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Assessment of Weld Integrity through Full Range Burst Test of API 5L X-70 Grade Line Pipe

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ABSTRACT

High pressure line pipes are widely used in oil and gas sector for the transportation of natural gas, oil and other petroleum products. Line pipe experiences high operating pressures in gas transportation that ranges from 200 to 1600 PSI depending on the size and length of the line pipe. For the safety point of view, to check integrity of line pipe and before getting the line pipes used in the field, Hydrostatic test is used for verifying mechanical integrity of pipe lines and is applied to check for leakages during hydrostatic testing. Burst test aims to evaluate the point of failure of the line pipe and assess the structural integrity of a welded pipe. In present work, an experiment research work is carried out to confirm weld and structural integrity of two API 5L PSL 2 X70 grade pipes manufactured by Helical submerged arc welding pipe mill. Burst tests are conducted at pressure in excess of the Ultimate tensile strength of the steel pipes and aimed to sustain the pressure as per API requirement. Both the pipes achieved the expected results.

Keywords: American Petroleum Institute (API), Weld integrity, Mechanical properties, Burst pressure, Burst test, Ductile fracture, Helical submerged arc welding (HSAW), Pipe wall thickness, Crack arrestor

INTRODUCTION

During the useful life and application of a line pipe, it is subjected to internal and external corrosion. Hydrocarbon fluids are major cause of internal corrosion and harsh environment due to the soil in case of off-shore is a major cause of external corrosion. Over a period of time, internal and external corrosion initiates pipe wall thickness reduction process. This leads to the declining in mechanical strength while the pipelines are exposed to high pressure conditions for longer periods of use.

To assure quality of line pipe, its testing becomes necessary. A large number of mechanical testing are carried out to examine the properties of the pipe and to predict its bearing ability.

Demofonti et al. [1] demonstrates that pipelines with higher strength levels are subjected to various mechanical tests. For high operating pressures line pipes, the assessment of fracture characteristics has been studied by means of laboratory and full scale tests. Researchers have attempted to describe safety criteria against a possible fracture by determining various fracture properties by means of studying the initiation and propagation of fracture upon failure. In addition the higher impact energy of pipe helps to resist such failures in hostile operating conditions.

Liessam et al. [2] states that in the entire scheme of the line pipe testing burst test considered to be a key part. During operating condition, the major load on any pipeline is the internal pressure exerted by the fluid. Many Pipeline codes allow hoop stresses in the pipe considering in design pressure as high as 80% of the specified minimum yield strength. Therefore to make sure sufficient pressure sustaining capability, a series of burst tests are conducted. The aim of the burst tests is to examine the fracture characteristics of the pipes, reliability of the weld and so understand the ductile fracture propagation control for the pipes thus complete safety of pipes in their application is assured.

In case of burst resistance of pipe [3-5], correlation of strength of pipe material is considered with ultimate tensile strength which covers Steel, Weld-seam and the Heat affected zones. As each of these three zones of a pipe has different strength levels, the full-degree burst test describes a composite integral response of the pipe to a high pressure condition. For security point of view, the control of ductile fracture initiation and propagation has been always a concern; Research reveals that pipes with low impact toughness energy values and lower percentage of shear area are likely to crack despite their higher UTS value. A relationship thus is made between the impact values of weldment or base steel and residual stresses developed during the pipe forming process helps to determine crack propagation mechanism.

As for the SAW pipe manufacturing process, limited practical knowledge and experience on the characteristic behavior of fracture resistance was available, in present experiment, two pipes manufactured from two different HSAW machines were selected and subjected to burst test. The Pipes selected in this experiment were manufactured as per API 5L PSL2, X70 (485 MPa yield strength) grade and were subjected to full degree burst test. Both the pipes were made from two different capacities with the same right hand direction spiral plants in size 914 mm × 14.3 mm [from HSAW-1] and size 914.4 × 17.5 mm [from HSAW-2 machines]. Subjected to bursting it was observed that although both the pipes burst well above the calculated burst pressure yet one of the pipes burst at a pressure very close to the calculated burst pressure. Detailed study was carried out to determine possible variation in pressure and explanations.

EXPERIMENTAL PROCEDURE

Selected two pipes were manufactured using the SAW process in two steps. In first step, three roller bending forming followed by SAW inside and outside welding. Pipes integrity was checked through Online Ultrasonic.

