FATIGUE OF OFF SHORE CONDENSATE RECYCLE LINE AT NATURAL GAS PRODUCTION FIELD

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ABSTRACT

After two years of operation, condensate recycle line at a natural gas production field was failed due to fatigue cracking. Fatigue was caused by combination of both cyclic stresses related to intermitted operation mode and stress concentration at base of fillet weld. Stress concentration was remarkably increased as a result of weld surface defects including undercut and overlap that caused sharp transition at fillet weld base. Internal welding defects such as porosity and lack of fusion could not played a role in crack formation. On the other and, failure could be encouraged by corrosion after exposing of crack surface to atmospheric condition.

The problem has been solved by improving geometry of fillet weld so that, acceptable contouring with smooth transition at fillet weld base was obtained that in turn resulted in reducing stress concentration. Periodic inspection was scheduled to check the existence of outer surface cracks and necessary action to be done in order to avoid sudden failure and unexpected shut down.

1 INTRODUCTION

A natural gas production field has been set into operation about two years ago at the Mediterranean coast. Natural gas produced from the well is processed through different stages including test separator, degassing oily water drum and production separator. In degassing oily water drum, both gases and condensate are separated. Then, separated condensate (hydrocarbon or mixer of oil in water) is transferred to production separator for further processing. Condensate transferring line was made of duplex stainless steel seamless pipes with 2” diameter, schedule 80. Attached to this horizontal line is ¾” duplex stainless steel pipe branch, in a vertical position, fillet welded to the main 2” line. A standby valve, for future plant modification, was fixed into ¾” pipe branch as shown in Fig. 1. Operating pressure and temperature of this line are ranging between 1192 ~ 1308psi (8.2 ~ 9.0MPa) and 30.7 ~ 35.7^{o}C (87.3 ~ 96.3^{o}F) respectively. The line is operated in an intermitted mode where it is subjected to several cyclic operations a day based on production condition.

Recently, condensate recycle line has experienced leakage at its fillet welded joint with ¾” pipe branch. Detailed non destructive testing were carried out then, flanges of standby valve were disconnected and spool including ¾” pipe branch with about 230mm length of 2” main line around the leaked zone was removed for comprehensive investigation and clarifying failure cause.

2 INVESTIGATION

The leaked zone was subjected to different non-destructive tests including visual investigation, thickness measurement and dye penetrant investigation. The leaked zone was confined to fillet weld connecting ¾” pipe branch to 2” main line. Visual inspection showed that the outer surface of the leaked zone is clean and free from deposits or indications for corrosion. However, some welding prominent as a result of using hand grinder after welding were observed. It also indicated a remarkable irregularity in weld surface, particularly at weld base where there was sharp transition between fillet weld and 2” pipe as a result of undercut and overlap (Fig. 2). The leakage was confined to this zone where a crack with about 40mm length was observed (Fig. 2). Examination of crack using magnifying lens indicated that width of crack is varied along its total length, suggesting multi-initiation sites. Absence of crack on other side of fillet weld was confirmed by dye penetrant test. It is noticed that non-cracked fillet weld side has a smooth transition with 2” pipe.

For internal investigation, the removed spool was split longitudinally into two halves (leaked and non-leaked) along its 2” pipe. Visual investigation of the inner surface of the leaked half showed smooth surface with no indications for internal corrosion. Both visual and dye penetrant investigations showed inner crack just facing that observed on the outer surface. This means crack observed on outer surface in Fig. 2 was propagated through full thickness of 2” pipe.

