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

ANALISA KERUSAKAN PIPA PIRING PELONTAR DARI BEJANA PURIFIED TEREPHTALIC 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 Terephtalic Acid Vessel; Lean Duplex 2205; Fatigue Fracture; Heat Affected Zone.

Abstrak

Pipa piring pelontar adalah bagian berputar dalam bejana PTA *yang mempunyai fungsi sebagai anti-kabut dengan cara melontarkan air panas ke dinding bejana sehingga gumpalan PTA pada dinding bejana dapat dilepaskan. Kerusakan terjadi pada pipa piring pelontar. Tujuan dari analisa kerusakan ini adalah untuk mencari akar sebab kerusakan pada pipa piring pelontar. Metode-metode yang dilakukan dalam analisa kerusakan ini adalah pemeriksaan dan pengujian fraktografi, metalografi, komposisi kimia, kekerasan dan perhitungan tegangan bending. Pemeriksaan pada permukaan patah dengan metode fraktografi menunjukkan patah lelah dengan ditemukannya banyak marka pantai. Posisi marka pantai tersebut memberi indikasi putaran bolak-balik pipa piring pelontar. Pemeriksaan dengan metode metalografi menunjukkan awal retak pada daerah pengaruh panas dari sambungan las antara pipa dan pelat penguat. Sedangkan hasil pemeriksaan komposisi kimia dan pengujian kekerasan menunjukkan bahwa material pipa piring pelontar sesuai dengan lean duplex 2205. Hasil perhitungan tegangan bending memberikan data pendukung berupa efek variasi beban pada pipa piring pelontar. Dengan demikian, kerusakan pipa piring pelontar disebabkan oleh patah lelah yang berawal dari daerah pengaruh panas sambungan las antara pipa dan pelat penguat.*

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

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INTRODUCTION

Purified terephtalic 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).

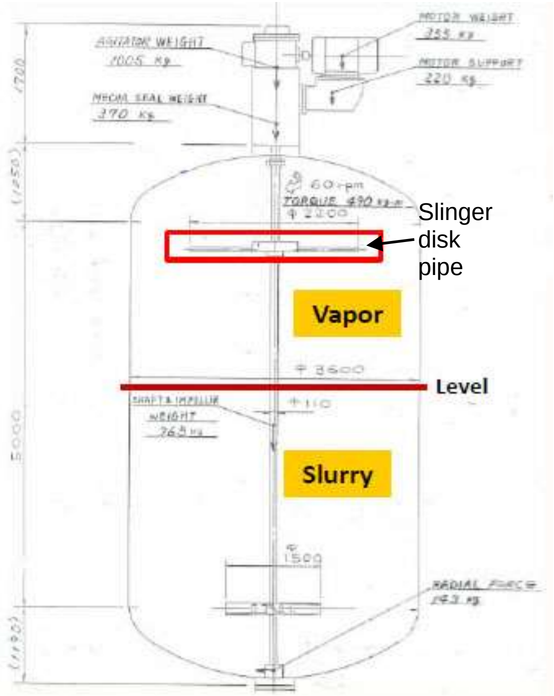

Figure 1.
Purified Terephtalic Acid (PTA) Vessel

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).

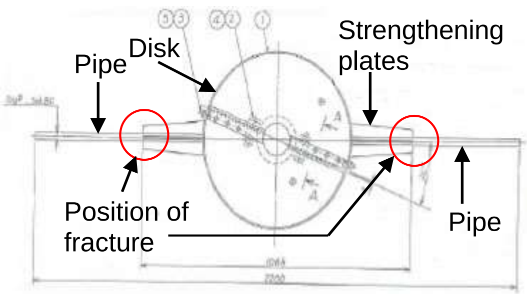

Figure 2.
The Slinger Disk Pipe Structure

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).

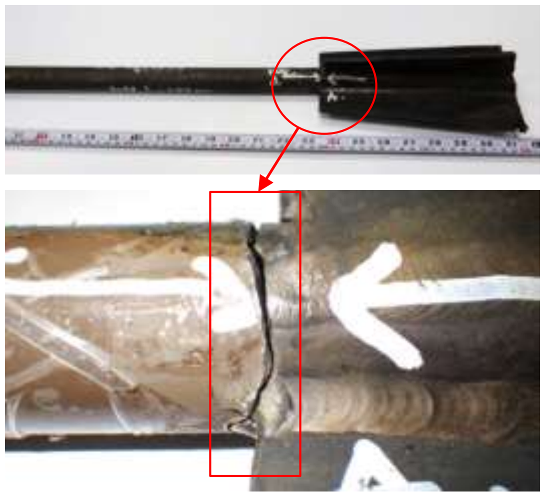

Figure 3.
Location of Fracture on The Slinger Disk Pipe (Red Circle And Magnified In Red Square)

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 1
Technical Data And Operational Data of Slinger Disk Pipe[1)]

Specification	Value
Motor	30 kW
Shaft rotation	60 rpm
Vessel Pressure	13.5 Kg/cm^2
Vessel temperature	195.8 ^{o}C
Slinger disk liquid flow	0.5 Ton/hour
Slinger disk material	Lean duplex 2205
Pipe size	¾“ schedule 80

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.

