Effect of Heat treatment on Preventing Hydrogen Cracking in Joining Procedure of Fitting to Pipeline in Hot Tapping

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Abstract

Hot tapping is a process by which ramification of in service pipelines are done. One of the phases of this process is to join splite tee fitting to the pipe. Joining of this component is mainly done by welding. This component has axial and circumferential welds to pipe. Circumferential welds are under higher stress in compare with axial welds. They are also directly joined to pipe. Therefore, these welds are subject of this investigation. Since pipeline is in service, and fluid is passing through it, in high flow rates, heat sink rate in welding zone is high and this leads to increase of weld cooling rate. Increasing of cooling rate is one of factors that may cause hydrogen cracking. Because of high temperature gradient, Hydrogen diffuses into the metal, and hydrogen atoms recombine to form hydrogen molecules. So pressure is made inside the cavity which contains hydrogen molecules. This pressure may increase up to the point that cause cracking in steels with low ductility and low tensile strength.

After welding phase, fitting joints will be under stress in next phase, and this makes them more sensitive because in the case of cracking, pipeline gets leakage. Codes and standards suppose solutions to prevent this defect. Among them API 1104 is a reference for "National Iranian Oil Company". By choosing proper type of electrode, welding procedure, fluid flow rate, welding positions, pre and post heat treatments, it is possible to prevent hydrogen cracking. In this investigation, formation of hydrogen cracking is proved by measuring cooling rate of the weld in splite tee ramification on an in service pipe containing gas with specific pressure (maximum pressure is considered) and effect of heat treatment to prevent this defect is studied. Material type of pipe is API 5L X62 and welding process is Shielded Metal Arc Welding with electrode type E7018. Also Magnetic Particle Testing and Ultrasonic Testing specifications are given to get optimum results in diagnosing the defect. Results of this investigation show that by post weld heat treatment, it is possible to prevent hydrogen cracking. Effect of electrode selection, Welding procedure, Welding position and fluid flow rate on preventing hydrogen cracking is also discussed.

Key words: Heat treatment, Hot tap, Hydrogen cracking, Splite Tee fitting

1.Introduction

Repair operations or correction of piping systems and oil and gas pipeline may become necessary because of several reasons:

A) Repairing middle olets in oil and gas pipeline (like repairing valves)
B) Joining of one pipeline to other pipeline or piping system
C) Elimination of all or a part of pipeline path to do repairs, changes or path correction.
D) The necessity of in site corrections to develop procedure units in order to increase production
E) Development and correction of multiple paths.

If it is possible to stop production for tapping operations of pipelines, then it is necessary to eliminate the part from production cycle temporarily and after making sure of its emptiness, cleaning should be done for several times in order to discharge flammables. Afterwards with cutting, welding and mechanical operations, tapping is done.

The eliminated part is put back in production cycle after tapping is finished. This operation cause damages to environment in addition to high costs due to production break. Therefore performing special methods as hot tapping in oil, gas and oil productions are necessary. This method is about installing a work piece like split tee on pipe and punching the pipe by means of hot tap machine which is called in service tapping. The word "hot" in this operation only implies that the pipeline is in service.

Hot tap equipment

Hot tap equipment include tapping fitting, isolation valve and tapping machine. (figure 1)

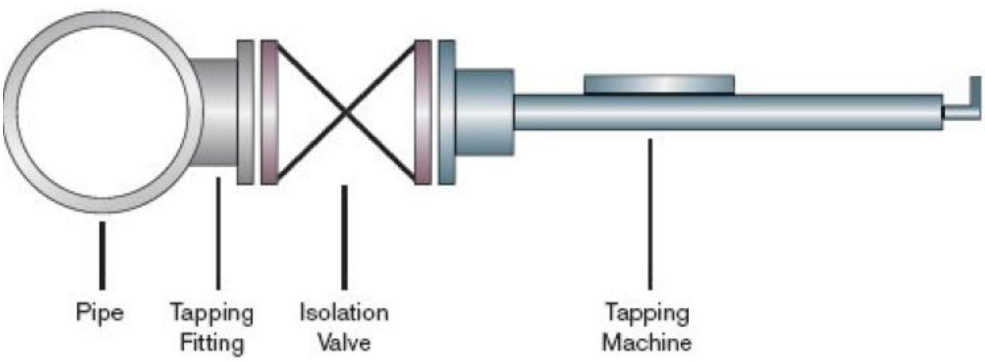

Fig. 1

Fitting is the piece that is welded to pipe and a nozzle and flange is joined to it. On the basis of hole and pipe diameters, there are several types of fittings among which the flange and nozzle that surrounds the pipe is the simplest and its name is split tee. It's indicated in figure 2.

