

EXAMINATION OF WELDED JOINT FROM THE COOLING SYSTEM OF PHOTOVOLTAIC INSTALLATION

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Abstract: *The quality of a welded joint in expansion tank of the water cooling system of a photovoltaic installation is identified. A lot of flaws are found after analyzing the macro- and micro structure, and the chemical content of the welded joint. The incorrectly followed mode of welding with high linear energy has resulted in high residual welding stresses, overheating of the metal and continued detention at high temperature. Thus the corrosion resistance of the metal in the heat affected zone (HAZ) decreases and this is the most likely reason for corrosion and cracking.*

1.Introduction

The tendency towards depletion of the global reserves of fossil fuels directly promotes the use of renewable energy, and in particular solar energy. The construction of photovoltaic power plants is one of the current paths for development of modern energy. The photovoltaic element itself is the generator to produce electricity from solar energy but there are a lot of other systems and components operating together that ensure the obtaining of electricity. The increased temperature of the photovoltaic element results in reduction of productivity, e.g. with 1% for each 1°C, and it requires to use cooling and ventilation systems.

The objective of the present study is to determine the quality of the weld joint "longitudinal seam" of an expansion vessel from the water cooling system of photovoltaic installation.

2.Materials and preparation

The expansion vessels are components of the water cooling installation that further comprises heat exchangers, pump, hoses, venting valve, stopcocks, control sensors for flow and pressure. The cooling liquid is ethylene glycol solution in distilled water (45/55 %). the temperature of the coolant varies between the ambient temperature (down to -10°C in winter time), typical temperature +50°C and maximum temperature +70°C. The installation operates at typical pressure 2bar, minimum pressure 1.5bar and maximum pressure 3.5bar. The expansion vessel is made out of steel AISI304 (1.4301). The expansion vessel is placed in a closed and well ventilated room and is entirely isolated from possible impact from any climatic factors, e.g. rainfall, sunlight, etc. The cooling installation is grounded via the pipes of stainless steel.

Samples from two expansion vessels are taken for examination:

Sample 1 - with inadmissible flaws (defects), and

Sample 2 - without flaws

Test specimens are cut out of the samples and prepared for:

- Spectral analysis in order to identify the chemical content of the base metal;
- Examination of the macrostructure of the welded joint;
- Examination of the microstructure of welded joint, HAZ and base metal;
- Examination of the phase content and distribution of elements in the welded joint.

Examination of the base metal

The results from chemical analysis of the steel out of which the expansion vessels are made and the data from the manufacturer 's documentation are compared in *Tabl. 1*.

Table 1

Data from the manufacturer (weight %)									
Element	C	Si	Mn	P	S	Mo	Cr	Ni	N
Measured	0.062	0.45	1.22	0.030	0.001	0.11	17.7	8.71	0.018
Max up to	0.07	1.0	2.0	0.045	0.015	*	17.5-19.5	8.5-10.2	0.11
Data from the examination, Sample 1 (weight %)									
Element	C	Si	Mn	P	S	Mo	Cr	Ni	N
Average	0.054	0.517	1.52	0.028	0.018	0.23	16.7	7.89	*
Data from the examination, Sample 2 (weight %)									
Symbol	C	Si	Mn	P	S	Mo	Cr	Ni	N
Average	0.062	0.537	1.20	0.031	0.024	0.31	16.7	8.01	*

* No data available

The comparison reveals that the measured contents of Cr and Ni are lower than those specified by the manufacturer. Chemically the examined material satisfies steel grade AISI304 (1.4301) but with slightly decreased contents of Cr and Ni.

3.Examination of the welded joint

Each welded joint consists of three characteristic zones: base metal (BM), weld seam (WS), and heat affected zone (HAZ), as each one needs to be qualified.

The key indicator for the quality of the welded joint is the state of its surface. According to БДC EN ISO 17637, this indicator is qualified through visual control by means of 3x magnifying glass, as well as stereo microscope *Technoval* (SM), and metallographic microscope *Metallovert* (OM). It comprises the three characteristic zones of the welded joint and is carried out both on the inner and outer surfaces of Sample 1 and sample 2.

