Failure Analysis of a Weld Neck Flange of the Discharge Piping of an Ethylene Compressor in a Petrochemical Complex

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Abstract - Failure Investigation was carried out on a fractured Weld neck flange of an 8” discharge pipeline of an ethylene compressor 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 flange due to incorrect normalizing practice after forging. Remedial measures to prevent a reoccurrence were proffered.

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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. Combining 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>
<thead>
<tr>
<th>C</th>
<th>Cr</th>
<th>Ni</th>
<th>Si</th>
<th>Mn</th>
<th>S</th>
<th>P</th>
<th>Cu</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.276</td>
<td>0.092</td>
<td>0.033</td>
<td>0.30</td>
<td>1.28</td>
<td>0.06</td>
<td>0.017</td>
<td>0.149</td>
</tr>
</tbody>
</table>

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
revealed that the microstructure and grain size vary considerably with the maximum 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 continuous 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 cleavage. Figure 6 fractograph of this sample shows mainly transgranular and intergranular and intergranular failure nodes. It could therefore be inferred that the failure of this sample was catastrophic 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 pointer to manufacturing flaws in the flange.

IV. Mechanical Test

a) Microhardness Test

The sample from fractured weldment, flange of pressure safety valve was 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 inhomogenity 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 = \( \frac{26}{2} \)in

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

Material of pipe = ASTM A 350 LF2

Designation: Similar to API 5L GR B

Operating pressure = 27kg/cm² = 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.

\[
P = \left( \frac{2 S t}{D} \right) \times F \times E \times T
\]

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/cm²

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.

\[ P_c = \frac{2E_y}{1-\lambda^2} \left( \frac{t}{D_m} \right)^3 \]

[Antaki (2005)]

Where \( P_c = \) minimum net collapsing pipe pressure (psi)  
E\(_y\) = modulus of elasticity = 28 x 10\(^6\)psi  
t = pipe thickness = 0.25in

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

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 flanged due to incorrect normalizing practice after forging and hydrogen embrittlement.

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
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

The author is grateful to Engineering Materials Development Institute Akure, Nigeria and the University of Legon, Ghana for providing the equipment used for this work.

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
REFERENCES

2. ANSI/ASME B31.4 Pipeline Transportation Systems for Hydrocarbon and other liquids, p9, ASTM International., USA, 2006.
8. Yong Bai and Qiang Bai (2005), Subsea Pipelines and Risers, Elsevier Inc, USA.

Fig 6 : SEM Fractograph of failed flange of PSV x300