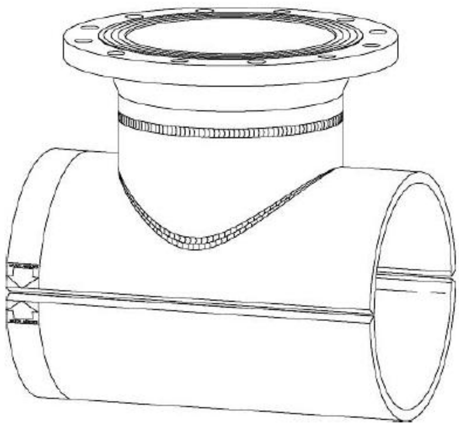

Fig. 2

Split tee is made of two parts; upper and lower ones which after being put on the pipe, axial welds join the parts together and conferential welds join the split tee to pipe. Nozzle to fitting joint is never welded from inside because the result strength in weld root causes serious damage to cutting equipment. So this joint is only welded from outside. After finishing welding operations, welds are compression tested. At the end of operation, the fitting together with the flange become permanent component of pipeline.

A valve, named isolation valve, prevents fluid exit. At first fitting is put on pipe and is welded to it, then isolation valve is fastened on the flange joined to fitting and hot tap machine is installed on isolation valve.

When pipelines contain high pressure natural gas, their failure may cause many serious dangers from pollution and financial losses to human injuries and death. In the process of joining fitting to pipe, probability of hydrogen cracking is high.

Cold cracking factors

1. Brittle microstructure
2. Development of residual stresses
3. Hydrogen embrittlement

As hydrogen is the smallest element with one electron, it has notable solubility and diffusion in steel. Therefore, it has a considerable significance in steel. This element is the most important reason of cold cracking.

Sources of hydrogen are as follow:

1. Moisture content of electrode coating
2. Remaining of fluxes on work piece
3. Hydrogen containing compounds on work piece
4. Moisture content of protective gas, leakage of water cooled torches
5. Moisture of atmosphere and arc environment

To dissolve in liquid, hydrogen must be in the form of atoms; because hydrogen molecules are too big to dissolve. This easily takes place by arc energy. After this transformation, diffusion and movement of hydrogen inside steels lattice is easily done. Dissolving continues until equilibrium between dissolved hydrogen in liquid and hydrogen of atmosphere is established.

Whenever water vapor contacts the liquid, H_2O reduces to H according to the following reaction:

$$Fe + H_2O \longrightarrow FeO + 2H$$

In inert gas protected processes, moisture is too low (1ml/100gr Fe) to make any problem. So in these processes if hydrogen absorption happens, it's because of surface contamination.

After absorption of hydrogen atoms in the liquid, while cooling to room temperature three stages take place:

1. Before solidification, excess hydrogen moves toward liquid surface because of reduction in saturation concentration and gets out. If solidification rate be higher than hydrogen outgo rate, noticeable amount of hydrogen remains in liquid and causes porosity.
2. After solidification, some hydrogen atoms diffuse in high temperature to reach piece surface. This happens mostly in first 24 hours but completes in three weeks. This time duration reduces to couple of hours if the piece is heat treated after welding. This hydrogen is called diffusible hydrogen.
3. Remained hydrogen makes interstitial solid solution which is called residual hydrogen. It gets out of piece work just in the case of reheating between 150 ^oC to 480 ^oC.

Hydrogen embrittlement mechanism

Stresses increase atoms distance to amount that is enough for hydrogen absorption. Atoms make molecules and internal pressure gets extremely high. For example absorption of 1cc/100grFe causes 200 Ksi internal pressure and the pressure causes three dimensional stresses which results in extreme sensitivity to cracking and brittle fracture.

Hydrogen cold cracking

Hydrogen cold cracking is the most important cracking which is direct result of hydrogen embrittlement. If applied stress to the piece be higher than a limit, this crack grows immediately and ends to failure. But if the stress be lower than the limit, ends to delayed cracking.

Cold cracking prevention methods in hot tapping

1. Reduction of heat affected zone hardness by using austenitic stainless steels and lower strength electrodes.
2. Preheat and post weld heat treatment
3. Low hydrogen processes like gas protection processes or usage of low hydrogen basic electrodes.
4. Change in joint design
5. Ultrasonic and magnetic particle testing after welding
6. Fluid flow control during welding

2.Experimental Procedure

To begin the procedure, digging is done along the pipe for 1 meter plus pipe diameter from the place of tapping toward left and right. This will be grooves width. Also 5 meters perpendicular to pipe along tapping direction and 1 meter inverse this direction (see fig.3) pipe coating is removed as much as 2.5 times of tapping diameter and pipe is cleaned by brushing. The thickness of pipes bare part specially the parts close to position of welding are measured and compared to as built thickness. Pipeline pressure is calculated according to Barlow equation:

$$P = \frac{2S\left(T - {}^{3}\!/_{32}\right)F}{D}$$

The resulted figure is the maximum pressure in pipe with the regular pressure of line. As the maximum pressure decreases, safety factor increases. In the equation P is for pressure (Psi), S for ultimate strength of metal (Psi), T for minimum thickness (in), F for design factor of line and D for outside diameter of pipe (in). In this experiment outside diameter is 40", pipe is made of API 5L X62 with 17 mm wall thickness and F is considered 0.72. So the result pressure is 1242 lb/in^2. For safety reasons, this pressure is reduced to 700 lb/in^2.

