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Repair of Cracks in High Thickness Quench and Tempered Steel

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ABSTRACT

During the planned shutdown in one of the Indian Oil, Petrochemical complex, Linear low density polyethylene plant fine longitudinal cracks were observed in the fillet weld of the heavy thickness sieve plate to bracing plate weld joint of a low pressure separator vessel. The crack was observed to be propagated (80-90% of total weld length) on the both side of fillet weld (toe region) of bracing and sieve plate weld joint in bracing. The root cause of the cracks was suspected to be improper heat treatment in shop resulting in cracking while in service for six months. Since the sieve plate and bracing are made of heavy thickness chrome-molybdenum quench- tempered steel also known as high strength steel, in-situ repair and in-situ post weld heat treatment is difficult. Repair of eight no. of joints with total length 12 meters, took much time. This paper discusses the various problems encountered during the repair of cracks. A thorough understanding of the technicalities involved in in-situ repair and heat treatment involved of low alloy high strength heavy thickness steel will help in proper planning and in reducing the repair time.

Keywords: Quench-tempered steel; low pressure separator; Sieve plate; high strength steel

INTRODUCTION

The LLDPE/HDPE plant in one of the Indian Oil complex, Panipat Naphtha Cracker has very low pressure operating vessel for the separation of vapour phase from the hot slurries. Two vessels are stacked together with a sieve plate between them. Operating temperature varies from 180°C to 200°C. The operating pressure varies from 10kg/cm^2 to 0.35kg/cm^2. The process fluid is a mixture of various polymeric hydrocarbons like C2, C3, C4 etc. the sieve plate and bracing plates are made of A517GrE, low alloy high strength steel with major alloying elements 1.34%Cr-0.36%Mo. Wall thickness of the sieve plate as well as bracing plate are same, i.e. 114mm. These plates were supplied in quenched and tempered condition and TEFLON coated. The purpose of the TEFLON coating is to meet the process fluid purity requirements. The four No. of bracing plates are welded to further reinforce the sieve plate strength against the impact load of weight of slurries above it and high velocity of process fluid impinging on it at high temperature. The fabrication and detail designing of this plate is done by M/s TPE, Mumbai and M/s Nova Chemicals, Canada respectively.

Earlier inspection of the equipment had not shown any significant observations. The intensity of longitudinal cracks **(Fig. 1)** necessitated removal of it; hence it was planned in August 2017 to repair the crack. Manual grinding machine was used to completely remove the crack and deposited weld metal in the fillet joint.

CRACKS ON ALL THE FILLET JOINTS BETWEEN SIEVE PLATE AND BRACING PLATE WELDING

After cleaning the polymer deposits the cracks were observed on the edges of fillet weld toe region. It had spread longitudinally towards the weld junction with the vertical joint. On removing the weld deposits by grinding from toe area the crack appeared to have gone inside up to the root. Manual machine grinding resulted in un-even joint fit-ups of irregular root size varying from 3 mm to 7 mm along the length. The preliminary visual inspection after complete removal of weld deposit confirmed that there was no penetration in root in the earlier weld. The inherited stress concentration usually associated with the fillet welds and improper joint configuration in steels having yield strength 80Ksi and higher is quite detrimental.

Several tests were done but the cause of the cracks could not be ascertained conclusively. Chemical analysis and hardness measurement was done. It is presumed when welding is finished and weldment is allowed to cool the mass of austenitic weld metal can transform to martensite. This transformation is accompanied by volumetric expansion because martensite is less dense than austenite. Higher hardness value of the weld deposits indicated high residual stress in the martensitic band of the fusion boundary which was not relieved earlier by heat treatment. Moreover alloying elements like Cr, Mn, Mo etc help in lowering the martensite start temperature during solidification from the austeniting range while. The final microstructure after tempering at 621°C of quench tempered steel comprises tempered martensite, ferrite, and lower bainite.

Hard phases like martensite and high residual stress in the Quench and tempered steel accompanied with improper joint configuration and insufficient root penetration could be the cause of cracks.

Table 2 : Hardness reading across the failed weld joint measure

Plate	Value (BHN)
1	247
2	256
3	194
4	226

Fig. 1 : Longitudinal Crack on Stiffener Fillet Weld of Sieve Plate can be seen.

Fig. 2 : Showing Post Heating Arrangement of Sieve Plate after Weld

Table 1 : Analysis (weight %) of samples from weld

Fe	Cr	Mo	C	Ti	Mn	Zn
97.031	1.46	0.415	0.09	0.104	0.9	0.037

WELD REPAIR

Although a detailed fitness for service was not carried out, it was felt that the size, number and distribution of cracks were too severe to leave the cracks unrepaired. The final repair procedure that was established was as follows:

PRE-HEATING

Due to heavy thickness of 114mm, and highly restrained joint design the pre-heating was done with caution to reduce the cooling rate of the HAZ. if the cooling rate is too slow, the reaustenized zone adjacent to weld metal zone while welding can transform to ferrite with regions of high carbon martensite or to the coarse bainite. Both microstructure lack toughness, next to this zone the previously tempered steel may be over tempered with decrease in strength. Suggested minimum pre-heat temperature as per qualified PQR after complete removal of initial weld deposit was 300°C. Complete removal of cracks was confirmed by dye penetrant test. It was found that if weld was deposited over previous cracks the cracking could propagate through the new weld. The pre-heating operation took several hours due to heavy thickness of the plates.

