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Failure Analysis of the Reducer Nipple of a Propylene Gas Tank in a Petrochemicals Complex

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Abstract

Failure Investigation was carried out on a fractured reducer nipple of pipeline connected to a propylene tank in a Petrochemical complex. The Investigation was carried out with the aim of determining the root cause of the failure. In the course of this investigation, Metallurgical techniques including micrography and fractography as well as stress analysis of the piping were carried out on the failed part. The root cause of the failure was identified as vibration induced fatigue enhanced by the non-homogeneity of the microstructure of the nipple. Remedial measures to prevent a reoccurrence were proffered.

Key Word: Metallography, Fractography, Failure, Analysis, Striation, Fatigue, transgranular.

1.0 Introduction

This article is based on the root cause analysis of a fractured reducer nipple of pipeline connected to a propylene tank in a Petrochemical complex. The line operated at a pressure of 32kg/cm2. The fractured end of the nipple has an outside diameter of 0.885in and a thickness of 0.167in. Picture of this nipple is presented in figures 1. Records showed that the piping have been in service for about thirteen years and failed within this period under similar circumstances and was repaired.

2.0 Scope of Report

The scope of the failure analysis includes:

(1) Complete metallographic analysis of failed pieces with scanning electron microscopy (SEM), and spectrometric analysis of material and weldment.

(2) Mechanical Testing include; hardness testing and Tensile strength determination.

(3) Combing piping stress analysis at fracture point

(4) Root cause determination and recommendations to avoid reoccurrence of failure.

3.0 Metallurgical Study of Failure

3.1 Spectrometric Analysis

The Chemical analysis of the nipple was carried out using an optical emission spectrometer which gave the composition presented in Table 1.

Table 1: Chemical Composition of Nipple Body

C	Cr	Ni	Si	Mn	S	P	Cu	Mo
0.31	0.28	0.04	0.25	0.8	0.04	0.035	0.035	0.12

This conforms to ASTM A105.

3.2 Metallographic Analysis

The fractured Heat affected zone (HAZ) of the reducer nipple of the pipe linking the propylene gas tank and the cracked weld joint in the by-pass line were prepared for metallography in accordance with ASTM E3, methods of preparation of metallographic specimen. The three samples were then observed under metallurgical microscope and the resulting micrographs are presented in figures 3 and 4. The grain sizes of the samples were also determined in consonance with the requirement of ASTM E 112.

Discussion of Micrographs

The micrograph of the reducer nipple of the propylene gas tank presented in figure 3 revealed that the nipple has a coarse grained ferrite-pearlite microstructure with ASTM grain size number 4 to 6. The variation in grain size depicts in homogeneity in the microstructure. The micrograph of the weldment (valve end of nipple) in figure 4 however revealed homogenous structure of pearlite in ferrite matrix with ASTM grain size number between 9 and 10. This micrograph also shows porosities on the weldment.

3.3 SEM Analysis

Samples from, reducer nipple of the propylene gas tank and the valve end of the nipple were subjected to SEM fractography using JEOL JSM-6390LV scanning electron microscope. In the course of the SEM fractography, several shots were taken at different points on each of the mounted samples at magnification of x300, x500 and x700. The resultant fractographs are presented in figures 5 though 10.

Discussion of SEM Fractographs

The fractographs of the nipple revealed the three-dimensional nature of the various grains which is typical of integranular brittle fracture as opined in Davis(1998). It also revealed fatigue striations characteristic of fatigue failure. The presence of an isolated tear in figure 8 shows the weldment is tougher than the body of the nipple.

4.0 Mechanical Test

4.1 Micro hardness Test

The samples of the reducer nipple of A propylene tanks were subjected to micro microhardness test using Leco microhardness tester LM 700AP, applying a load of 50gf in a dwell time of 15 seconds. The test was carried out in accordance with ASTM standard E92, standard test method for Vickers hardness of metallic materials and ASTM E384, standard test for microhardness of materials. The result of the test is presented in table.

Table 2 : Microhardness Test Result of Reducer Nipple

	VHN	VHN	VHN	Average VHN	Deviation	Range	Converted to BHN
Nipple Body	122.3	129.3	117.8	123.1	5.7	11.5	116
Weldment	152.4	168.4	166.5	162.4	8.7	16.0	150

Discussion

The high values of the deviation in the hardness of the three points taken in each of the sample shows in-homogenity in the microstructure of the flange.

