems are virtually faced when the welding parameters are strictly adhered to. However, the presence of significant share of martensite, e.g. in a flat bar before welding, together with the failure to observe the welding regimes (e.g. welding speed >0.7 m/min) and the cool-down being too rapid after welding, leads to the formation of dominating plate structures in the joint (Fig. 4b), which significantly reduce the fracturing work and promote cracking of the joint. For the above reasons, the manufacturers of membrane panels of the T24 steel support the idea of heat treatment to be carried out after welding, although it is not obligatory for thin-walled tubes. The improvement actions undertaken allowed the development of a qualified WPQR technology for welding membrane panels of industrial boilers made of the 7CrMoVTiB 10-10 steel.

5. REFERENCES

[1] Brózda J. Stale energetyczne nowej generacji stosowane na urządzenia energetyki o parametrach nadkrytycznych i ich spawanie. (In Polish) Biuletyn Instytutu Spawalnictwa, nr 5/2006
[2] Huseman R. Advanced (700 ^{o}C) PF Power Plant: A Clean Coal European Technology. Advanced Material for AD700 Boilers, Cesi Auditorium, Milano, 2005.
[3] Arndt J. and other. The T23 / T24 Book – New Grades for Waterwalls and Superheaters Vallourec & Mannesmann Tubes, 1998
[4] Hagen I., Bendick W. Creep resistant ferritic steel for power plant. Mannesmann Forschungsinstitut GmbH
[5] Bendick W., Fuchs R., Heuser H, and other. Application capability and welding of modern heat resistant steela (T/P91, T/P23, T/P24), Symp. Rafako SA. 2003