During the visual control of Sample 1, a rupture (defect) is found within the area marked by the client. From the outer side there is a dark trace parallel to the weld at about 3mm distance. The same trace, however much more pronounced, is seen from the inner side too. There is corrosion on the inner side of the weld and the adjoining zone from the side of the welded joint. The flaw is located within the dark trace zone.

The surfaces of Sample 1 (Specimen No1) are shown in *Fig. 3*. There are local surface flaws found in the HAZ. The metallographic observations reveal the presence of cracks, which are inadmissible defects by all quality standards for welded joints, including ISO 5817 (БДC EN 25817).

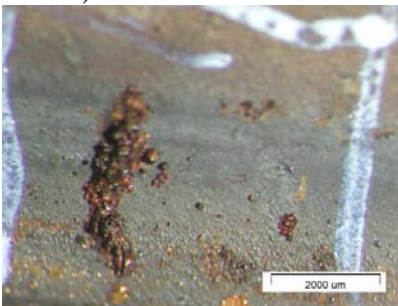


Fig. 1a. Flaw on the inner surface, Spec. No1, SM

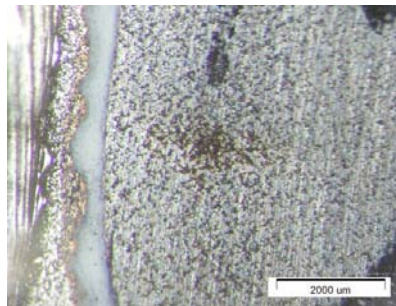


Fig. 1b. Flaw on the outer surface, Spec. No1, SM

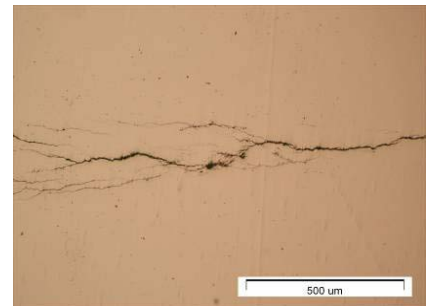


Fig. 1c. Flaw on the outer surface, (after grinding and polishing), Spec. No1, SM

The defect runs perpendicular to the welded joint and a network of cracks is observed. There are no flaws observed on the surfaces of Specimen No 2.

The surfaces of the weld seams are shown in *Fig. 2, a)* and *b)*. There are no flaws found on the surfaces of the weld seams.