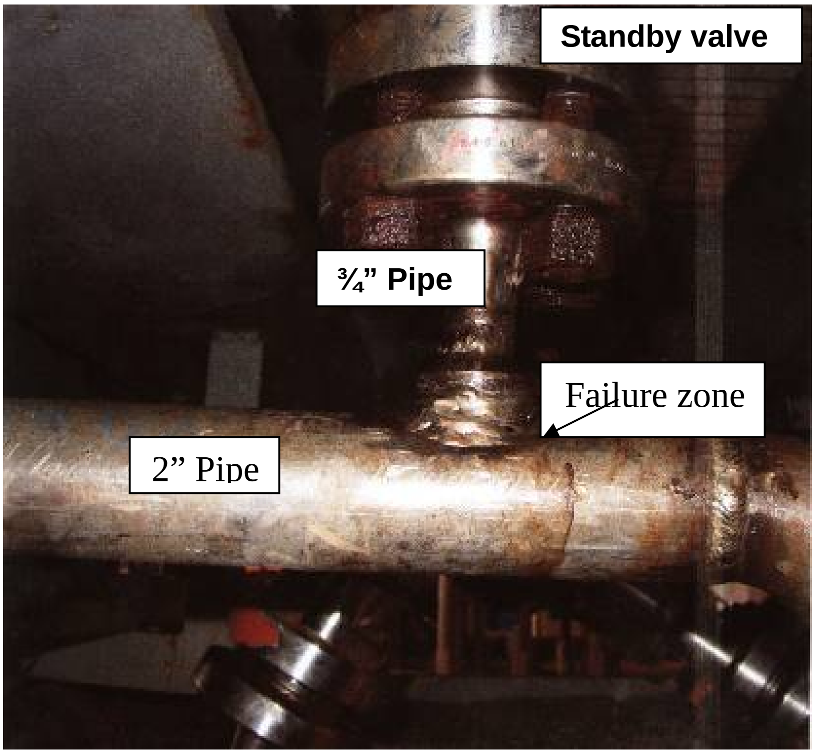

Fig. 1. Part of condensate recycle line showing ¾" pipe branch fillet welded to 2" main horizontal line where leakage has occurred.

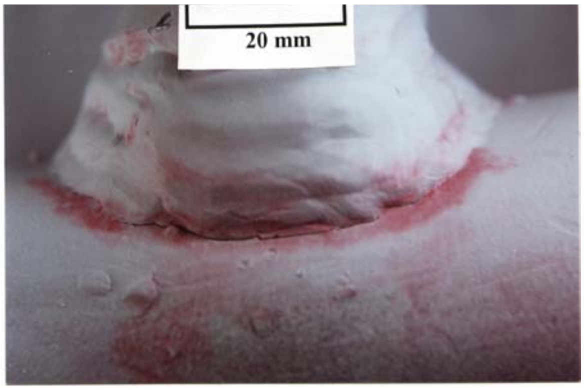

Fig. 2. Outer surface of leaked zone after dye penetrant test showing crack at base of fillet weld where sharp transition is obvious.

Low magnification stereoscopic examination of the observed crack indicated that crack width on outer surface was relatively wider than that on inner surface. This has been confirmed through investigating different cross sections of leaked zone. Macrograph of a cross section taken from leaked zone is shown in Fig. 3. It can be noticed that crack width at outer side is relatively wider than that at inner side and this increase the probability of crack initiation at outer surface. Crack was initiated at weld toe, just beside fusion

line of fillet weld of 2” pipe.
Generally, the failure seems to be a brittle where no thinning or variation in wall thickness was observed. This has been confirmed by a survey of wall thickness measurements using UT-thickness meter. Uniform wall thickness of about 3.85mm for 2” pipe was recorded at both cracked and non-cracked zones.

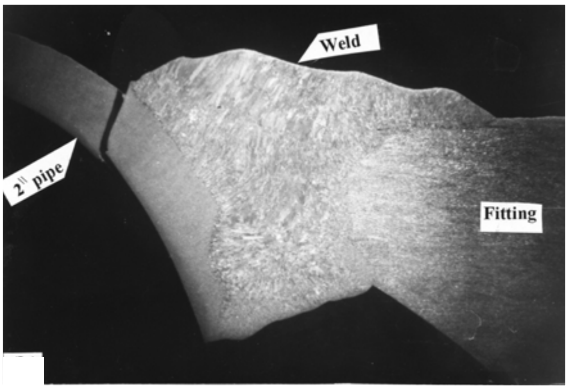

Fig. 3. A cross section of leaked zone showing through-thickness crack with wider width at weld toe.

