PRACTICAL SOLUTION FOR AVOIDING FAILURE OF ABSORPTION TOWER AT A NITRIC ACID PLANT
--- Replacing Welding by Mechanical Joining ---

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ABSTRACT

After ten years of operation, the absorption tower at a nitric acid plant was failed due to stress corrosion cracking. SCC was caused by combination of both welding residual tensile stresses and chloride ions accumulated due to rain and/or vapor contaminated with chloride. Irregularity of fillet weld surface helped in occurrence of cycles of wetting and drying conditions of weld surface that in turn resulted in chloride concentration.

The problem has been solved by changing design of the fixation system of the rain water collector in order to avoid combination of tensile stresses and chloride, the condition necessary for occurrence of SCC. In other words, fixation of rain water' collector to the tower' shell was done using mechanical means instead of fillet welds that in turn result in eliminating tensile stresses and reducing chloride concentration.

1 INTRODUCTION

The subject absorption tower has been set into operation ten years ago. It is made of type 304L stainless steel with 79285mm height and 5850mm diameter. Wall thickness of its shell is ranging between 24mm at bottom and 10mm at top.

The tower is used for producing 60% concentrated nitric acid. Inlet of the processing gases is near from the tower' bottom zone where shell wall thickness is 24mm while the outlet is at the top of the tower where wall thickness is 10mm. The processing operations include passage of NOX gases through 37 trays from bottom to top of the tower.

Design temperature and pressure of the tower are 50/100^oC (122/212^oF) and 170psi (1.17MPa) while its operating temperature and pressure are 18/58^oC (64/136^oF) and 141psi (0.97MPa) / 151psi (1.04MPa) respectively.

Figure 1 shows a schematic illustration of longitudinal section of the tower and its attachments. The tower was surrounded from outside with a collar located at 5200mm from its bottom. The collar was made of 3mm thick type 304L stainless steel with 40mm height and it was fixed to the tower' shell using fillet welds. The collar was used as a fixation ring for a round shape rain water' collector that was made also from 3mm thick type 304L stainless steel with 100mm width and 100mm height. Rain water' collector was fixed to the collar using two sides fillet welds.

2 PROBLEM

Recently, the absorption tower developed leaks around the fixation collar (ring) of the rain water' collector spite lager wall thickness (24mm) of tower shell at this zone.

3 INVESTIGATION

Visual and dye penetrant tests of the leaked zone, after removing both collar and rain water' collector disclosed branched cracks at the outer surface of tower shell (Figure 2). Cracks were confined only to the shell' zone that was covered with the collar. Cross sections from the failed tower' shell were cut out and prepared for chemical analysis, hardness measurements, optical and scanning electron microscopy examinations, and EDX micro-chemical analysis.

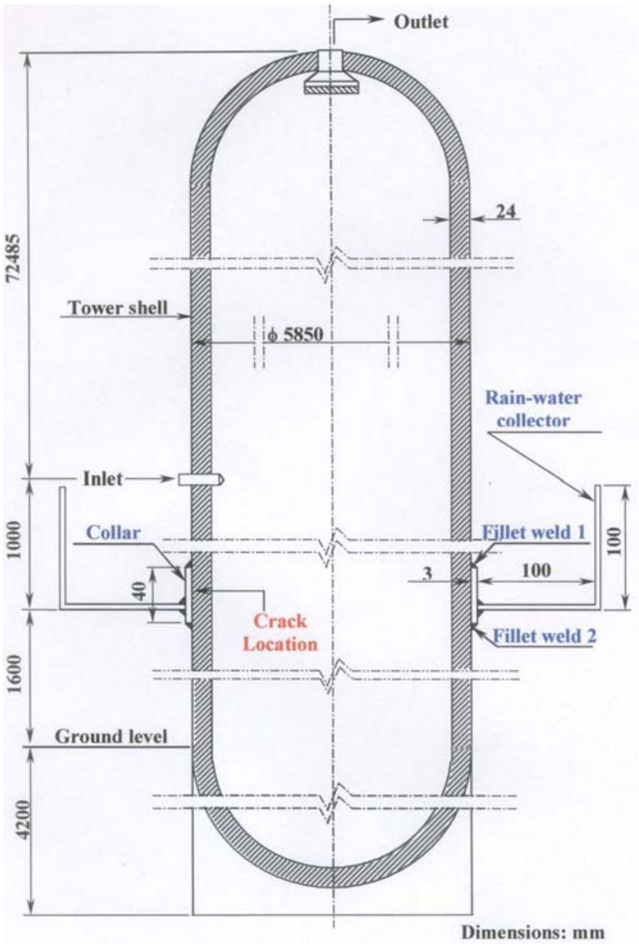

Figure 1. Schematic illustration of a longitudinal section of the tower showing rain water' collector and its fixation collar where leaks were occurred.

