WELDCRACKING IN FEEDWATER CONTAINERS OF INKOO POWER PLANT

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ABSTRACT

Severe cracks were found especially in the weldments of radial reinforcement bands of the feedwatercontainers made of HSLA steel. These welds were made using submerged arc method using two weldruns and a preheat of 150°C. The cracks have their origin in corrosion grooves located on to penetration boundaries. There the microstructure consisted of martensite, bainite and secondary carbides.

One of the main reasons to the cracking is the vanadium content of the parent metal. In the welding process the vanadium dissolves in the weld around the penetration boundaries and is retained there in excess because of the fast cooling. These enriched zones around the weld penetration are transformed to martensite and bainite because of fast cooling and the high hardenability factor of vanadium. These boundaries give raise to an internal stress concentration and to a lowered anodic potential which together are detrimental.

The width of the boundary is measured to be only about 0.1-0.2 mm so it can not always be detected by usual hardness measurements. Because of the high hardenability due to vanadium the preheat temperature used is shown to be too low.

The second weldrun caused a tempering of formed martensite but because of the precipitation of secondary carbides the usually beneficial effect of the post-weld-heattreatment is not realised.

INTRODUCTION

The Inkoo power plant is located in Finland near by Helsinki on the seacoast. It is a coal fired conventional power plant consisting of four units.

The first annual reinspection of the power plant feedwater containers revealed severe cracks especially in the weldments of the vacuum reinforcement bands. The most severe cracks were 13-14 mm deep and continuously 3 m long. When extending the inspection to the other units, similar cracks starting from corrosion groove were found even in other types of welds in all feedwater-containers which had been in use. The over-all dimensions of the tubular feedwatercontainers were 28500 x ∅ 3400 mm, the wall-thickness being 18 mm. The allowed working conditions consisted of a temperature of +200°C and a pressure range from vacuum to 15 kp/cm^2. In the construction there were reinforcement bands used against vacuum operation. These inside bands were welded to the shell using submerged arc method with two weldruns. The first weldrun was made as a filler weld towards the shell using ESAB OK Autorod 12.11 ∅ 4 mm as filler wire and ESAB OK Flux 10.61 as welding powder, the welding parameters being 500 A, 30 V and 24 m/h. The second weldrun was made towards the 20 mm thick and 80 mm high band in a similar way to the first weld but changing the electrical parameters to 450 A and 26 V. This combination of flux and filler wire is known to give a resulting weld with a composition of C ~ 0.1, Si ~ 0.2 and Mn ~ 0.6. The preheating temperature was controlled to be in the range of 150-200°C during the welding. The width of the preheating zone was about 150 mm on both sides of the weld to be made. Preheating was also used with secondary weldments. The welding powder was dried for 2 1/2 h at 250°C before welding.

The steel used for the shells of feedwatercontainers was a HSLA finegrained steel having a nominal analysis of C < 0.20, Si ≤ 0.40, Mn = 1.20/1.70, P ≤ 0.035, S ≤ 0.035, Ni = 0.40/0.70, V = 0.12/0.22 %. The analysis of different heats used in construction showed the vanadium content to be 0.17 % in eight plates and 0.13 % in one plate welded together to form the shell of the container of unit II. The reinforcement bands were made of C-Mn type steel plates corresponding to R St 37.2 according to DIN standard.

EXPERIMENTAL RESULTS AND DISCUSSION

A sample of a cracked weld was taken from the feedwatercontainer of unit III. The sample was a weldment of the reinforcement band and the shell.

The crack started from a corrosion groove (Fig. 1) in the fusion boundary between the weld and the shell plate. Typical stress-corrosion induced cracking behaviour can be seen in Fig. 1. The role of corrosion in the cracking can be seen from the multiple small lakes in the crackriver where as the stress-influenced cracking continues like a zig-zag veining through different areas where in fact no plastic straining is possible /1/. In Fig. 2 one can detect a corrosion lake from where the crack goes further through three veins. In the isles between the veins a martensitic-bainitic microstructure can be revealed. Using transmission electronmicroscopy on carbon replicas prepared from these sites (Fig. 3) one can see that the non-plastic zone originates not only in the low temperature phase transformations but in the precipitation of secondary carbides, too. This kind of phenomena

often gives rise to well known stress-relief-cracking. In the present case the necessary heattreatment for such reheatcracking has been produced by the second weldrun.

By studying the results the microhardness measurements (Fig. 4) one can see that at first the cracking follows the path of the high hardnessvalues. This path is only 0.1-0.2 mm wide and thus can easily be missed when making traverses to measure Vickers hardness using weights of 3 kg or more.