Inspection followed by radiographic inspection for 100% length of the pipes. Furthermore, the pipe of size 914.4 × 14.3 mm and the other pipe of size 914.4 × 17.5 mm were subjected to Hydrostatic test at 167 Bar and 136 Bar for 10 s, respectively. Before subjecting the pipes to burst testing, both open ends of the pipes were sealed with the same pipe cut pieces whose strength, thickness and forming parameters are the same as of pipes, schematic representation of male and female parts of these ends and their assembly with the pipe are shown in Figure 1. Hose pipes were fitted on one end of the pipe for filling the pressurizing media. Water was chosen as the pressurizing medium for the burst test. For safety point of view, preceding to the filling of water, wooden pellets and sand filled bags were placed on the floor, the pipe were lowered on these sand filled bags and the nearby area was barricaded and restricted so that upon releasing of pressurized water during pipe bursting, any unwarranted incident can be proactively avoided.

Figure 1: (Sequence left to right): Female part, male part, female and male part welded together, female and male part welded to the pipe

A High pressure water pump with 10 bar maximum drive pressure was used for the purpose. High pressure air driven pump was connected to the sealed pipes and water was allowed to fill in.

Burst pressure calculation for HSAW-2

API 5L X 70 PSL-2 helical submerged arc welded pipes of the dimensions mentioned below were selected.

Nominal Wall Thickness, t=17.5 mm; Nominal outside Diameter, D=914.4 mm; Yield strength, S=574 MPa; Burst Pressure, P=2 St/D=220 bar, from the calculated formulae [6,7], the expected burst pressure with respect to yield strength value of pipe material was calculated. Considering nominal wall thicknesses of the pipes used, nominal bursting pressure calculated as:

P=2 * S * T/D

P=2 * 574 * 17.5/914.4

P=21.97 MPa or

P=21.97 × 10=219.7 Bar or 220 Bar (Rounded off)

Whereas, Minimum Pressure required exceeding with respect to Ultimate tensile strength calculated as:

P=2 * S * T/D

Where P is the minimum burst pressure with respect to UTS, S is the Ultimate tensile strength of pipe material in MPa, T is nominal wall thickness in mm and D is the specified outside Diameter in mm.

P=2 * 649 * 17.5/914.4

P=24.84 MPa or

P=24.84 * 10=248.41 Bar or 248 Bar (Rounded Off)

Burst pressure calculation for HSAW-1

API 5L X 70 PSL-2 helical submerged arc welded pipes of the dimensions mentioned below were selected.

Nominal Wall Thickness, t=14.3 mm; Nominal outside Diameter, D=914.4 mm; Yield strength, S=597 MPa; Burst Pressure, P=2 St/D=187 bar, from the calculated forumale, the expected burst pressure with respect to yield strength value of pipe material was calculated. Considering nominal wall thicknesses of the pipes used, nominal bursting pressure calculated as;

P=2 * S * T/D

P=2 * 597 * 14.3/914.4

P=18.67 MPa or

P=18.67 × 10=186.7 Bar or 187 Bar (Rounded off)

Whereas Minimum Pressure required exceeding with respect to Ultimate tensile strength calculated as:

P=2 * S * T/D

Where P is the minimum burst pressure with respect to UTS, S is the Ultimate tensile strength of pipe material in MPa, T is nominal wall thickness in mm and D is the specified outside Diameter in mm.

P=2 * 669 * 14.3/914.4

P=20.92 MPa or

P=20.92 * 10=209.2 Bar or 209 Bar (Rounded Off)

RESULTS AND DISCUSSION

The actual pressure at which both pipes burst practically measured with same diameter but with different thickness, same material with welded on different spiral plant are illustrated in Table 1.

Table 1: Calculated burst pressure vs. actual burst pressure

S. No.	Pipe Identification	Dimension (Dia. × thickness) in mm	Calculated Burst Pressure With respect to Yield Strength of Pipe Material (Bar)	Calculated Burst Pressure With respect to Tensile Strength of Pipe Material (Bar)	Maximum Pressure attained before burst	Actual Burst Pressure
01	HSAW-2	914.4 × 17.5	220	248	257	252
02	HSAW-1	914.4 × 14.3	187	209	222	218

Following to the water filling, and continuously rising of water pressure, the pipe which was made from the HSAW-2 unit burst at 252 bar pressure. Examining the failure, as shown in Figure 2, it was observed that the crack appeared to be a ductile fracture as the crack initiation point started from the body of the pipe and propagated in two opposite longitudinal directions parallel to the pipe axis and perpendicular to the radial hoop stresses [8,9], schematic representation of burst test setup and fracture dimension detail is highlighted in Figure 3.