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Hardness Test

Hardness test is conducted to verify the slinger disk pipe material specification by hardness tester Frank Finotest 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 %)

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

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

Elements	Strengthening plate	Lean Duplex 2205
Fe	61.7	Remain (Fe base)
C	0.0278	Max. 0.030
Si	0.350	Max. 1.00
Mn	0.465	Max. 2.00
P	0.0151	Max. 0.030
S	< 0.0001	Max. 0.015
Cr	24.6	21.1-23.0
Mo	3.83	2.50-3.50
Ni	7.67	4.50-6.50

Hardness Test Result

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

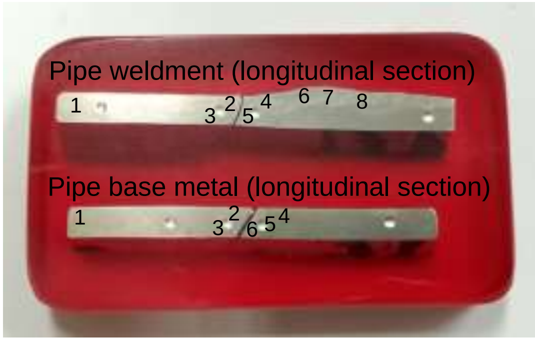

Figure 4.
Location of Hardness Tests on The Sample of Slinger Disk Pipe

Hardness test result as represented by a sample of slinger disk pipe shows that the material hardness is in accordance with the standard of lean duplex 2205 as shown in Table 4.

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

No	On base metal	On weldment	Lean Duplex 2205
1	249	239 (BM)	270
2	341	262 (HAZ)	
3	299	262 (BM)	
4	293	289 (HAZ)	
5	295	271 (BM)	
6	302	266 (WM)	
7		271 (WM)	
8		296 (WM)	

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

Fractography and Metallography

Examination result of fractography on the fracture surface of slinger disk pipe shows multiple beachmarks 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.

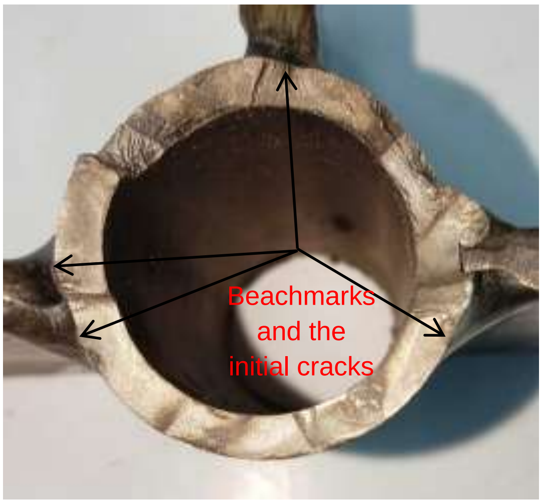

Figure 5.
Multiple Beachmarks on The Fracture Surface And Their Initial Cracks Location

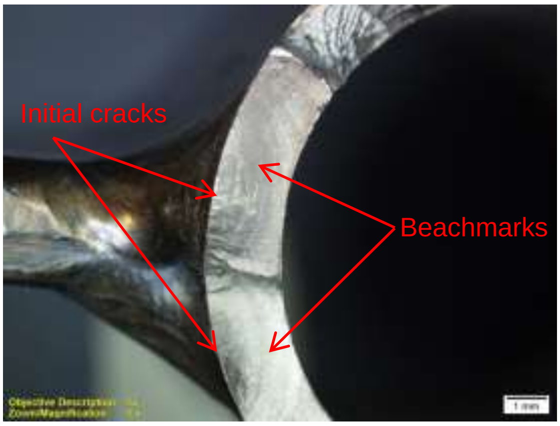

Figure 6.
Magnification of Figure 5 Shows Two Beachmarks With The Cracks Initiated From Two Weld Joints

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.

