Inspecting for chloride stress corrosion cracking in unpainted austenitic stainless steel vessels

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Chloride Stress Corrosion Cracking (CSCC) is a form of environmental-induced cracking that can occur in austenitic stainless steels. The cracking typically is transgranular in nature and occurs when stressed material is exposed to a chloride containing aqueous environment at temperatures greater than 60°C, due to either applied or residual stresses.

It can occur readily under thermal insulation at temperatures between 60° C and 150° C when water is allowed to get under the insulation. The water may contain chlorides due to marine location, industrial pollution or through the leaching of chlorides from the insulation. The water will concentrate in contact with the hot metal surface and evaporate causing local concentration of the chlorides to levels where cracking will occur. At temperatures below 60° C, cracking will not occur under insulation unless the water is highly acidified. At temperatures greater than about 150° C, experience indicates that cracking has a low probability of occurring. This is postulated due to the fact that the water evaporates before it can concentrate on the metal surface.

Equipment selected for inspection met all the criteria for CSCC; *ie* it was of unpainted stainless steel, had damaged insulation open to moisture ingress and was operating in the critical temperature range. A significant contributor to the overall CSCC of the equipment was that leaking steam-tracing connections were present under the insulation or in positions where they could leak into the insulation at breaks in the weather jacketing.

Preparation

All equipment to be examined was fully scaffolded for access, insulation was removed and the items visually inspected for signs of leakage.

There was visible evidence of leakage and cracking at welds and, surprisingly, in plate areas remote from any welding, which is unusual but has been seen before. Local forming stresses and membrane operating stresses are sometimes sufficient to cause cracking with sufficient chloride concentration.

Examination was carried out in the following areas:

- All weld seams for a distance of 75 mm either side of the weld centreline
- All external areas local to internal attachment welds
- Any areas showing visible evidence of leakage or the classical visual telltales for cracking.

These areas were cleaned using a range of techniques, including baking soda, high-pressure water washing and standard degreasers. It is important to note, however, that thorough cleaning of the surface is required to allow for adequate inspection. A technique comprising high-pressure water blasting to remove loose insulation, dirt and scale, followed by baking soda blasting to remove rust deposits over the cracks, was found to be the most effective technique. Although it removed the bulk of the rust cap, it did not remove the discoloration that provides a telltale for the crack location.More aggressive cleaning techniques such as sandblasting obliterate the discoloration telltales and also can often peen the cracks shut so that they are not detectable by liquid penetrant inspection.

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The case studied

MATERIAL:	Unpainted austenitic stainless steel type 321 (18/8/Ti)
EQUIPMENT:	Vessels/columns
WALL THICKNESS:	6-10 mm
OPERATING TEMPERATURE:	70-105°C
INSULATION TYPE:	Asbestos-containing

Examination

Examinations were carried out from both external and internal surfaces using a variety of techniques ranging from eddy current testing to vacuum box and soapy bubble test.

It is interesting to note that, although the external appearance of through-wall leak areas was that of well-defined cracks up to 200 mm in surface length, internally there was no visible evidence of cracking and the material appeared to be in good condition. However, when red liquid penetrant was applied to the outside surface and a vacuum box attached internally, the penetrant appeared on the internal surface, clearly showing the extent of cracking. This was generally confined to minor pinholes, confirming that crack initiation was indeed external and that the developed length of the crack on the surface had a much greater length-to-depth aspect ratio than one would expect.

Areas of external cracking were then investigated using a combination of eddy current testing and colour-contrast penetrant flaw detection with soft white developer.

Following cleaning, penetrant was applied to the area to be examined and allowed to soak for 60 minutes. Excess penetrant was then removed by wiping with a lint-free cloth soaked in penetrant remover. Soft white developer was then applied with a development time of 30-45 minutes. The procedure used had been shown from previous comparative trials to give maximum sensitivity.

It was found that some visible cracks did not show on penetrant examination, probably as a result of the tight nature of the stress corrosion cracking and also the presence of corrosion product within the cracking, preventing absorption of the penetrant, see Figures 1 and 2.

Thorough cleaning was then carried out to remove developer and penetrant. This was followed by eddy current inspection using equipment with absolute and differential probes operating at frequencies from 10 to 100 kHz. The equipment was calibrated on stainless steel calibration blocks with EDM notches and EDM notched weld samples. OIS Teesside (UK) and Precision Inspection Inc (USA) developed the procedure used.

