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I. Introduction

The 8" piping that branches out from the main discharge piping of an Ethylene compressor, failed after thirteen years of service life. The pipe carries ethylene gas at approximately 27k/cm^2 at 75-80^{0}C. The failure took place on the upstream side of a pressure safety valve (PSV) in the discharge piping of an ethylene compressor around the HAZ between the 4" weld neck flange and the weldment of the 4" to 8" reducer. The reducer was completely snipped (fractured) off from the weld-neck flange. This was attributed to process upset. Photograph of the failure weldneck flange is presented in figure 1. This paper presents the failure analysis carried out with the aim of finding the root cause.

II. Scope of Report

The scope of this report covers the failure analysis of the fractured HAZ between the 4" weld neck flange and weldment of 4" to 8" reducer of the pressure safety valve. The material used is therefore limited to the sample from the fractured 4"class 300 flange.

The scope of the failure analysis includes:

i. Complete metallographic analysis of failed pieces with scanning electron microscopy (SEM), and spectrometric analysis of material and weldment.
ii. Mechanical Testing include; hardness testing and Tensile strength determination.
iii. Combing piping stress analysis at fracture point
iv. Root cause determination and recommendations to avoid reoccurrence of failure.

III. Metallurgical Study of Failure

a) 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 Weld neck flange samples

C	Cr	Ni	Si	Mn	S	P	Cu
0.276	0.092	0.033	0.30	1.28	0.06	0.017	0.149

This conforms to ASTM A350 LF2

b) Metallographic Analysis

The fractured weld-neck flange of the pressure safety valve was 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 2 and 3.

i. *Discussion of Micrographs*

The micrograph of the fractured weld-neck flange of the pressure safety valve presented in figure 2, shows coarse grain microstructure and the presence of widmanstatten ferrite. The metallographic examination

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revealed that the microstructure and grain size vary considerably with the maxim and minimum ASTM grain size numbers being 3 and 6 respectively. The grain sizes of the samples were determined in consonance with the requirement of ASTM E 112.The un-etched specimen presented in figure 3 shows a number of porosities.

c) SEM Analysis

Sample from the weld neck flange of pressure safety valve, was 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 4, 5 and 6.

i. Discussion of SEM Fractographs

The SEM fractograph of the weld neck flange of pressure safety valve presented in figure 4 shows the three-dimensional nature of the various grains which is typical of (brittle) intergranular fracture as opined in Davis(1998). The figure also shows various cleavages which is typical of (brittle) transgranular fracture. The fatigue striations revealed by this fractograph are characteristic of fatigue failure. Another very prominent revelation of the SEM fractograph of figure 4 is the presence of a continous threadlike rod of inclusion which is a very likely point of crack initiation. The fractograph in figure 5 shows clearly the transgranular fracture in a clearage. Figure 6 fractograph of this sample shows mainly transgular and intergranular and intergranular failure nodes. It could therefore be inferred that the failure of this sample was catasrophic and was to a largely extent by brittle mode. The inclusion and blow holes in figure 3 as well as the dark particles in this micrograph are a ponter to manufacturing flaws in the flange.

IV. Mechanical Test

a) Microhardness Test

The sample from fractured weldment, flange of pressure safety valvewas subjected to 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 2.

Table 2 : Microhardness Tests Result of pressure safety valve of weld neck flange

VHN	VHN	VHN	Average (VHN)	Deviation	Range	Converted to BHN
168.3	134.8	137.7	146.9	18.5	33.5	143

i. Discussion

The high value of the deviation in the hardness of the three points tested, shows in-homogenity in the microstructure of the flange.

b) Tensile Strength of materials

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

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

For the flange, Tensile strength = 3.296 x 143 = 471.33Mpa.

V. Stress Analysis of Failed Weldneck Flange

a) Determination of the maximum allowable pressure (Design pressure)

Data:

Nominal outside diameter, D = 4.5in

Nominal inside diameter, d = 4in

Mean diameter Dm = 4.25in

Operating Temperature = 75 – 80°C (167 – 176F)

Material of pipe = ASTM A 350 LF2

Designation: Similar to API 5L GR B

Operating pressure = 27kg/cm^2 = 385.354psi

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

$$P = (2\ St/D) \times F \times E \times T \qquad 5.1$$

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 = 0.25in

D = 4.5in

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 0.25 ÷ 4.5) x 0.72 x 1.00 x 1.00

= 2800Psi = 197.26kg/cm^2

b) 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.