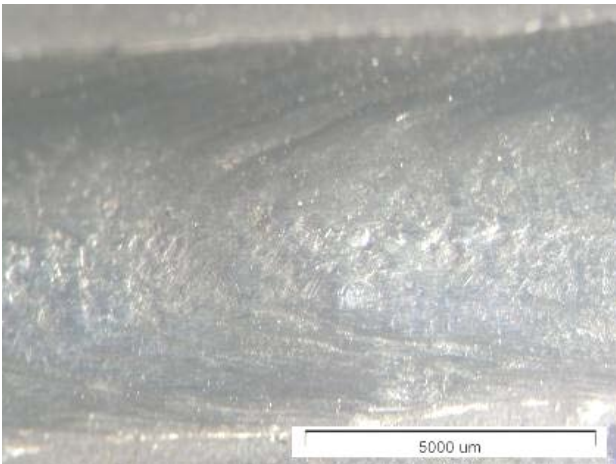


Fig. 2a. General view of the welded joint, Spec No1, SM

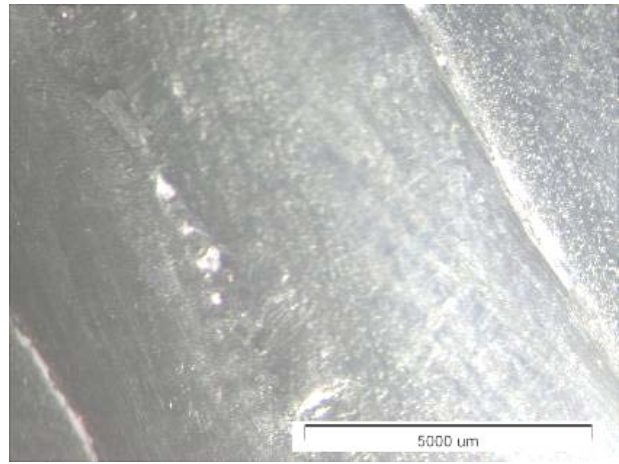


Fig. 2b. General view of the welded joint, Spec No2, SM

The microstructure of cross-section of the longitudinal weld seam (Sample 1) is shown in *Fig. 3a*. The micro-structure is typical for weld seam metal of austenitic steel containing relatively small amount of ferrite. The cross section of the weld seam metal in Sample 2 (Spec. 2) has considerably smaller dimensions. (*Fig. 3b*). Obviously the seam is made with much lower linear energy of welding and meets the requirements of ISO 5817 (БДС EN 25817).

Furthermore, the dimensions of the cross section of the weld metal in Sample 1 are too large, i.e. 7.90 mm width and 2.59 mm height. For comparison, the thickness of the base metal is 1.02 mm. Also, the weld seam metal has spilled onto the base metal with no weld interfusion between the two metals.

There are flaws observed: a large pore in the middle of the seam (*Fig. 3a*) and lack of interfusion in the transitions from weld seam metal to base metal (*Fig. 4*).

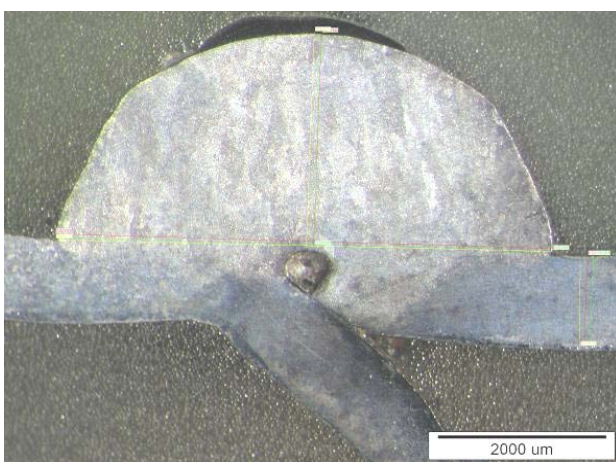


Fig. 3a. Macro structure of Spec. No1, SM.
The dimensions of the weld seam measured from the image are: width $B=7.90+0.02$ mm; height $h=2.59+0.02$ mm. Thickness of the base metal $d=1.02+0.02$ mm



Fig. 3b. Macro structure of Spec. No2, SM.
The dimensions of the weld seam measured from the image are: width $B=5.42+0.03$ mm; height $h=0.63+0.14$ mm. Thickness of the base metal $d=1.04+0.02$ mm



Fig. 4. Flaws in the transitions from weld seam metal to base metal, left and right end of the seam, OM

The micro-structure of the HAZ metal depends on the micro-structure of the base metal and the thermal cycle of welding. The latter alters the microstructure of the base metal in HAZ as a result of the thermal deformation welding cycle. This means that during heating and cooling the micro-structure of HAZ metal alters due to the alterations in austenitic grains size, diffusion processes taking place that lead to redistribution of the chemical elements, the formation of carbides or new phases, etc. The macro-structures of the weld seam, the HAZ and the BM are shown in the images in *Fig. 5*.

The examinations using Scanning Electron Microscopy (SEM) and Electron Probe Micro-analysis (EPMA) are carried out. The images of the micro-structure of cross sections of the weld seams in secondary electron mode are shown in (*Fig. 6*). The inter-crystal cracking (the defect on the outer surface of the vessel), as well as the variation of chrome content within the cracking zone are shown in *Fig. 7*.