Figure 2: HSAW-2 burst pipe fracture representation, crack initiated from the pipe body, propagate but arrested by the weld bead

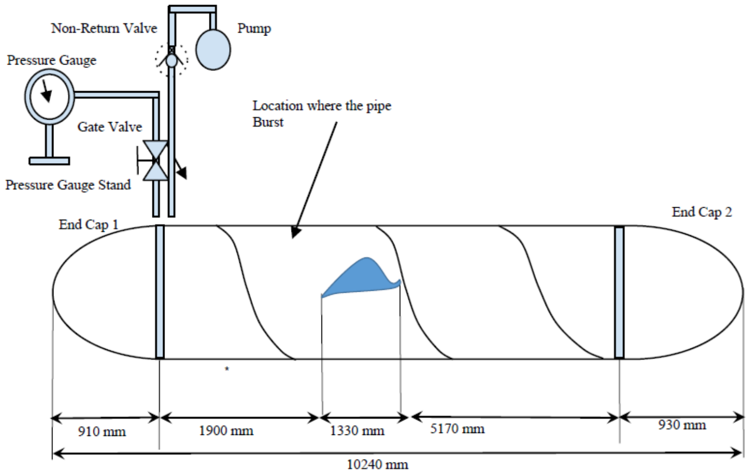

Figure 3: Burst test schematic representation for HSAW-2 pipe specimen

The crack though did not propagate through the weld seam length, which shows that not only the weld seam was strong enough (as the pipe burst from the pipe body) but it also acted as a crack arrestor (As it resisted the crack propagation and did not allow the crack to pass through it). Examining the failure of the other pipe (as shown in Figure 4) which was made from the HSAW-1 unit showed the same characteristic in terms of crack initiation point and crack propagation as the pipe made from HSAW-2 however the crack propagated through the weld bead which showed that weld seam was not as strong enough as in the case of pipe made from HSAW-2, the pipe burst at 218 bar pressure [10,11]. Prior to bursting, the pipe bulged from the centre similar to the balloon until it finally gave away crack, schematic representation of burst test setup and fracture dimension detail is highlighted in Figure 5.

Figure 4: HSAW-1 burst pipe fracture representation, crack initiated from the pipe body and propagated through the weld bead

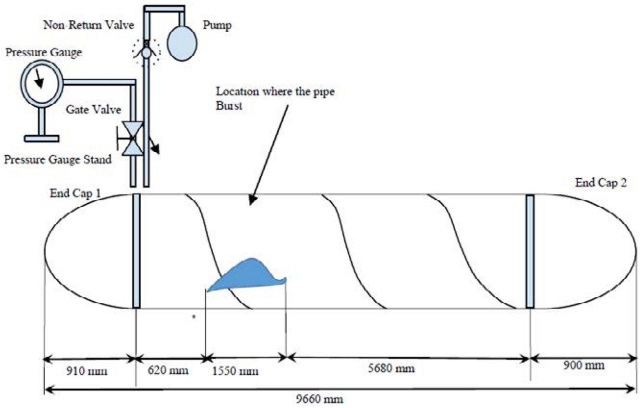

Figure 5: Burst test schematic representation for HSAW-1 pipe specimen

Upon examining the pipes, it was observed that pipes of HSAW-1 and HSAW-2 both had the crack initiated from the base metal which revealed that the weld seam of each pipe was sound and stronger as compared to the base metal. Fractured surfaces of both the pipes revealed ductile fracture as the appearance of fractured surface was rough and showed patches of cup and cone structure.

CONCLUSION

It is observed that the most sensitive parameter in calculation of burst pressure is the pipe wall thickness. In fact that pipe bursting at lower pressure occurs due to the local wall thinning. For that reason in pipeline applications tolerance considerations play an important role in design as can be witnessed in this practical demonstration the same diameter, material grade but of two different thickness pipes subjected to burst test. Consistency in the pipe manufacturing process can be justified through the burst test results which are very close to those warranted by theory. One of the probable reasons in case of pipe made from HSAW-1 the pressure not increased beyond a certain value was due to the plastic deformation which implies localized lower yield strength. A greater amount of fluid could be accommodated due to the increase in volume which results due to the expansion of pipe before fracture.

In theoretical calculation of minimum burst pressure there is a chance of little deviation in account of the exact value of UTS or the diameter which is taken as outside diameter rather than inside diameter. This is because in actual the radial stresses act upon Inside diameter of the pipe (as the fluid flows inside of the pipe). Considering tolerances, the minimum expected pressure for HSAW-2 and HSAW-1 is 220 and 187 Bars respectively however the pipes HSAW-2 and HSAW-1 actually burst at 252 and 218 Bars, respectively. Before fracture, the pressure has reached up to 257 and 222 bars for HSAW-2 and HSAW-1 respectively. This means that the pipe has attained its UTS value and then plastically deformed leading to drop in pressure before fracture.

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