4.2 Tensile Strength of materials

The tensile strength = KxBHN Mpa [Rao (1998)]

Where k = 3.296 for allow steel and 3.342 for plain carbon steel.

For the nipple body, tensile strength = 3.296 x 1.6 = 382.Mpa

For the weldment, Tensile strength = 23.342 x 150 = 501.3Mpa

5.0 Stress Analysis of Failed Reducer Nipple

5.1 Determination of the maximum allowable pressure (Design pressure)

Data:

Nominal outside diameter, D = 0.885in

Nominal inside diameter, d = 0.55in

Mean diameter Dm = 0.7175in

Operating Temperature = 75 – 80oC (167 – 176F)

Material of pipe = ASTM A 105

Designation: Similar to API 5L GR B

Operating pressure = 32kg/cm2 = 456.7psi

The maximum allowable pressure is determined in accordance with ANSI/ASME B31.8 standard for Gas Transmission and Distribution system by the equation.

P = (2 St/D) x F x E x T 5.1

Where, P = Design pressure, (psi)

S = Specified minimum yield strength (psi)

t = Nominal wall thickness (in)

D = Nominal outside diameter (in)

F = Design factor

E = Longitudinal joint factor

T = Temperature de-rating factor.

S = 35,000psi [ANSI/ASME Code B31-8-2003, Appendix D]

t = 0.157IN

D = 2.357in

F = 0.72 [ANSI/ASME Code B 31-8-2003 Table 841.1A]

E = 1.00 [ANSI/ASME Code B 31-8-2003 Table 841.1B]

T = 1.00 [ANSI/ASME Code B 31-8-2003 Table 841.1C]

Therefore Design pressure,

P = (2 x 35,000 x 0.0.167 ÷ 0.885) x 0.72 x 1.00 x 1.00 = 9510.5Psi = 670kg/cm2

5.2 Determination of the collapsing pressure of pipe

The collapsing pipe pressure is determined, taking into consideration the effect of lateral contraction by the DNV equation.

$$Pc = \frac{2E_y}{1-\lambda^2}\left[\frac{t}{D_m}\right]^3 \quad 5.2$$

[Antaki (2005)] Where Pc = minimum net collapsing pipe pressure (psi)

E_y = modulus of elasticity = 28 x 10^6 psi

t = pipe thickness = 0.167in

D_m = Mean diameter of pipe = 0.7175in

λ= Poisson ration = 0.29

Therefore, collapsing pipe pressure,

$$Pc = \frac{2 \times 28 \times 10^6}{1-(0.29)^2}\left[\frac{0.167}{0.885}\right]^3$$ =410,827psi=28,942.8 Kg/cm²

5.3 Determination of Maximum allowable net external pressure for pipe with eccentricity (1% out-of-roundness)

$$P_e^2 - \left[2S\left(\frac{t}{D}\right) + \left(1 + 0.03\left(\frac{D}{t}\right)P_c\right)\right]P_e + 2S\left(\frac{t}{D}\right)P_c = 0$$

[Yong Bai and Qiang Bai (2005)]

Where P_e = maximum allowable net external pressure
Pc = critical value of collapsing pressure
S = yield stress allowable stress value.

= 30,250 psi [ANSI/ASME code B31-4-2006, Table 402.3.1(a)

$$P_e^2 - \left[2\,x25{,}200\left(\frac{0.167}{0.7175}\right) + 410{,}827.6\left(1 + 0.03\left(\frac{0.7175}{0.167}\right)\right)\right]P_e + 2\,x25{,}200\left(\frac{0.167}{0.7175}\right)x410{,}827.6 = 0$$

$$P_e^2 - 475{,}510.81P_e + 4{,}819{,}308{,}354 = 0$$

$$P_e = 10{,}360.8psi = 729.9Kg/cm^2$$

5.4 Hoop Stress (Sh) Analysis

Sh = (Pe – Pi) (D – t)/2t 5.4

= (10,360.8 – 456.7) (0.885 – 0.167)/2 x 0.167

= 21,289psi

Hoop stress criterion of ABS (2000) according to Yong Bai and Qiang Bai (2005) is given by

= Sh < F x S x T = 0.72 x 35000 x 1 = 25200

The hoop stress for the pipe is therefore appropriate since it is less than the value obtained from the criterion.

6.0 Conclusion / Root Cause of Failure

(1) The nipple failed by brittle fracture, the cracks being mainly intergranular in nature.

(2) The fatigue striation in the SEM fractography revealed the fracture mechanism as fatigue.

(3) The grain size variation of the nipple shows in-homogeneity of the coarse microstructure.