Specimens from both leaked and non-leaked zones of the removed spool were cut out and prepared for chemical analysis, optical and scanning electron microscopic examinations, and hardness measurements. Result of chemical analysis of the failed 2” pipe showed that chemical composition of the used pipe is a typical for duplex stainless steels (Table 1).

Optical micrographs of a cross section taken at 20 mm in front of the through-thickness crack’ tip are shown in Fig. 4. It is noticed that single, non-branched crack was initiated on the outer surface just at weld toe, beside fusion line then it propagated through base metal toward inner surface (Fig. 4-a). Higher magnifications around crack' tip indicated transgranular crack type (Fig. 4-b). Analysis of crack tip using EDX technique showed that the main components are iron oxide and chloride.

Microstructure of weld metal and HAZ consists of large ferrite grains with continuous networks of austenite at the ferrite grain boundaries and intragranular austenite precipitates. The coarse grained HAZ region adjacent to fusion line could be resulted from nearly complete austenite dissolution on heating and subsequent ferrite grain growth. Widmanstatten austenite precipitated from the grain boundary austenite was observed in weld metal. Microstructure of base metal is duplex with approximately equal volumes of both ferrite and austenite phases. Since hot working of duplex stainless steel is normally performed in the austenite-ferrite, two-phase region, the resultant microstructure tends to be strongly oriented along the working direction (Fig. 4-b).

Optical micrograph of a specimen taken from non-leaked zone of 2” pipe is shown in Fig. 5. The most important notice is the initiation of a non-branched crack on the outer surface just at weld toe, beside fusion line then its propagation through base metal toward inner surface. Path of this crack was principally through grains (transgranular). Microstructure of base metal, HAZ and weld metal of non-leaked zone is similar to that of leaked zone.

Away from weld toe where crack was initiated, optical microscopic investigation of fillet welded joint disclosed some internal welding defects such as lack of fusion between weld passes and porosity at both leaked and non-leaked zones.

Survey of hardness measurements indicated almost same hardness values at both leaked and non-leaked zones where no distinct difference between hardness of base metal (277 Hv), HAZ (280 Hv) and weld metal

(275 Hv) was obtained.

Table 1. Result of chemical analysis of the failed pipe.

Element	wt. %
C	0.015
Si	0.57
Mn	1.18
P	0.027
S	0.001
Cr	21.87
Mo	3.06
Ni	5.06

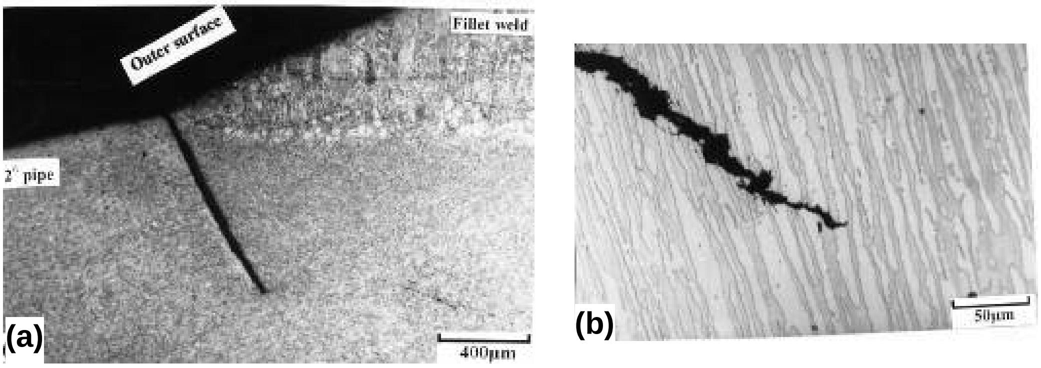

Fig. 4. Optical micrographs of a cross section taken at 20 mm in front of through-thickness crack' tip showing non-branched (a) and transgranular (b) crack initiated at weld toe.

