FAILURE ANALYSIS ON SLINGER DISK PIPE OF PURIFIED TEREPHTALIC ACID (PTA) VESSEL

ANALISA KERUSAKAN PIPA PIRING PELONTAR DARI BEJANA PURIFIED TEREPTALIC ACID (PTA)

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Abstract

Slinger disk pipe is a rotary part of PTA vessel with function as anti-fog by swinging hot water to the shell wall to remove solid PTA at the shell wall. Failure took place on this slinger disk pipe. The purpose of failure analysis is to find the root cause of failure. Methods conducted in this failure analysis are examination and testing of fractography, metallography, chemical composition, hardness, and calculation of bending stress. Examination on the fracture surface by fractographic method revealed fatigue fracture with the presence of multiple beachmarks. The position of those multiple beachmarks gave indication of alternation rotation of slinger disk pipe. Examination by metallographic method revealed that initial cracks initiated from heat affected zone of pipe and strengthening plates weld joint. However, result of chemical composition examination and hardness test showed that material of slinger disk pipe were in accordance with lean duplex 2205. Calculation of bending stress gave supporting data of various load effects to slinger disk pipe. Therefore, failure of the slinger disk pipe was caused by fatigue fracture which were initiated from head affected zone of pipe and strengthening plates weld joint.

Key Words: Slinger Disk Pipe; Purified Terephtallic Acid Vessel; Lean Duplex 2205; Fatigue Fracture; Heat Affected Zone.

Abstrak


Kata Kunci: Pipa Piring Pelontar; Bejana Purified Terephtalic Acid; Lean Duplex 2205; Patah Lelah; Daerah Pengaruh Panas.

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INTRODUCTION

Purified terephthalic acid (PTA) vessel is consisted of shell, rotary parts, and nozzle. The shell has two sections of PTA slurry and vapor. Slinger disk pipe is the rotary part at vapor level\(^1\) (Figure 1).

![Figure 1. Purified Terephthalic Acid (PTA) Vessel](image1)

Slinger disk pipe is consisted of disk, pan two pipes, three strengthening plates each side. The pipes are welded to the disk and strengthened by three plates\(^1\) (Figure 2).

![Figure 2. The Slinger Disk Pipe Structure](image2)

Slinger disk pipe rotates in the vapor section of PTA vessel. Through a nozzle, a hot water is directed to the pan disk and from the pan disk the hot water is swung to the shell wall. By swinging the hot water to the shell wall, blocking PTA at the shell wall is fluidized and removed.

Failure took place on the both pipes of the slinger disk pipe at the strengthening plates tip. For this failure analysis, it is taken one failure pipe as sample (Figure 2 and 3).

![Figure 3. Location of Fracture on The Slinger Disk Pipe (Red Circle And Magnified In Red Square)](image3)

The purpose of this failure analysis is to find out the root cause of failure on slinger disk pipe and to provide recommendations in order to prevent similar failure in the future.

MATERIALS AND METHODS

The sample is taken from the failed slinger disk pipe as shown in Figure 3. Material of the slinger disk pipe is lean duplex 2205\(^1\). Technical data and operational data are listed in Table 1.

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motor</td>
<td>30 kW</td>
</tr>
<tr>
<td>Shaft rotation</td>
<td>60 rpm</td>
</tr>
<tr>
<td>Vessel Pressure</td>
<td>13.5 Kg/cm(^2)</td>
</tr>
<tr>
<td>Vessel temperature</td>
<td>195.8 (^\circ)C</td>
</tr>
<tr>
<td>Slinger disk liquid flow</td>
<td>0.5 Ton/hour</td>
</tr>
<tr>
<td>Slinger disk material</td>
<td>Lean duplex 2205</td>
</tr>
<tr>
<td>Pipe size</td>
<td>3/4” schedule 80</td>
</tr>
</tbody>
</table>

Failure analysis on slinger disk pipe is conducted based on examination and testing as follow:

Chemical Composition Examination

Examination of chemical composition is conducted to verify the slinger disk pipe material specification by OES (optical emission spectrometer) whether it is in accordance with lean duplex 2205.
Hardness Test

Hardness test is conducted to verify the slinger disk pipe material specification by hardness tester Frank Finotes whether it is in accordance with lean duplex 2205.

Fractography and Metallography Examination

Examination of fractography and metallography is conducted to observe fracture modes on the fracture surface, and metallography is to observe the microstructure and defects.

Bending Stress Calculation

Calculation of bending stress is conducted to obtain supporting data of various load effects on the slinger disk pipe.