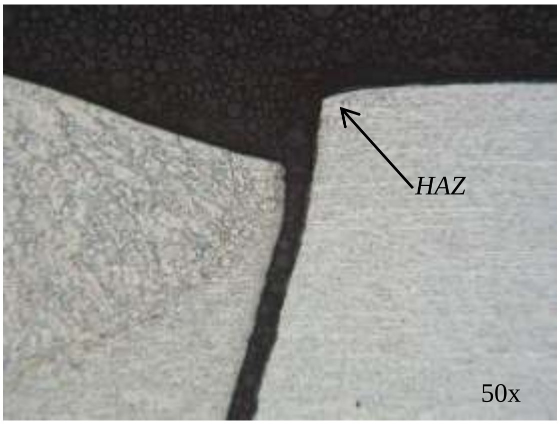

Figure 7.
The Fracture is Initiated From HAZ Which Then Propagated to Base Metal.

Bending Stress Calculation

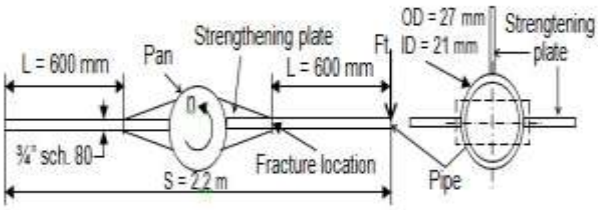

Figure 7. Dimension of Slinger Disk Pipe

Calculation of maximum bending stress:
Data [1]:
Motor Power P = 30 kW = 30,000 Nm/s
Slinger length S = 2.2 m
Rotation n = 60 rpm = rps
Circumferential speed v = πSn = 3.14 x 2.2 m x 1 rps = 6,908 m/s
Tangential force F_T = P/v = 30,000 Nm/s / 6,908 N = 4,342.8 N
Distance from plate tip to pipe tip L = 600 mm
Moment on the pipe at plate tip M = F_T x L = 4,342.8 N x 600 mm = 2,605,675 Nmm
Pipe dimension = ¾" schedule 80
Pipe OD = 27 mm
Pipe ID = 21 mm
Moment of inertia I = $\pi(OD^4 - ID^4)/64$ = $3.14(27^4 - 21^4) / 64 = 16,532\ mm^4$
Radius of pipe r = OD/2 = 27/2 = 13.5 mm
Bending stress at the plate tip σ_B = Mr/I = 2,605,675 x 13.5 / 16,532 = 2,128 N/mm^2
Tensile stress of pipe material σ_U = 869 N/mm^2 [5]
Calculation result is maximum stress σ_B is higher than the tensile strength of material.

Calculation of proper pipe size
Data:
Yield stress σ_Y = 644 N/mm^2 [5]
Safety factor S_F = 2[6]
Allowable stress σ_A = 644 / 2 = 322 N/mm^2

Moment of inertia $I = Mr/\sigma_A$ = 2,605,675 x 13.5 / 322 = 109,245 $mm^4 = \pi(OD^4 – ID^4)/64$
$(OD^4 – ID^4)$ = 64 x 109,245 / 64 = 2,226,632 mm^4
ID = 0.75 OD
$OD^4 – (0.75\ OD)^4 = 0.68\ OD^4$ = 2,226,632 mm^4
OD^4 = 2,226,632 / 0.68 = 3,275,000 mm^4
OD = $(3,275,000)^{1/4}$ = 42.5 mm
Pipe selection: 1½“ schedule 40

Calculation of power
Bending moment at plate tip $M = I\sigma_A/r$ = 16,532 x 322 / 13.5 = 394,321 Nmm
Tangential force $F_T = M/L$ = 394,321 / 600 = 657 N
Power $P = vF_T$ = 6,908 m/s x 657 N = 4,540 Nm/s = 4,540 W = 4.54 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[1)] 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[7,9,11)] 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)[8,10)]. Effect of the reversing rotation is all points on the slinger disk pipe are subjected alternately to tension stress and compression stress. For every beachmark has initial crack. All initial cracks are initiated from heat affected zone of weld joint of pipe and strengthening plates. It is supported by the result of metallography examination (Figure 7).

Moreover, it can be observed that the area of beachmarks are relatively reach more than half of cross section area of the pipe (Figure 5). It indicated that the nominal load on the slinger disk pipe is low.

Calculation of bending stress is conducted in three conditions, i.e. under maximum load with pipe size of ¾” schedule 80, under maximum load with pipe size of 1½” schedule 40, and under half yield stress with pipe size of ¾” schedule 80.

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.

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