METALOGRAPHIC INVESTIGATION OF STAINLESS STEEL TUBES FOR SOLAR COLLECTORS

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Abstract: *This investigation was performed on the request of the Company for production of the solar systems collectors. Subject of the investigation is the segment of the solar stainless steel collector for the heating water in the swimming pool. The system was installed in the private property and was in use until August 2015 (about one month after installation) when it was disconnected for a period of about one month. After that system was restarted again and it was noticed that many cracks appeared in vertical tubes ϕ8 mm of collector manufactured of S304 stainless steel. In the horizontal pipes made of S316 steel cracks were not detected. This investigation should give the answer what is the reason for appearing of cracks in stainless steel pipes for pretty short period of exploitation.*

Keywords: SOLAR COLECTORS, STAINLESS STEEL, STRESS CORROSION CRASCKS, TIG WELDING

1. *Introduction*

For production of solar collectors generally were used copper tubes but in the current time tubes produced from austenitic stainless steels are in use nowadays. Besides good physical properties these steel possess excellent corrosion properties. But presence of chlorine in water can cause serious problem during exploitation conditions of these tubes. Such problems appear during exploitation in this case too. It means that many cracks appear in the embedded solar pipes. Performed metallographic investigations had to show what is the reason or reasons for cracks appearing.

2. *Material and investigation*

Solar thermal collectors consist of stainless steel tubes. Vertical tubes are with diameter of ϕ8 mm and thickness of 0.4 mm, and were produced from AISI 304 austenitic steel. Horizontal tubes are produced from AISI 316 austenitic steel with diameter of ϕ18 mm and thickness 1 mm. Chemical composition of tubes is given in table 1.

Fillet welds (branch) of tubes was performed. Welding of pipes was done by TIG welding process. As filler material was used welding wire from AISI 316 steel (diameter of 1 mm), Argon was used as a protective gas (10 l/min). Welding current is 50 -60 A.

Table 1 *Chemical composition of investigated stainless steel tubes*

Chem. comp,%	AISI 316	AISI 304
C	0.0184	0.0364
Cr	17.74	18.42
Si	0.387	0.386
Ni	9.5	7.70
Mo	2.08	0.216
Mn	1.89	1.31
P	0.035	0.043
S	0.05	0.05
W	0.066	0.023

Damaged welded segment consisting of horizontal and vertical pieces (tubes) was given for investigation. The segment was cut in order to obtain two equal parts. One of them is shown in figure 1. This segment was prepared for metallographic investigation. Standard metallographic preparation of specimen was performed. After grinding at different abrasive papers, polishing with suspension of Al_2O_3 was done. Finally chemical etching with V2A etchant was made. Macro photo of investigated segment is given in Figure 1. After polishing specimen was analyzed under optical microscopy (OM) using different magnifications. Figures 2 (a and b) presents micro photos taken from the polished specimen, and concern to the vertical (inclined) tube. As can be seen from the micro photos besides the biggest crack which can be seen with naked eye, many thinner cracks were detected. They are located beneath and above the biggest crack.

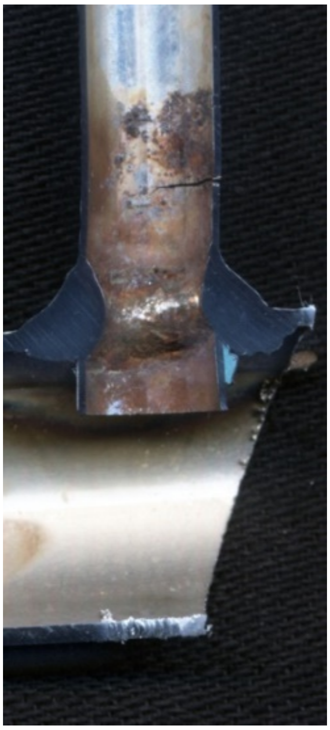
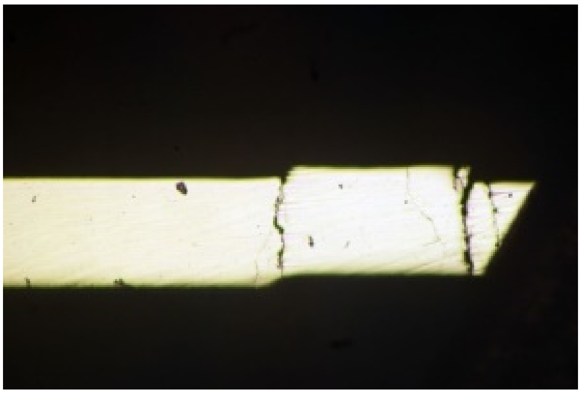