WELDING PROCEDURE

The welding process selected was SMAW. The initial welding process used was also SMAW but high strength E8018B2L grade electrode was used. The welding electrode recommended for all of the layers in newly qualified PQR was E-309MoL. The pre-heat used was 300°C. No interruption in welding or preheat was permitted until the completion of the welding. Post heating was recommended at 350°C for 2 hours after completion of welding. It was required to cover the weld joint along with HAZ area with insulating blanket after post heating. Post heating and covering with insulating blanket after post heating was recommended to prevent hydrogen induced cracking. The post weld heat treatment (PWHT) cycle was waived due to application of E309MoL electrode.

Excessive heat input when welding a quench and tempered steel can reduce the strength and toughness of weld joints. Such reductions occur in HAZ or weld metal both. Consequently slow welding process like GTAW and slow welding techniques like weaving method was avoided. Heat input during the welding was restricted to 40Kj/in with the specified pre-heat temperature. The heat input limitation needed to assure adequate mechanical property in the weld metal and HAZ, larger weld beads have poor notch toughness. Good practice for welding quench and tempered steel is smaller stringer beads. Hence all the joints were welded in stringer bead. Initially it was mandated to carry out PWHT below the tempering temperature of the steel but due to heavy thickness of the plates and short-term shut-down, the WPS-PQR was developed with austenitic steel low hydrogen electrode to weld the quench and tempered steel.

A range of engineering issues most related to metallurgical nature of the weldment were of concern due to dissimilar metal welding (DMW) envisaged using austenitic stainless steel electrodes, E309MoL. differences in physical and mechanical properties between the weld metal and base metal will always exist. Differences in coefficient of expansion may result in locally high stress that can promote service failures, particularly due to thermal cycling from low to high temperature. Control of weld metal microstructure particularly in the initial or root pass is normally of critical importance since weld deposit can range from fully martensitic to fully austenitic or may exhibit mixtures of austenite, ferrite and martensite. In addition a composition transition region will exist between the bulk weld metal and the base metal having different microstructure.

The Schaefller diagram is useful in providing microstructures approximation for dissimilar welding since carbon steel, low alloy steel and stainless steel can be plotted on this. The heat input was limited to 36Kj/Inch against the maximum suggested reading of 40Kj/inch in initial pass so as to minimize the dilution. The dilution was expected to fall within 45% to retain a austenite + ferrite microstructure after solidification. Predicting the transition region microstructure is difficult as it may change dramatically over a short range. Because of transition in composition between the A517GrE and the diluted 309MoL electrode, a narrow region of martensite can exist along the fusion boundary. This results in sharp increase in hardness across the fusion boundary region as shown in **Table 3**. Welding as per above procedure did not result in any cracking and the same procedure was employed.

POST HEAT TREATMENT

The austenitic stainless steel electrode E309MoL used for welding the joints provide enough cushion that reduces the restraint when two members being welded move together

Table 3 : Hardness Reading Across the Weld Joint after repair

Plate	Value (BHN)
1	205
2	212
3	208
4	210

under the effect of weld shrinkage. Peening was also done on weld layers to avoid shrinkage stresses.

The chrome-moly quench tempered steel plates had a thickness of 114mm. Any welding on this thickness requires PWHT by ASME section VIII Division 1. However, with the approved WPS and PQR the PWHT was waived considering the inter-granular cracking which may take place in grain-coarsened region of HAZ of the base metal. The inter- granular cracking occurs by stress rupture, usually in the early stages of PWHT of quench tempered high strength steel. Post heating the weld at 350°C inch/hour was suggested as per approved WPS/PQR.

Post heating of the joints was done with heating elements **(Fig. 2)**. To avoid high magnitude of thermal stresses coils were wrapped on alternate joints. Two 300mm wide band of heating elements centring the weld joint were applied soon after the welding job was completed with asbestos cover. At 350°C soaking for 4.5 hours were carried out as per thickness requirement of the code. The joints were allowed to cool under asbestos after post-heating duration as required as per approved WPS/PQR.

FOLLOWING PRECAUTIONARY MEASURES WERE TAKEN WHILE DOING THE REPAIR JOB AND HEAT-TREATMENT

- Pre-heating the plate before grinding the weld joints to remove cracks due to its heavy thickness. Grinding to 1/32 inch below the exposed surface to remove any deposits.
- Choosing joint design with groove edges for good penetration and minimum weld restraint.
- Peening the weld, this plastically deforms the weld metal so that final shrinkage forces are greatly reduced in the joint. Peening is most effective when done when the weld metal is still hot, immediately after removal of slag. Peening was done in all pass except root and final passes.
- Buttering the toe area of fillet welds. Using stringer bead back step techniques to minimize the heat input reduce porosity and the dissimilar metal dilution.
- Contouring the weld properly avoiding too much convex and concave profile.

CONCLUSION

Any extensive in-situ repair of heavy wall thickness equipments made of air hardenable steels is difficult and time consuming. A detailed welding procedure must be prepared for the repair. It must allow for a pre-heating treatment if applicable. The post heating procedure must be designed to avoid steep thermal gradients and allow for free movement of the equipment during heating and cooling.

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