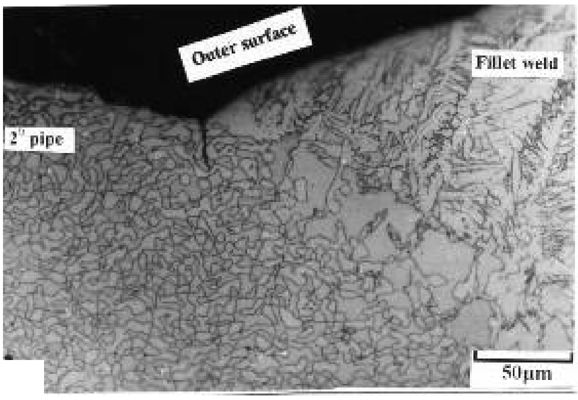

Fig. 5. Optical micrographs of a cross section taken from non-leaked zone showing straight and transgranular crack initiated weld toe.

In order to help in identification of failure mechanism, through-thickness crack' surface was subjected to both stereoscopic and scanning electron microscopic examinations. Low magnification stereoscopic photograph of crack surface is shown in Fig. 6. Fracture features include a brittle appearance and multiple initiation sites. Multiple fracture initiation sites can be seen on outer surface beside weld boundary, just at weld bead conjunction where stress concentration sites (undercuts and overlaps) were existed. Generally, a single macroscopic direction of crack propagation is possible to be defined particularly for deeper cracks where a single, more uniform, crack front is formed in the macroscopic direction of crack propagation.

Scanning electron micrographs of the most probable crack initiation zones are shown in Fig. 7. The important notice is the transgranular crack propagation behavior within the grain and the unclear fatigue striations.

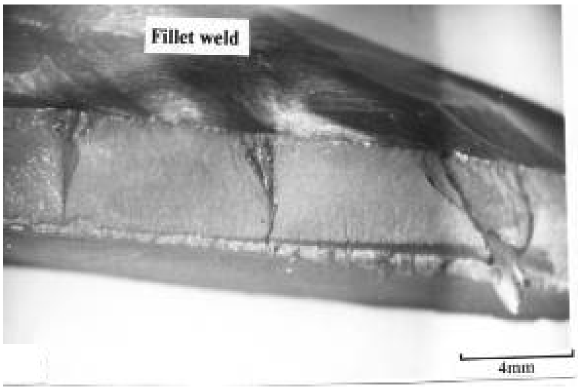

Fig. 6. Stereoscopic photograph of cracked surface showing brittle appearance and multiple initiation sites for fracture.

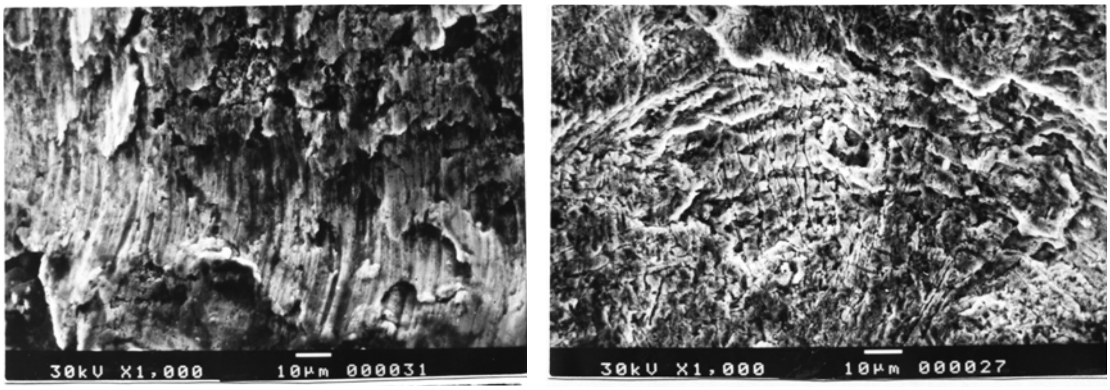

Fig. 7. Scanning electron micrographs of fracture initiation zones showing unclear fatigue striations.