RESULTS AND DISCUSSIONS

Examination and Testing Results

Chemical Composition

Examination result of chemical composition of slinger disk pipe and strengthening plates are in accordance with the standard of lean duplex 2205 as shown in Table 2 and 3.

Table 2.
Chemical Composition Examination Result of Slinger Disk Pipe (Weight %)

<table>
<thead>
<tr>
<th>Elements</th>
<th>Pipe</th>
<th>Lean Duplex 2205</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe</td>
<td>65.1</td>
<td>Remain (Fe base)</td>
</tr>
<tr>
<td>C</td>
<td>0.0269</td>
<td>Max. 0.030</td>
</tr>
<tr>
<td>Si</td>
<td>0.356</td>
<td>Max. 1.00</td>
</tr>
<tr>
<td>Mn</td>
<td>1.02</td>
<td>Max. 2.00</td>
</tr>
<tr>
<td>P</td>
<td>0.0292</td>
<td>Max. 0.030</td>
</tr>
<tr>
<td>S</td>
<td>0.0001</td>
<td>Max. 0.015</td>
</tr>
<tr>
<td>Cr</td>
<td>23.2</td>
<td>21.1-23.0</td>
</tr>
<tr>
<td>Mo</td>
<td>3.23</td>
<td>2.50-3.50</td>
</tr>
<tr>
<td>Ni</td>
<td>6.13</td>
<td>4.50-6.50</td>
</tr>
</tbody>
</table>

Table 3.
Chemical Composition Examination Result of Strengthening (Weight %)

<table>
<thead>
<tr>
<th>Elements</th>
<th>Strengthening plate</th>
<th>Lean Duplex 2205</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe</td>
<td>61.7</td>
<td>Remain (Fe base)</td>
</tr>
<tr>
<td>C</td>
<td>0.0278</td>
<td>Max. 0.030</td>
</tr>
<tr>
<td>Si</td>
<td>0.350</td>
<td>Max. 1.00</td>
</tr>
</tbody>
</table>

Hardness Test Result

Location of hardness tests of the slinger disk pipe are shown in Figure 4.

Table 4.
Hardness Test Result of Slinger Disk Pipe (HV)

<table>
<thead>
<tr>
<th>No</th>
<th>On base metal</th>
<th>On weldment</th>
<th>Lean Duplex 2205</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>249</td>
<td>239 (BM)</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>341</td>
<td>262 (HAZ)</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>299</td>
<td>262 (BM)</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>293</td>
<td>289 (HAZ)</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>295</td>
<td>271 (BM)</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>302</td>
<td>266 (WM)</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>271</td>
<td>271 (WM)</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>296</td>
<td>296 (WM)</td>
<td></td>
</tr>
</tbody>
</table>

Note: BM (base metal), HAZ (head affected zone), WM (weld metal)

Fractography and Metallography

Examination result of fractography on the fracture surface of slinger disk pipe shows multiple benchmarks and their initial cracks as an evidence of fatigue fracture under reverse bending load as shown in Figure 5-6.
Initial crack of each beachmarks are located at the center of beachmark.

Figure 5. Multiple Beachmarks on The Fracture Surface And Their Initial Cracks Location

Figure 6. Magnification of Figure 5 Shows Two Beachmarks With The Cracks Initiated From Two Weld Joints

As can be seen in the Figure 5 that the beachmarks position are diametrically opposite each other in the same transverse plane, it indicates that the applied bending moment is reversing (alternating), all point in pipe are subjected alternately to tension and compression stress\(^2\). It means that the rotation of slinger disk pipe is reversing (alternating).

Examination result of metallography shows that the crack propagation initiated from HAZ which then propagated to base metal, while the microstructure is austenite in ferrite matrix\(^3\) in normal condition\(^4\), as shown in Figure 7.

Figure 7. The Fracture is Initiated From HAZ Which Then Propagated to Base Metal.