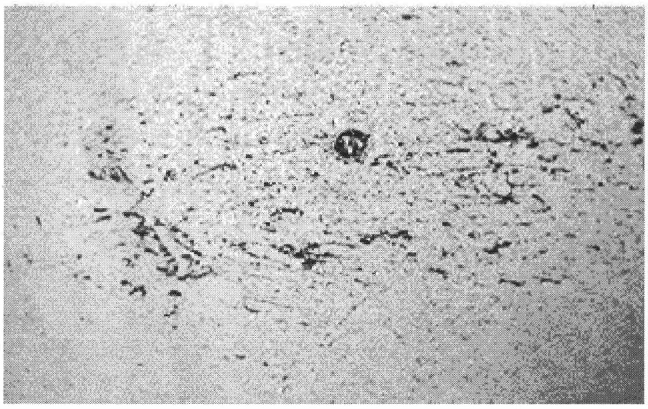

Figure 1. Visual indications

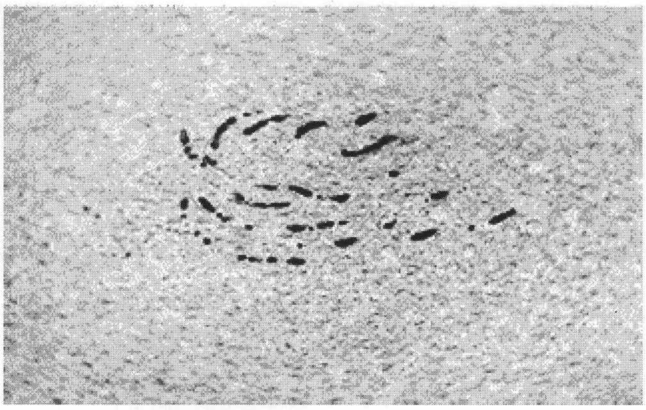

Figure 2. Penetrant indications

All visible crack indications were detected and sized in terms of length and depth using the eddy current test method. In addition, fine cracking was detected in regions where there were no visible indications. Eddy current inspection covered large areas with greater speed than that achievable with penetrant flaw detection.

Where CSCC is known or suspected, it is recommended that examination of equipment should be carried out initially by eddy current testing, followed up as necessary with penetrant flaw detection to show up cracked regions for recording and reporting purposes.

Follow-up repairs/replacement

On completion of the surveys and identification of all areas of CSCC, the probability of failure of each vessel affected by CSCC was evaluated, based on materials engineering experience within the company and by the application of fracture mechanics. Industrial experience is that CSCC results in weeping leaks and the cases of actual catastrophic failure are extremely rare.

The conclusion was that the larger, more severe areas of cracking could not be effectively evaluated by experience and fracture mechanics evaluation. This resulted in new top heads being fitted to a column and tank.

On areas of less severe CSCC, a peening process was applied using a stainless steel tool with a mushroom head to seal any cracking. Crack closure was verified first by penetrant flaw detection and then by vacuum box and soapy bubble testing. These tests confirmed that all leaks had been closed.

Final testing was done by acoustic emission monitoring on three of the vessels to complement the industrial experience and fracture mechanics analysis that indicate the vessels had no potential for catastrophic failure due to the CSCC.

Two vessels were hydraulically pressure tested and one pneumatically tested, and acoustic emission monitoring carried out following MONPAC and ASTM procedures for data acquisition and analysis. AE activity was detected in the regions previously identified as having suffered CSCC, but data analysis indicated that unstable crack growth (*ie* vessel tearing) would not occur. The testing provided assurance that the vessels were suitable for continued operation until they could be replaced. Ongoing monitoring will identify any additional crack extension or growth to allow for ongoing assessment of the fitness for service of the vessels.

In order to reduce the risk of further CSCC, all vessels were grit blasted to a surface finish suitable for painting and, once painted, were re-insulated using Pearlite with AluZinc cladding. Removable windows were built into the insulation and cladding to allow periodic monitoring for any further cracking in the areas identified to be leaking or having deep cracking. Future eddy current testing will be possible without removal of the protective paint coating. These protective steps will stop any initiation of further cracking and are anticipated to dramatically reduce the progression of existing cracks.