Figure 1 *Macro photo of welded segment (branch weld) cut for metallographic preparation*

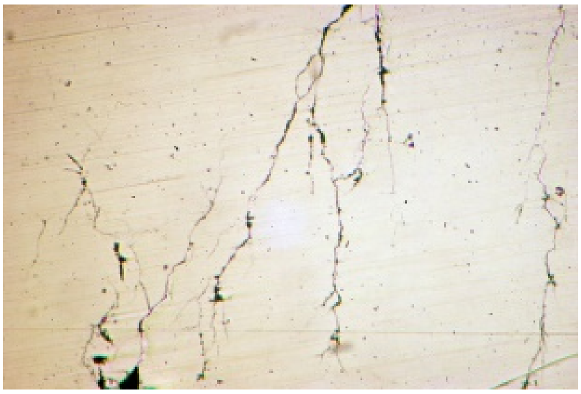
a



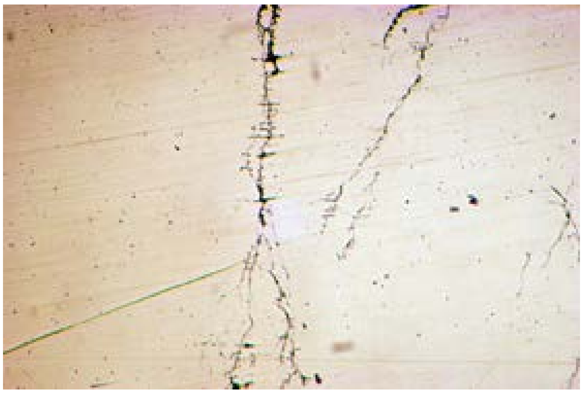
b

Figure 2 *Micro photo of polished specimen (vertical tube), with the main crack x50*

Figures 3 concern to the same tube (vertical) and it can be seen that these cracks are pretty thin and have characteristic branch form. It has to be said that that these crack propagate trough entire thickness of the tube wall.



a



b

Figure 3 *Micro photo of polished specimen (vertical tube), x200*

In some cases as first appear pitting corrosion and after that stress corrosion cracks appear, figure 4

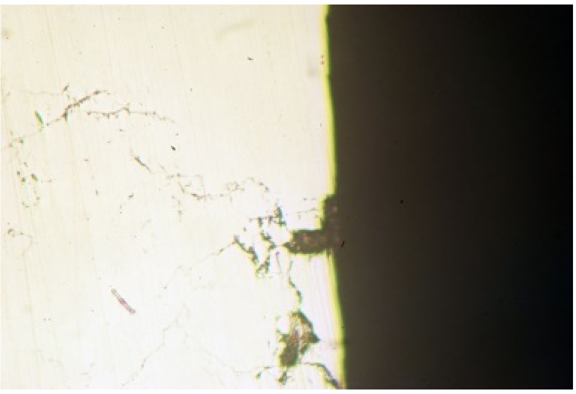
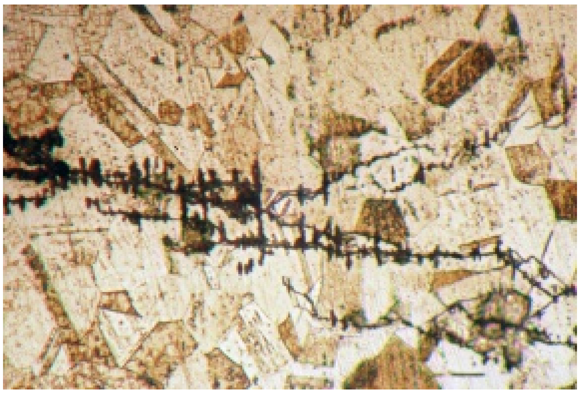
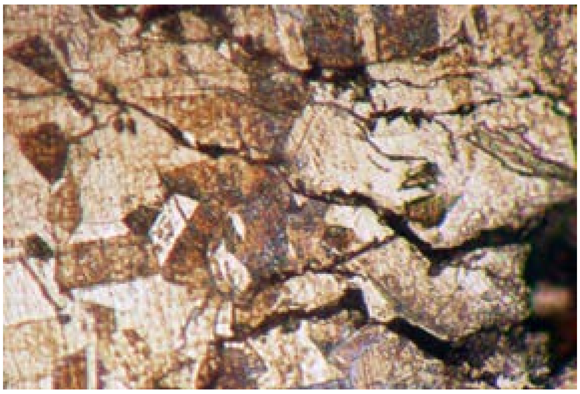