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

[Antaki (2005)]

Where Pc = minimum net collapsing pipe pressure (psi)

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

t = pipe thickness = 0.25in

D_m = Mean diameter of pipe = 4.25in

λ = Poisson ration = 0.29

Therefore, collapsing pipe pressure,

$$P_C = \frac{2\text{x}28\text{ x}10^6}{1-(0.29)^2}\left[\frac{0.25}{4.25}\right]^3 = 12{,}445\text{psi}=878.75\text{Kg/cm}^2$$

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

$$P_e^2 - \left[2S\left(\frac{t}{D}\right) + \left(1 + 0.03\left(\frac{D}{t}\right)P_c\right)\right]P_e + 2S\left(\frac{t}{D}\right)P_c = 0 \qquad 5.3$$

[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.

= 25,200 psi [ANSI/ASME code B31-4-2006, Table 402.3.1(a)

$$P_e^2 - \left[2\text{ x}25{,}200\left(\frac{0.25}{4.25}\right) + 12{,}445\left(1 + 0.03\left(\frac{4.25}{0.25}\right)\right)\right]P_e + 2\text{ x}25{,}200\left(\frac{0.25}{4.25}\right)\text{x}12{,}445 = 0$$

P_e^2- 21756.7P_e +36895764.71 = 0

P_e=1,853.8psi=130.6Kg/cm^2

d) Hoop Stress (S_h) Analysis

$$S_h = (P_e - P_i)\,(D - t)/2t \qquad 5.4$$

= (1,853.8 – 385.35) (4.5 – 0.25)/2 x 0.25

= 12,481.825psi

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

$$S_h \leq F \text{ x } S \text{ x } T = 0.72 \text{ x } 35000 \text{ x } 1 = 25{,}200$$

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

VI. Conclusion / Root Cause of Failure

From the analysis carried out, the following conclusions may be drawn;

1. The three samples provided failed by catastrophic brittle fracture, the cracks being intergranular and transgranular.
2. The failure mode is therefore brittle fracture and the mechanism is fatigue.
3. The clearage like flakes (crack) observed in the SEM fractographs are attributed to stresses produced by localized transformation and decreased solubility of hydrogen during cooling after hot working (forging). Hydrogen in excess of 5ppm plays an important role in this phenomenon and can be prevented by vacuum degassing treatment.
4. The pipe stresses are appropriate.
5. Failure of the 4" weldneck flange of pressure safety valve was a result of vibration induced fatigue enhanced by the weakened microstructure of the flangedue to incorrect normalizing practice after forging and hydrogen embrittlement.

VII. Recommendations

1. The flange used for replacing the faild one should be sourced from vendors that can guarantee the use of vacuum degassing after forging as this has been found to reduce hydrogen to less than 3ppm in forgings which ultimately preclude the possibility of hydrogen embrittlement.
2. The flange used for replacing the new one should be subjected to normalizing heat treatment at 910^{0}C for 30minutes as research work carried out by Belgian Welding Institute for a material of similar composition revealed that

the aforementioned normalizing practice yielded fine grain and fairly homogeneous microstructure with ASTM grain size number 8 to 9 and little variation in the flange hardness.

VIII. Acknowledgement

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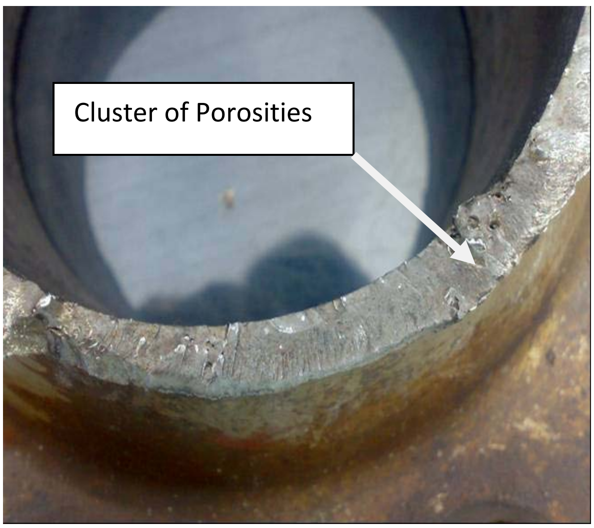