This very thin martensitic zone on the fusion boundary could have been formed because of the high solubility of V in iron (= 0.54 at % V). In this case the system Fe-V has a liquidus at 1531°C and solidus at 1530°C, so the supersaturation due to the fast cooling is possible. Moreover the carbon in solution in the discussed temperature range doesn't enhance the vanadium carbide precipitation because V_2C is in balance with V-5 % C solid solution /2, 3, 4/. According to Grossmann's calculations of hardenability /5/ the factor for V is 13 which in this case can on the above mentioned basis be extended to the actual concentration values of the porridge like fusion boundary of the parent metal which during the welding process is not mixed into the weldpool. Because of the resulting high tendency to martensitic transformation this stressconcentrating nonplastic narrow zone is formed, whilst the secondary precipitation mere decreases further the plasticity.

The corrosion groove following the fusion boundary has probably its origin in the carbon supersaturated massive ferrite seen in Fig. 2. The high temperature ferrite can contain up to 0.1 % carbon. Even after secondary precipitation between 600°C and 800°C followed with fast cooling this solid solution can have a minimum carbon concentration of 0.06 % compared with ferrite in balance to carbon in roomtemperature having a concentration about 10^{-7} % /6/: This difference can lead to much pronounced anodicity (~ 10 x) of the ferrite of higher carbon content /6/.

A simulation test piece for the above mentioned sample was made using different preheating temperatures. It was found that preheat temperatures even of 200°C and 250°C did not fully remove the varying levels of the measured hardness values in the penetration boundary. The preheat temperature of 150°C as used in the industrial welding process is thus shown to be too low.

CONCLUSIONS

1. Weldment cracking was found after service in fine-grained low-alloy steel feedwatercontainers. The start of the cracking is found to be in a corrosion groove. This groove is thought to be formed because of the pronounced anodic behaviour of massive ferrite at this position.

2. The cracking is found to follow a narrow high hardness martensitic bainitic path. This zone is thought to form a stress concentrator without plasticity, thus being responsible for cracking.

3. The formation of the zone is considered to be caused by the high V-content of the parent metal. The resulting precipitation of secondary carbides further decreases the poor plasticity.

4. Corrosion phenomena in the crack promote further the cracking.

5. The preheating temperature used (150°C) is shown to be too low in relation to the prevention of the martensitic phase transformation.

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Parent metal Weld

Fig. 1. An overall view of the cross section of a cracked weld region. 150x.

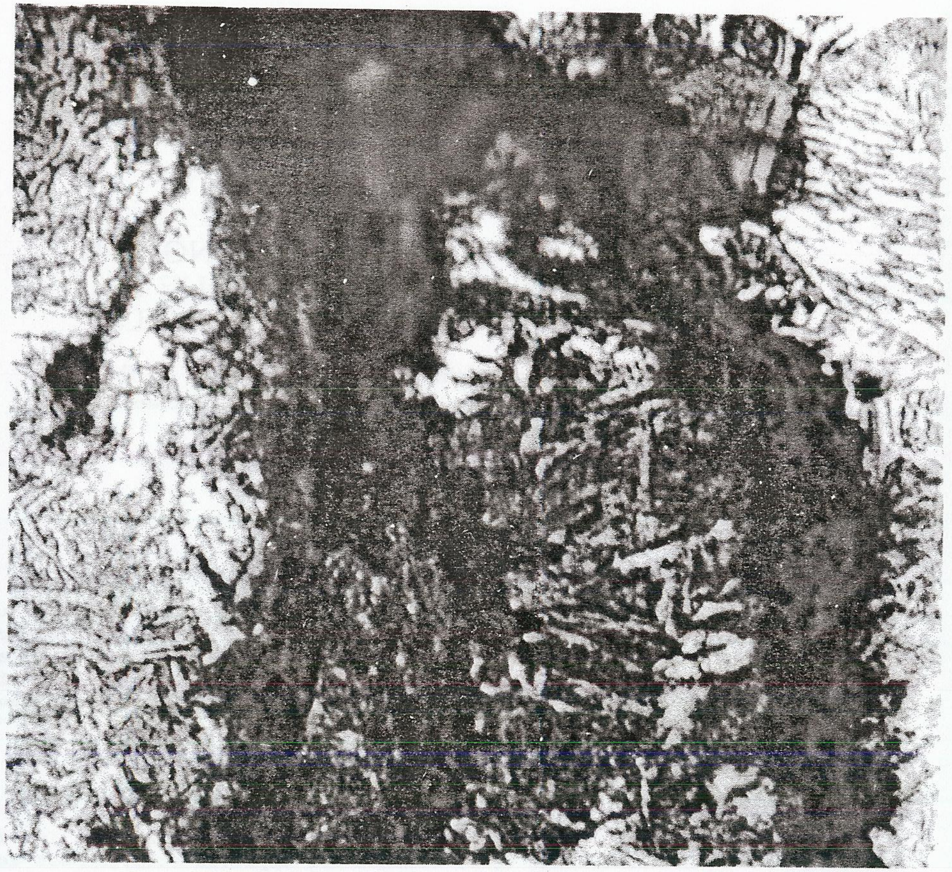

Fig. 2. An enlarged view of the crack propagation showing on the top a corrosion "pool" in the crack. 2020x.