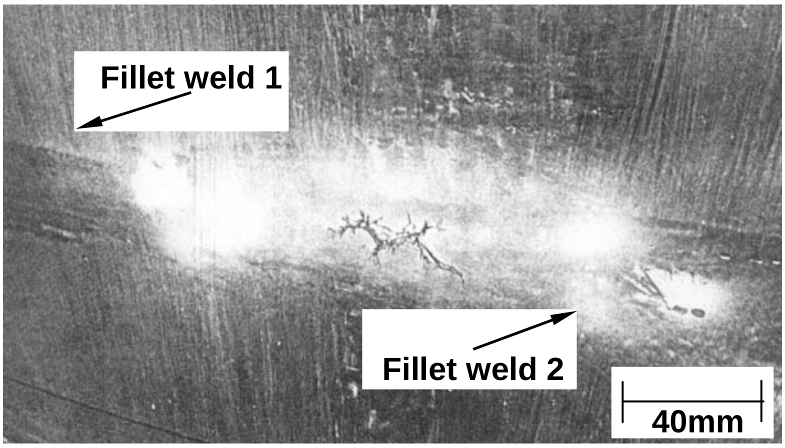

Figure 2. Close-up view of the outer surface of leaked shell' zone, after removing rain water' collector and its fixation collar showing branched type cracks confined between fillet welds of collar with shell.

Data from chemical analysis of the failed tower' shell fell within the specified range for type 304L stainless steel. A survey of wall thickness of the failed shell' zone has confirmed that almost no reduction in wall thickness was recorded. Minimum wall thickness was 23.9mm while the original one was 24.0mm.

Figure 3-(a) shows optical micrograph of a cross section taken from the leaked zone. The most important notice is that cracks were initiated at the outer surface of the tower shell then, it propagated through thickness toward inner surface. The cracks exhibited branching as they propagated through shell wall thickness. Higher magnification indicated that paths of these branched cracks principally were on grain boundaries (intergranular) as shown in Figure 3-(b).

Optical microscopic investigation confirmed that cracks were confined only to the leaked zone where no cracks were observed at non-leaked one. Microstructure observed for both leaked and non-leaked zones was identical to that of type 304L austenitic stainless steel. No grain boundary precipitates or depleted zone were observed. Hardness measurements revealed no significant difference in hardness values across wall thickness of non-leaked zone where an average hardness value of about 180Hv was obtained.

Scanning electron microscopic examination of the outer surface of a failed zone revealed branched cracks around a corrosion pit as shown in Figure 4. EDX microanalysis of this zone indicated chlorine at crack path. However, higher chlorine content was found at corrosion pits.

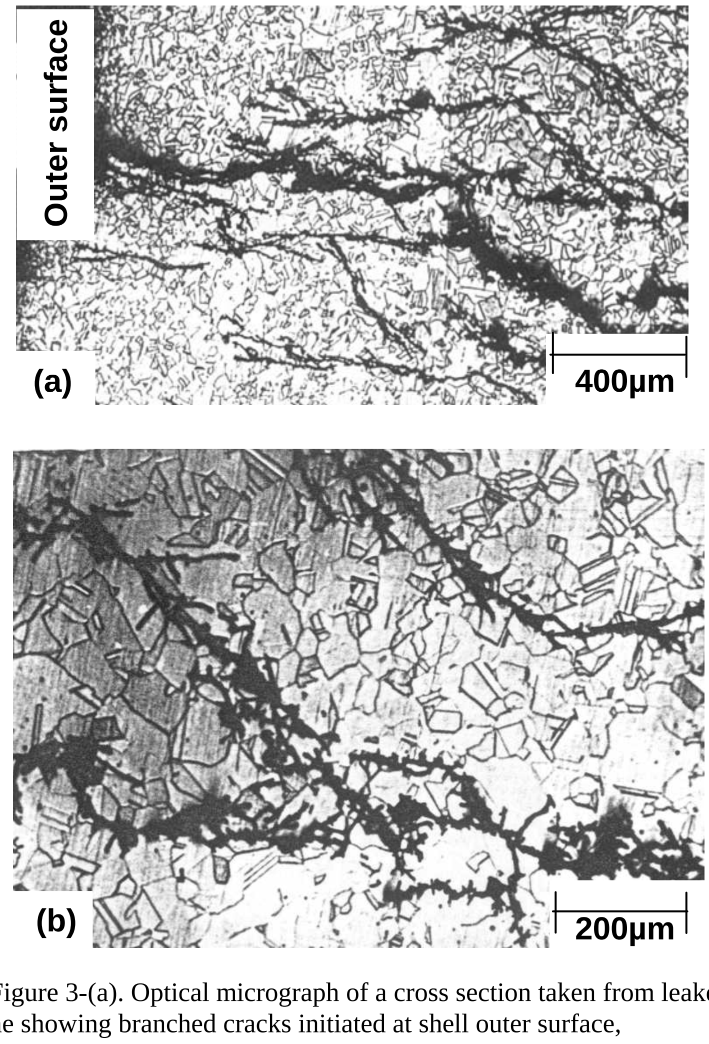

Figure 3-(a). Optical micrograph of a cross section taken from leaked zone showing branched cracks initiated at shell outer surface,
(b) Higher magnification showing grain boundary crack propagation.