Bending Stress Calculation

Calculation of maximum bending stress:

Data \(^1\):

- Motor Power \(P = 30 \text{ kW} = 30,000 \text{ Nm/s}
- Slinger length \(S = 2.2 \text{ m}
- Rotation \(n = 60 \text{ rpm} = \text{rps}
- Circumferential speed \(v = \pi Sn = 3.14 \times 2.2 \text{ m} \times 1 \text{ rps} = 6.908 \text{ m/s}
- Tangential force \(F_T = P/v = 30,000 \text{ Nm/s} / 6.908 \text{ N} = 4,342.8 \text{ N}
- Distance from plate tip to pipe tip \(L = 600 \text{ mm}
- Moment on the pipe at plate tip \(M = F_T \times L = 4,342.8 \text{ N} \times 600 \text{ mm} = 2,605,675 \text{ Nmm}
- Pipe dimension = \(\frac{3}{8}''\) schedule 80
- Pipe OD = 27 mm
- Pipe ID = 21 mm
- Moment of inertia \(I = \pi(OD^4 - ID^4)/64 = 3.14(27^4 - 21^4) / 64 = 16,532 \text{ mm}^4
- Radius of pipe \(r = OD/2 = 27/2 = 13.5 \text{ mm}
- Bending stress at the plate tip \(\sigma_B = Mrl = 2,605,675 \times 13.5 / 16,532 = 2,128 \text{ N/mm}^2
- Tensile stress of pipe material \(\sigma_U = 869 \text{ N/mm}^2\)

Calculation result is maximum stress \(\sigma_B\) is higher than the tensile strength of material.

Calculation of proper pipe size

Data:

- Yield stress \(\sigma_Y = 644 \text{ N/mm}^2\)
- Safety factor \(S_F = 2\)
- Allowable stress \(\sigma_A = 644 / 2 = 322 \text{ N/mm}^2\)
Moment of inertia \( I = \frac{Mr}{\pi} = 2,605,675 \times 13.5 / 322 = 109,245 \text{ mm}^4 = \pi \left( \frac{OD^4 - ID^4}{64} \right) \)

\( ID = 0.75 \text{ OD} \)

\( OD^4 - (0.75 \text{ OD})^4 = 0.68 \text{ OD}^4 = 2,226,632 \text{ mm}^4 \)

\( OD^4 = 2,226,632 / 0.68 = 3,275,000 \text{ mm}^4 \)

\( OD = (3,275,000)^{1/4} = 42.5 \text{ mm} \)

Pipe selection: 1½” schedule 40

Calculation of power

Bending moment at plate tip \( M = \frac{I\omega^2}{r} = 16,532 \times 322 \times 13.5 = 394,321 \text{ Nmm} \)

Tangential force \( F_T = \frac{M}{L} = 394,321 / 600 = 657 \text{ N} \)

Power \( P = vF_T = 6,908 \text{ m/s} \times 657 \text{ N} = 4,540 \text{ Nm/s} = 4,540 \text{ W} = 4.54 \text{ kW} \)

From the calculation of stress, it is obtained:

- With the motor power is 30 kW and the rotation is 60 rpm, the maximum bending stress on the location of fracture is above tensile strength of lean duplex 2205
- With the motor power is 30 kW and the rotation is 60 rpm, need pipe dimension of 1½” sch. 40
- With the pipe dimension of ¾” schedule 80, the power should be limited up to 4.54 kW

**Discussions**

Results of chemical composition examination and hardness test indicated that the material of slinger disk pipe is in accordance with Lean Duplex 2205 specification, therefore failure of slinger disk pipe is not caused by wrong material selection.

Results of fractography and metallography examination show that the mode of fracture is fatigue fracture which is indicated by the presence of multiple beachmarks on the fracture surface with the locations are diametrically opposite each other (Figure 5-6). It gave a clue that the rotation of slinger disk pipe is reversing (alternating). Effect of the reversing rotation is that the slinger disk pipes are subjected to tension and compression stress reversely, and may create stress riser on the HAZ to increase local stress concentration. Finally, the root cause of the failure is high stress concentration on heat affected zone of the pipes and the strengthening plates.

**CONCLUSION**

From all examination and testing, it can be concluded that the cause is fatigue fracture. The fracture are initiated by initial cracks from heat affected zone (HAZ) of welding joint of the three strengthening plates and the pipe, which then propagated under operational load to form beachmarks. It can be observed the beachmarks have their own initial on each plate welding HAZ so multiple beachmarks were created. Accumulatively the area of those beachmarks may reach more than half of cross section area that indicates of low nominal working stress. Furthermore, location of those beachmarks are diametrically opposite each other means that the rotation of slinger disk pipe is reversing (alternating). Effect of the reversing rotation is that the slinger disk pipes are subjected to tension and compression stress reversely, and may create stress riser on the HAZ to increase local stress concentration. Finally, the root cause of the failure is high stress concentration on heat affected zone of the pipes and the strengthening plates.

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**AUTHOR CONTRIBUTION**

The main contributor of this paper is Sukandar. The other authors are Triwobowo and Yana Heryana.

**REFERENCES**