Figure 4 *Micro photo of polished specimen (vertical tube), x200*

Figures 5 concerns to the etched microstructures of inclined tube. Austenitic grains are clearly seen and in all case stress corrosion cracks (SCC) are present. Cracks propagate mainly transgranularly but in some case intergranular propagation can be seen.



a



b

Figure 5 *Micro photo of etched specimen (vertical tube), x200*

3. Discussion

As can be seen from macro photo (Figure 1) the biggest crack is clearly seen and includes almost one half of the tube vertical segment. It can be seen too that this cracks is located on the corroded surface of the inclined tube. It can be seen from the figure 1 that there is neither corrosion products nor cracks in the horizontal tube S316. Weld metal can be clearly seen too. It is obvious that weld size is too big for this thickness of pipes. It means that too much heat is input which contributes for residual stress in the welded joint.

Another thing that some characteristic defects in the weld area can't be seen.

As can be noticed from micro photos many cracks are present at different position in the specimen (vertical tube). They are located beneath and above the main crack. But all of them are located in the corroded area. It is noticeable that these cracks have form of branches and almost all of them propagate trough entire thickness of the wall. Propagation of cracks is mainly trans granular (through the austenite grains), but in some cases intergranular crack propagation can be seen (across the grain boundaries).

It can be said the vertical (inclined) tube is extremely corroded. These cracks detected in the vertical tubes are typical examples of stress corrosion cracks (SCC). The main reason for their appearing is interacting of the work of collector system. In that period, chlorine water in the didn't circulate through the tubes. The remaining water in the tubes evaporates and concentration of chlorine in the inner surfaces of the tubes drastically increased. Much higher than usual concentration in the water during the normal work of the collectors. Temperature of tubes according obtained information was over than 200 ^{0}C.

According obtained information, almost all cracks at vertical tubes are located at the same position (in the lower part of tubes) like on the investigated specimen. It is well known from appropriate technical literature that SCC appears in the sea water and in medium with increased concentration of chlorine. It is known too that SCC appears at temperature over 60 ^{0}C []. And very significant factor is presence of longitudinal tensile strength in material. It could be residual stresses, from welding for example. As can be seen from the macro photo weld thickness is much higher than the pipe thickness. In this case there is welding heat input in these thin pipes. When collector system was restarted, cold water pass through the tubes heated at temperature of about 200 ^{0}C which caused thermal shock in the tubes. In this case all main factors for SCC appearing were fulfilled – high chlorine concentration, temperature over 60 ^{0}C and tensile strength. It has to be point out that if the collectors worked continuously appearing of stress corrosion cracks should be avoid

Three main factors dealing at the same time are the most influencing factors which cause stress corrosion cracks appearing i.e. increased temperature residual stress and presence of chlorine,

4. Conclusion

It is obvious that stress corrosion cracks in the smaller, vertical pipes appear as result of three main factors which act in the same time – increased chlorine concentration, increased temperature and tensile strength. It is a period when the collector was not in function (for the period of about one month). In that period, because of high temperature of tube (over 200 ^{0}C) water in the tubes evaporate and the concentration of chlorine on the tube walls increase many times compared with concentration of chlorine in the water. During restart of the system very fast cooling of the tubes (200 ^{0}C) with water at ambient temperature are the reason for appearing of cracks in the pipes and damaging of collector system.

In our opinion if the collector system was working permanently appearing of SCC cracks should be avoid. According obtained information, collectors were working about one month before to be interrupted. During this period of permanent work of collectors cracks didn't appear. They appeared immediately after restart of the collector system.

Molybdenum increase corrosion properties of austenitic steels too

5. Literature

http://www.npl.co.uk/upload/pdf/stress.pdf

http://www.npl.co.uk/upload/pdf/stress_corrosion_cracking_basics.pdf

http://www.asminternational.org/documents/10192/1849770/06355G_Sample.pdf/daf91547-a566-4f77-83a0-1fca83b87157

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