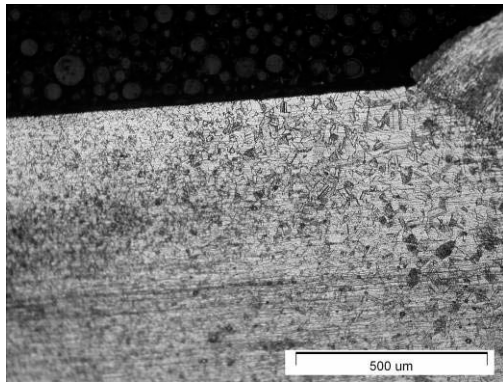


Fig. 5a. Microstructure of weld seam, HAZ (austenitic structure with deformation strips), Spec. 2, OM

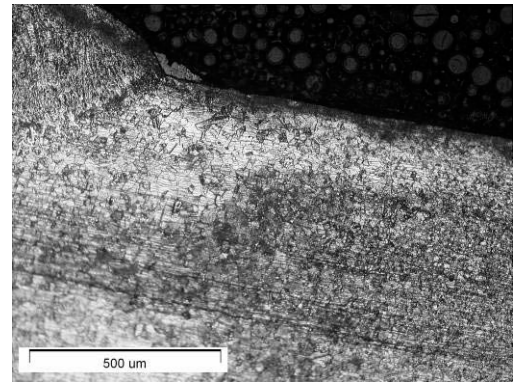


Fig. 5b. Microstructure of weld seam, HAZ and base metal, Spec. 2, OM

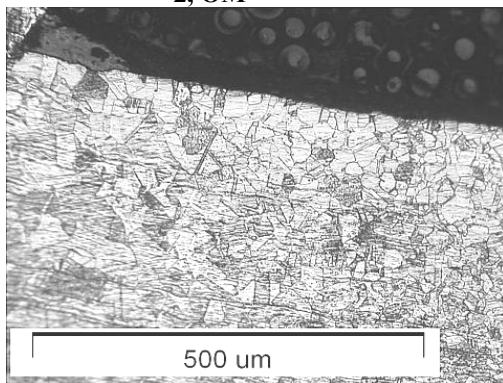


Fig. 5c. Microstructure of HAZ (austenitic structure with deformation strips, thickened boundaries of individual grains), Spec. No1, OM

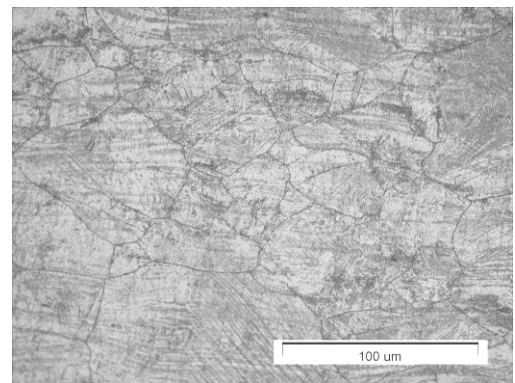


Fig. 5c. Microstructure of base metal (austenitic structure, thin, clear grain) boundaries, Spec. No1, OM