Fig. 3. A TEM picture of a replica of the martensitic bainitic path with secondary precipitates. 60000x.

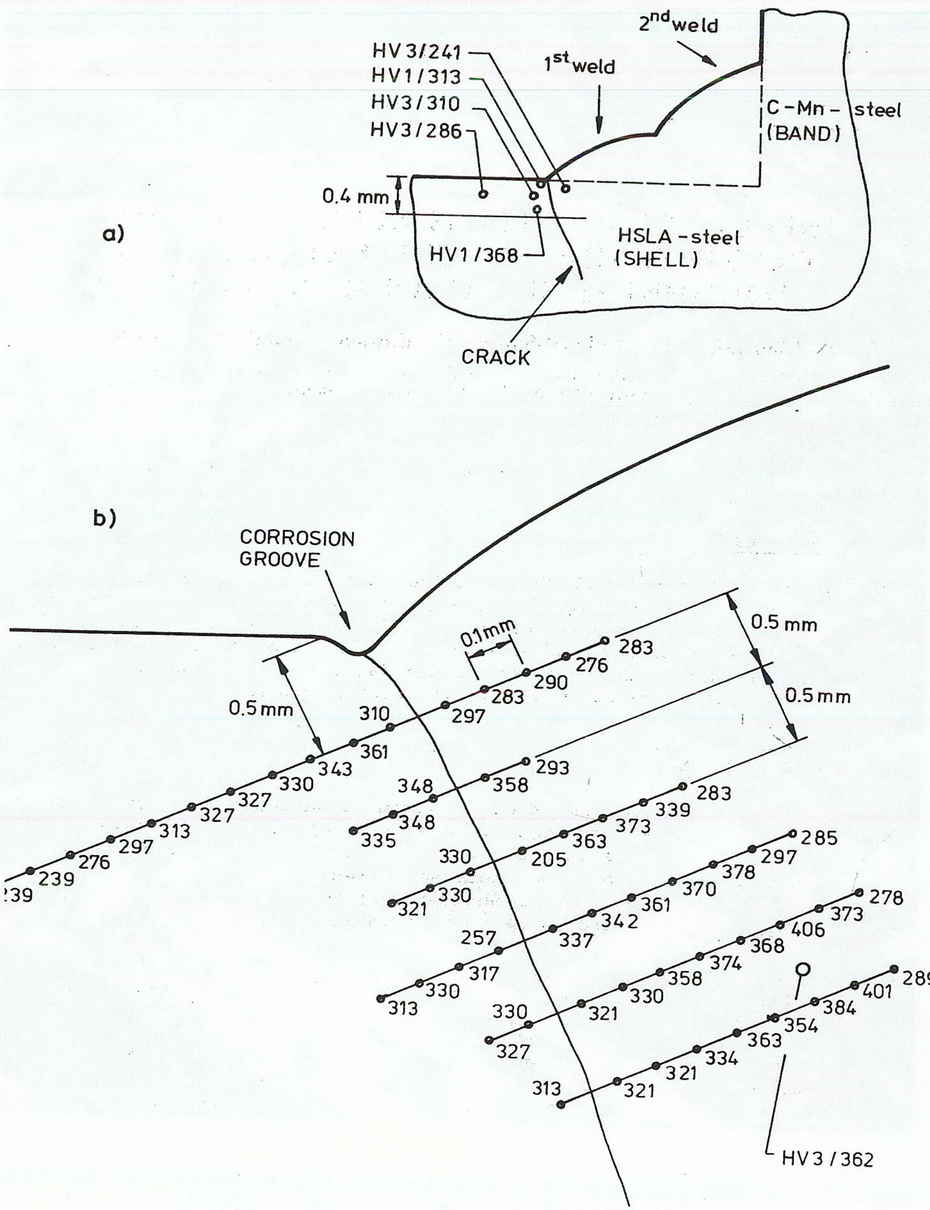

Fig. 4. Hardness measurements around the crack.
a) Preliminary tests.
b) HV 1 measurements.