3 DISCUSSION

Visual and macroscopic examinations showed that the leaked zone was confined only to the base of fillet weld joining ¾” pipe branch to 2” pipe where stress concentration sites (undercuts and overlaps) were existed. It showed also brittle fracture with multi-initiation sites on outer surface.

Chemical analysis, microstructural investigation and hardness measurements of the failed 2” pipe showed that its material was identical to duplex stainless steels. No abnormal microstructure or hardness was obtained for weld metal, HAZ or base metal of both leaked and non-leaked zones.

Optical microscopic investigation disclosed non-branched cracks initiated on outer surface just at fillet weld toe of ¾” pipe branch’ fitting to 2” main line then, propagated through base metal toward inner surface. All cracks observed were propagated through grains and perpendicular to the metal surface. Scanning electron microscopic investigation showed unclear fatigue striations at fracture initiation zones. These findings support fatigue as a main failure mechanism. However, the failure could be accelerated by corrosion after exposing of crack surface to atmospheric condition. The presence of chloride as an aggressive ion for stainless steel could be related to rain, or sea water mist penetrating through crack depth.

Generally, corrosion fatigue is a form of deterioration that can occur without concentration of a corrosive substance. The term refers to cracks propagating through a metal as a result of cyclic tensile stresses operating in an environment that is corrosive to the metal. The stresses that contribute to failure are associated with extremely applied mechanical fatigue loads. Vibration caused by a compressor in a piping system, have been found a typical condition contributing to corrosion fatigue in a number of instances. Actually, the vibration may not even be very severe. However, the resulting stresses act additionally to the existing internal tensile stresses. Thus, the resulting mechanical fatigue may bring the stresses beyond the level at which cracking occurs. Even though the stress level applied is below the fatigue limit, notches, cavities, and other defects that act as local stress raisers will accelerate fatigue failure.

Since longitudinal cracks were produced in the subject case, it is evident that the principal cyclic stresses is produced by both fluctuations in internal pressure and vibration due to intermitted operation mode (several operation cycles a day). It is believed that stress concentration at the base of fillet weld, related to undercut and overlap, played a remarkable role for initiation of fatigue damage on outer surface.

CONCLUSION AND RECOMMENDATIONS

Based on the results obtained in this investigation, it can be concluded that the likely cause of the subject failure is attributed mainly to fatigue. Cyclic stresses due to intermitted operation mode combined with stress concentration at the base of fillet weld, due to undercut and overlap, could encourage and accelerate fatigue particularly, with the existence of a relatively heavy standby valve (Fig.1). Failure could be encouraged also by corrosion after exposing of crack surface to atmospheric condition. On the other hand, internal welding defects such as porosity and lack of fusion could not played a role in crack formation.

In order to increase the lifetime of the subject condensate recycle line, cyclic stresses and/or stress concentration sites should be avoided. Since cyclic operation mode of the subject line can not be prevented, cyclic loads were minimized, by removing the standby valve. Besides, fillet weld geometry was improved so that smooth transition between fillet weld and 2” pipe was achieved that means reducing stress concentration at weld base. In other words, fillet weld free from undercut and overlap that works as stress concentration sites was made.

Periodic inspection was scheduled in order to check the existence of outer surface cracks at the concerned fillet weld then, necessary action, including repairing or replacing the defected zone, to be carried out in order to avoid sudden failure and unexpected shut down.

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