The 40" ×60" split tee is installed on the pipe in a way that the tapping diameter be in horizontal plain and longitudinal weld cap pass is removed as much as it becomes in a surface with pipe. After mentioned settings, welding is done according to figure 3.

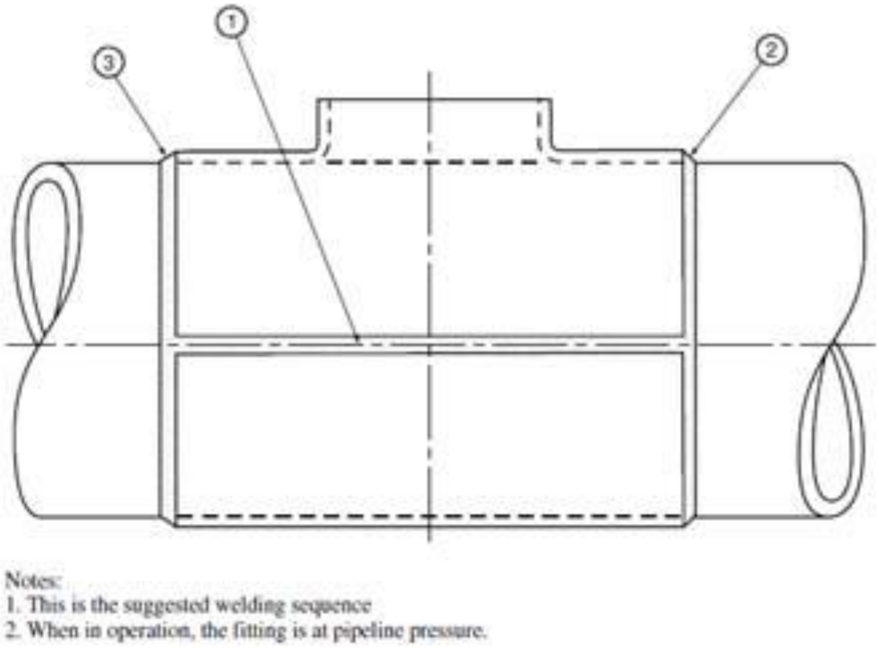

Fig. 3 Welding sequence

After making sure of correct installation of split tee on the pipe, SMAW process with low hydrogen E7018 is performed. Welding Procedure Specification is according to API1104 standard and specifications of "National Iranian Gas Company".

By a laser thermometer from the type infrared thermometer, model Lutron TM-958 with temperature range -20^{o}C to 300^{o}C, temperature of circumferential welds heat affected zone is measured one inch after welders hand.

To prevent cold cracking, the weld and 3 in of pipe is post weld heat treated. For this purpose normalizing is done at 950^{o}C for 13 sec. the heat treatment cycle is shown in figure 4.

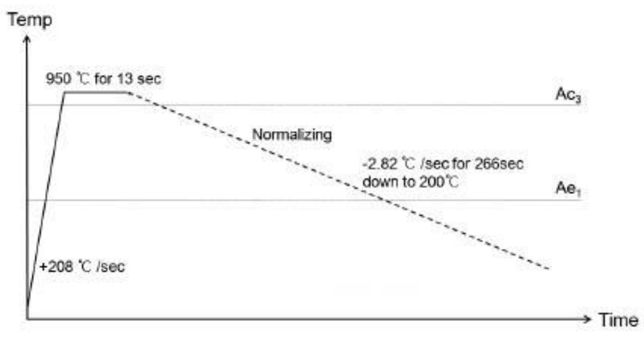

Fig.4 Heat treatment cycle

To make sure that cold cracks do not show up, tapping operation is ceased and after 48 hours weld is tested by magnetic particle testing and ultrasonic testing.

3.Results

Measured temperatures by laser thermometer along the weld length and HAZ are as mentioned in table 1. Temperature was not higher than 86 ^{o}C in anywhere.

Measurement point	***T10***	***T9***	***T8***	***T7***	***T6***	***T5***	***T4***	***T3***	***T2***	***T1***
HAZ	***62***	***59***	***55***	***54***	***63***	***59.5***	***48***	***49***	***53***	***40***
Weld	***75***	***74***	***77***	***76***	***76***	***73***	***75***	***73***	***75***	***77***

Table 1

UT and MT did not show any cracking in surface and depth of weld and HAZ.

4.Conclusions

Regarding to heat transfer rate and weld temperature reaching under 100^{o}C, immediately after welding operation, hydrogen cracking is possible. Therefore, hydrogen cracking risk shall be reduced before tapping operation.

By normalizing, dislocation density which increased after rolling, decreases, recovery and grain growth happens, martensite microstructure (that was appeared during welding) transforms to ferrite and pearlite microstructure. So hardness decreases and toughness improves. It means that post weld heat treatment changes the brittle microstructure into ductile microstructure, eliminates residual stresses, gives hydrogen the chance to diffuse toward the surface and emit. So all factors which were mentioned as hydrogen cracking reasons are eliminated.

Also electrode type, welding process, fluid velocity, welding position and preheating help to prevent cold cracking, which should be studied in future investigations.

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