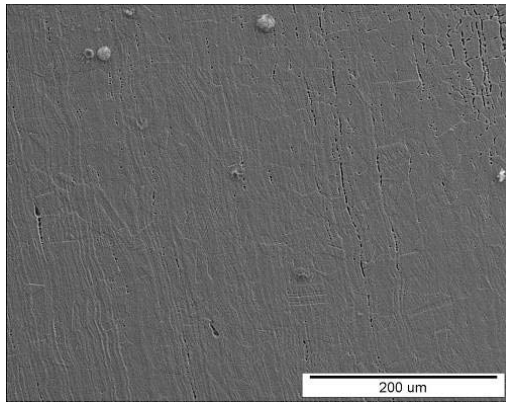


Fig. 6a. Microstructure of HAZ close to the weld seam, Spec. No1, SEM

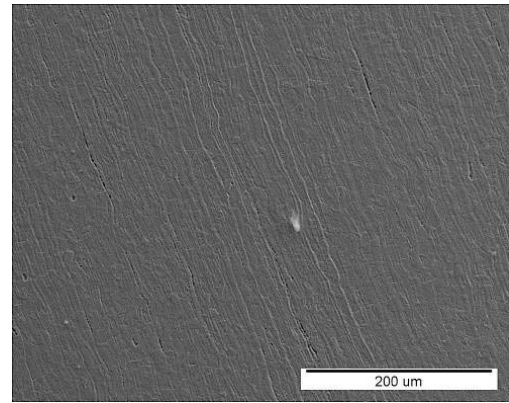


Fig. 6b. Microstructure of HAZ - base metal, Spec. No1, SEM

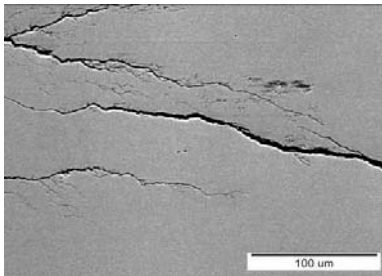


Fig. 7a. Inter-crystal cracking (flaw on the outer surface), Spec. No1, SEM

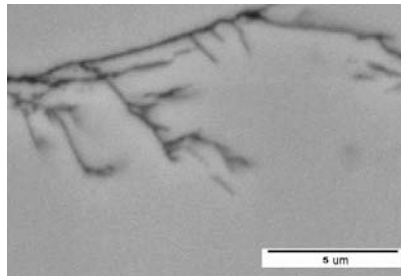


Fig. 7b. Inter-crystal cracking in the area where the variation of chrome content is examined, Spec. No1, SEM

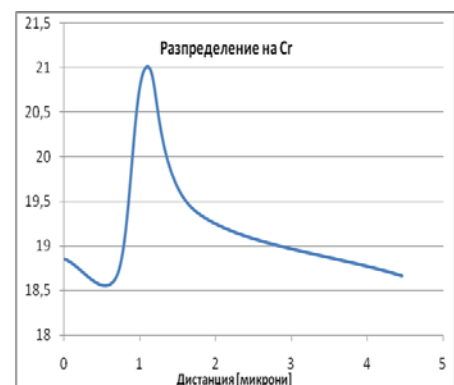


Fig. 7c. Variation of chrome content within the zone of inter-crystal cracking, PMA

There are distinct areas of inter-crystal corrosion observed in Sample 1 (Specimen No1), as well as numerous inter-crystal cracks that are unacceptable flaws.

4. Results and discussion

The mode of welding applied during manufacture of the expansion vessel is inappropriate because of the excessive linear power, i.e. the energy input per unit length of the seam. The longitudinal weld seam of Sample 1 (Specimen No1) is qualified as defective since it doesn't meet the requirements of ISO 5817 (БДС EN 25817) for quality level «B» and quality level «C» according to the following indicators:

- Angle of transition from weld seam metal to base metal. For Sample 1 (Specimen No1) it is equal to 90 degree and does not meet the requirements for the lowest quality level «D». This angle shall be more than 150 degree for quality level «B» and more than 100 degree for quality level «C». The reason is the excessive convexity (i.e. height) of the seam;
- Spillage a portion of the seam metal onto the base metal. This is unacceptable for both quality levels «B» and «C».

The uneven heating of the metal in the HAZ leads to occurrence of temporary and residual deformations and stresses. The residual welding stresses can reach high values, including up to the yield strength of the base metal, due to the mode of welding with high linear energy. They intensify the processes of corrosion, especially stress corrosion in the HAZ. The stresses arising during operation of the expansion vessel caused by periodic changes in pressure and temperature have a similar impact. The stresses in the expansion vessel metal are the reason for the development of occurred corrosion defects into micro- and macro cracks. The overheating of HAZ metal facilitates

the diffusion processes that leads to re-distribution of the alloying elements and especially chrome, as well as to formation of chrome carbides. Thus the chrome content in localized areas decreases which leads to decreased corrosion resistance of steel in the HAZ.

5. Conclusions

The expansion vessel Sample 1 is poor quality. A lot of flaws are found therein, e.g. areas with corrosion and numerous cracks. The longitudinal weld seam of the expansion vessel is poor quality too. The sharp transition angles between the weld seam metal and base metal, and the spillage of weld seam metal onto the base metal with lack of interfusion are inadmissible defects.

The most probable reason for occurrence of corrosion and cracks in Sample 1 (Specimen No1) is the inappropriately chosen mode of welding with high linear energy. It has lead to occurrence of high residual stresses in the HAZ, as well as to overheating and continued detention of the HAZ metal at higher temperature. All abovementioned circumstances lead to a lower corrosion resistance of the HAZ metal and initiation and development of cracks.

References

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[3] ISO 5817 (БДC EN 25817)