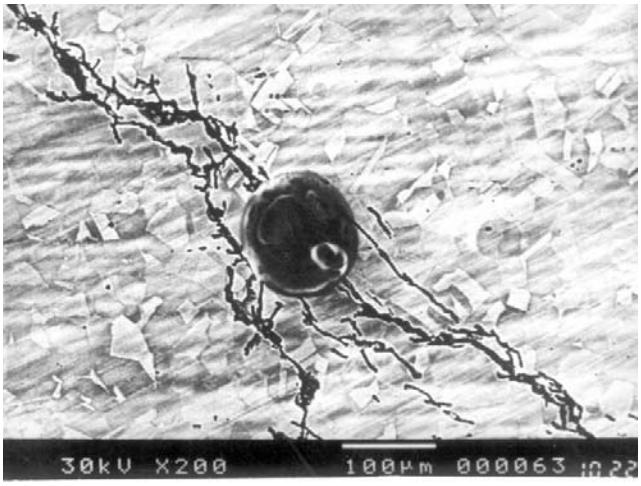

Figure 4. Scanning electron micrograph of outer surface of shell' leaked zone showing branched cracks around a corrosion pit.

4 DISCUSSION

Stress corrosion cracking (SCC) was identified as a failure mechanism. Equipment made of austenitic stainless steels generally sustain SCC when contacted by hot chlorides in aqueous solution, even in concentrations of only a few parts per million. Therefore, chloride attack is insidious, and operating personnel may not be aware of such a problem until failure occurs.

Failure caused by SCC produces both thick-walled fracture faces, regardless of the degree of metal ductility, and branched intergranular cracking. This cracking phenomenon has serious consequences since it can occur at stresses within the range of typical design stress.

SCC refers to cracking caused by the simultaneous presence of tensile stress and a specific corrosive medium. Tensile stresses may be either applied, such as those caused by internal pressure, or residual, such as those induced by welding or forming. The minimum stress depends on temperature, alloy composition and environment composition. The tensile stresses that contributed to the subject failure were primarily residual stresses caused by circumferencial fillet weld of collar with shell. The corrosive medium is related to the existence of chlorides, as an aggressive ion for stainless steels, due to wetting of metal outer surface with rain water and/or vapor contaminated with chloride.

It was clear that cracks were initiated first at the outer surface of upper fillet weld of collar with tower' shell (fillet weld 1 in Figure 1) then, penetrated through this fillet weld. Irregularity of fillet weld could help in cycles of wetting and drying conditions of its surface that in turn resulted in chloride concentration. After cracks penetrated this fillet weld, rain water has passed and accumulated through clearance located between collar and shell and this created a stagnant condition. This stagnant condition combined with high stress concentration between fillet weld 1 and fillet weld 2 (Figure 1) created a sufficient condition for initiation of SCC at the outer surface of the tower' shell zone covered by the collar (Figure 2).

Corrosion pits on the outer surface of the leaked zone accelerated the formation of SCC since it acts as stress raisers. Stress concentration increases tremendously as the radius of pit decreases. SEM examination disclosed branched cracks around a corrosion pit (Figure 4) that confirms initiation or starting of SCC at the base or root of corrosion pits. Once a crack has started, the tip of the advancing crack has a small radius and the attendant stress concentration is great. The conjoint action of stress and corrosion is a must for further crack propagation.

Propagation of SCC through shell' wall thickness, toward inner surface, continued until operating stresses exceeded the yield strength of the material, and failure occurred. As the cracks progressed, the stresses exceeded the strength of the remaining intact shell, and a brittle thick-walled failure occurred.

5 REMEDY AND LESSON LEARNED

The leaking zone around the circumference of the absorption tower' shell in addition to 250mm above and below it was replaced with new part of the same stainless steel. The newly inserted shell ring, replacing the leaked zone is 500mm height with the same diameter and thickness of shell.

However, combination of corrosive medium and tensile stresses should be eliminated in order to avoid such failure in the future. Since chloride ions as a corrosive medium are difficult to be avoided then, tensile stresses due to welding should be considered. In this respect, fixation of the rain water' collector around the tower' shell was done using mechanical means instead of fillet welds. This will eliminate tensile stresses and reduce chloride concentration that in turn will prevent SCC.

Bibliographies

1. R. D. Barer and B. F. Peters, Why Metals Fail, 6th ed., Gordon and Breach Science Publishers, New York, 1991.
2. ASM Handbook, Failure Analysis and Prevention, Vol. 11, Materials Park, OH: ASM International, 1996.
3. V.J. Colangelo, F.A. Heiser, Analysis of Metallurgical Failures, 2nd. ed., New York, NY: Wiley, 1987.
4. R.D. Port, H.M. Herro, The Nalco Guide to Boiler Failure Analysis, McGraw- Hill, USA, 1991.
5. M.G. Fontana, Corrosion Engineering, 3rd ed. (New York, NY: McGraw-Hill, 1987).