(4) Failure of the reducer nipple of a propylene gas tank as a result of vibration induced fatigue enhanced by the non-homogeneity of its microstructure.

7.0 Recommendations

Irrespective of the accompanying certificate, it is advised that new nipples to be installed be subjected to in-house normalizing heat treatment at 910oC for 30 minutes as this will go a long way in improving the homogeneity of its microstructure.

Acknowledgement

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Figure1: Failed Reducer Nipple

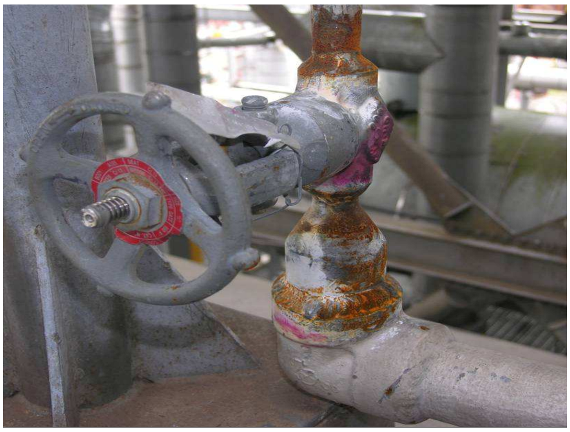

Figure 2: Repaired Reducer Nipple

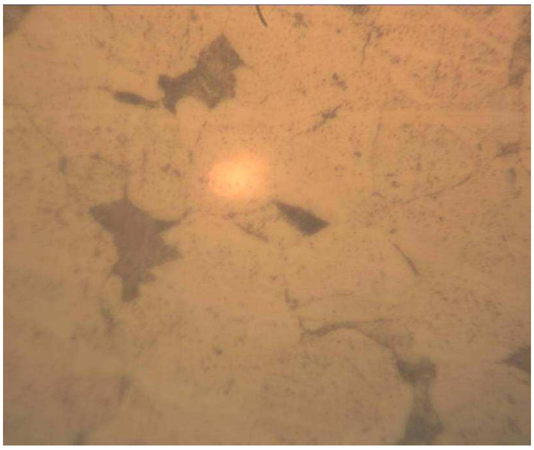

Figure 3: Micrograph of reducer nipple, 2% nital etch x800

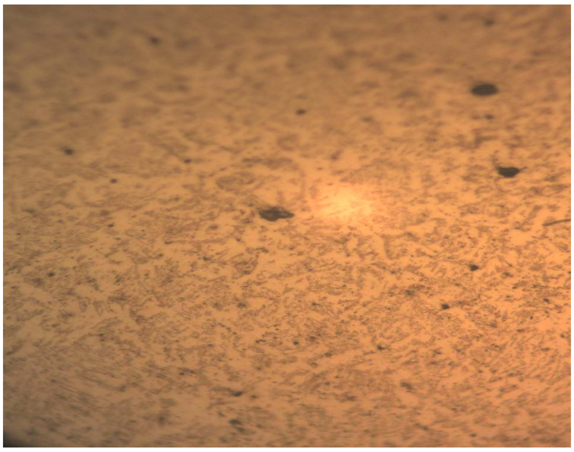