Fig 1 : Failed PSV Weld neck flange showing porosities

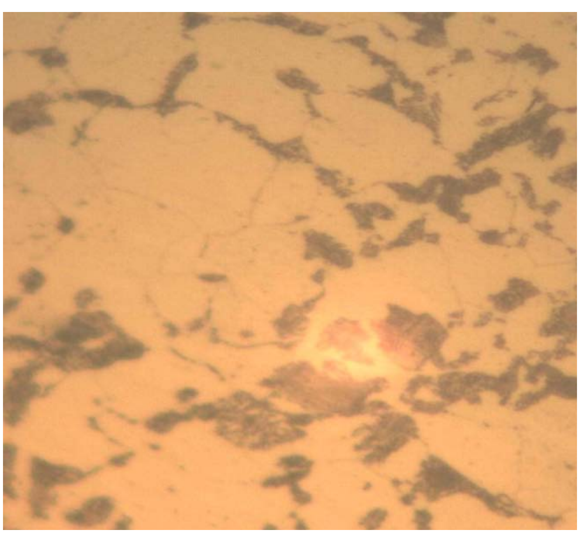

Fig 2 : Micrograph of weldneck flange of PSV, 2% nital etched x 800

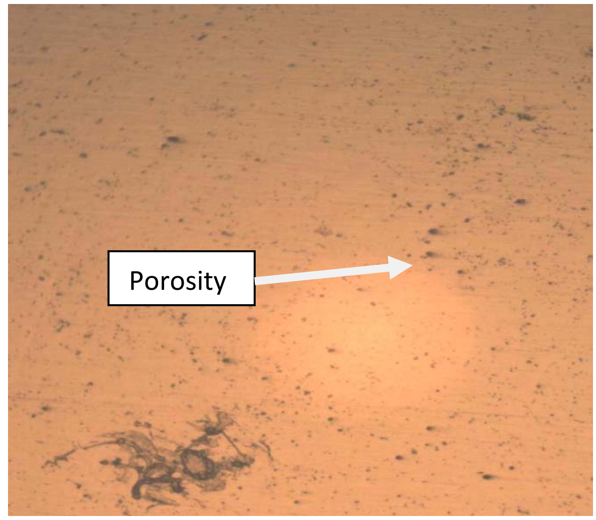

Fig 3 : Micrograph of weldneck flange of PSV, unetched x100 showing porosities

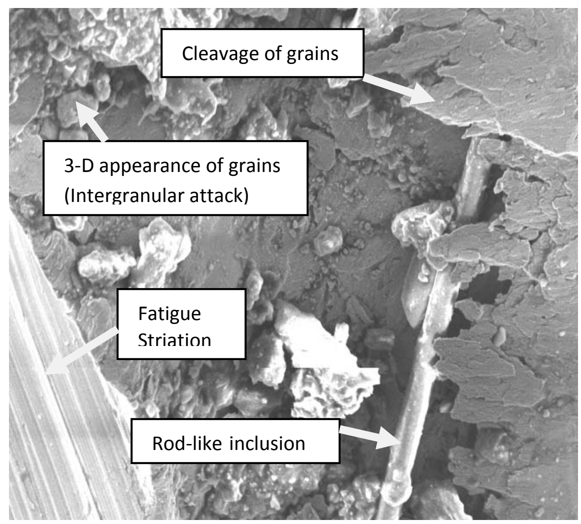

Fig 4 : Fractograph of failed weldneck flange of PSV x500

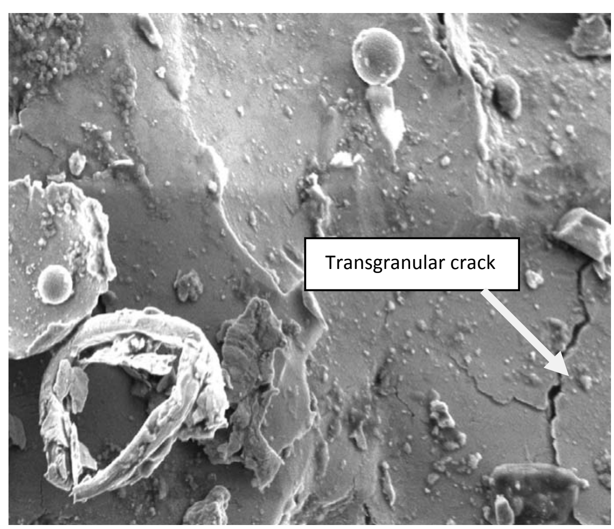

Fig 5 : SEM Fractograph of failed flange of PSV x700

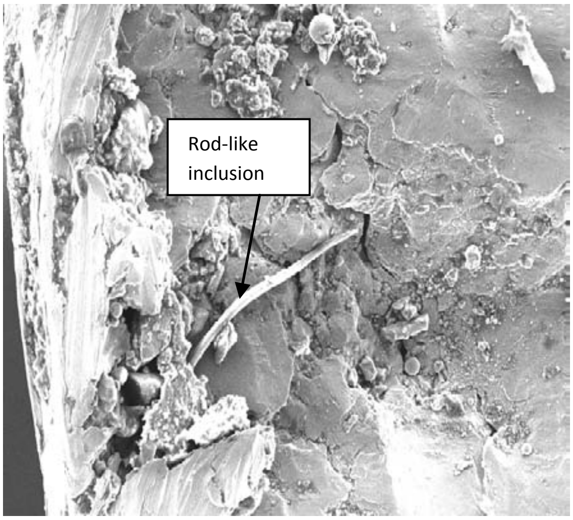

Fig 6 : SEM Fractograph of failed flange of PSV x300

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