Figure 4: Micrograph of valve end of reducer nipple, 2% nital etch x400

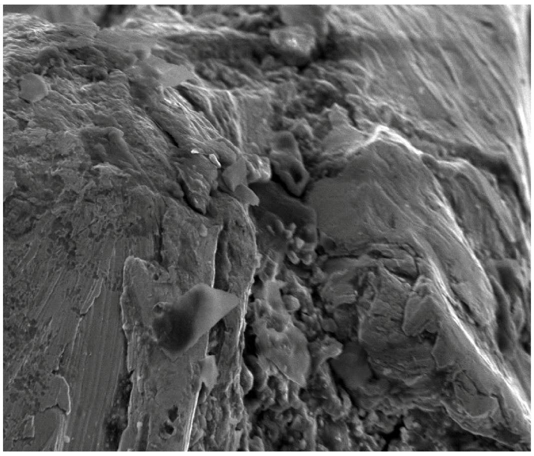

Figure 5: SEM Fractograph of failed reducer nipple, x700

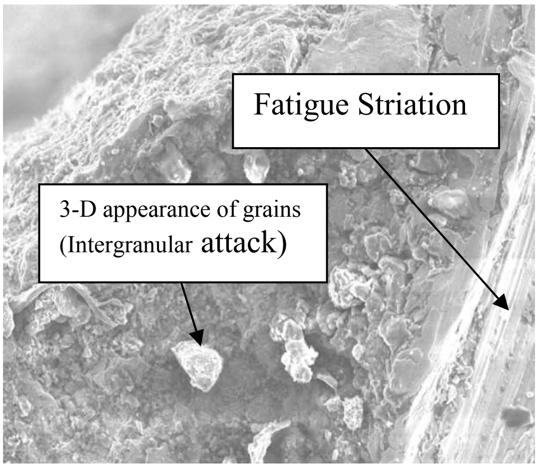

Figure 6: SEM Fractograph of failed reducer nipple , x300

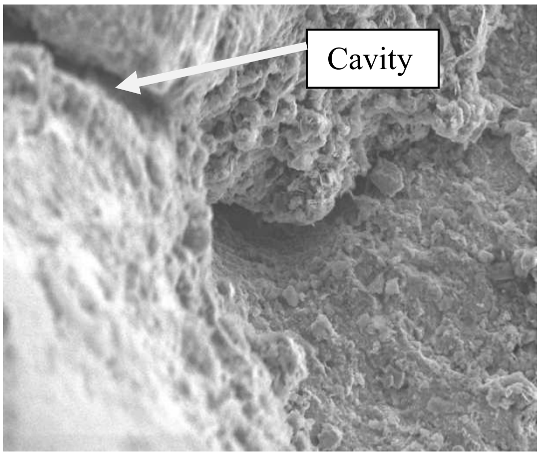

Figure 7: SEM Fractograph of failed reducer nipple, x500

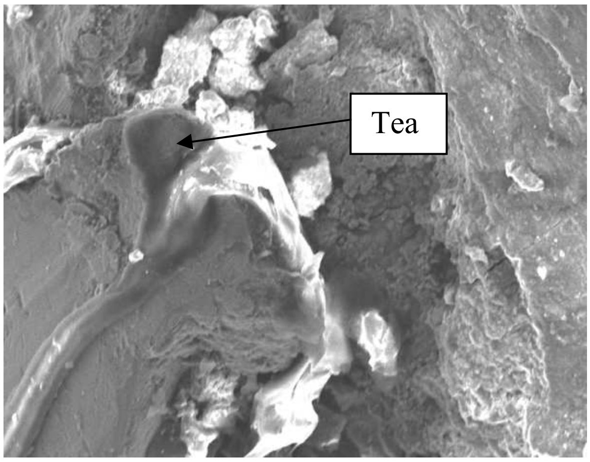

Figure 8: SEM Fractograph of failed valve end (weldment) of nipple, x500

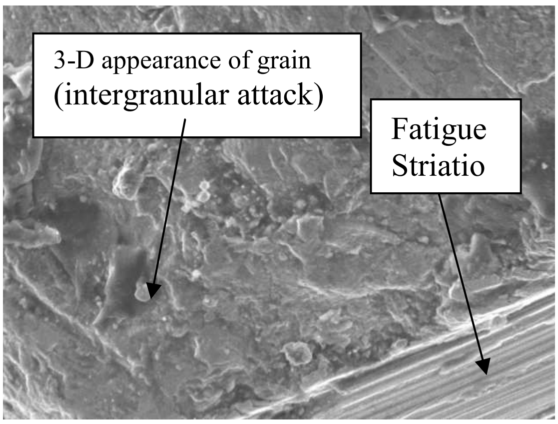

Figure 9: SEM Fractograph of failed valve end (weldment) of nipple, x700

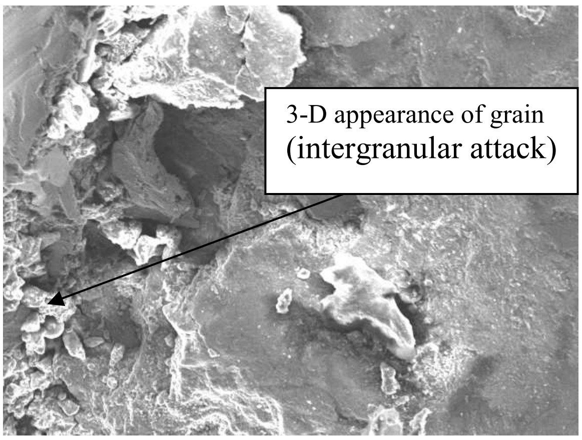

Figure 10: SEM Fractograph of failed valve end (weldment) of nipple, x300