Failure Analysis of a Heat Exchanger Tube

By

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
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Approved by,

____
(Assoc. Prof. Dr. Patthi Bin Hussain)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

July 2010

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

MUHD ZULKIFLI MD. ZAIN

ABSTRACT

This report presents failure analysis on carbon steel SA – 179 heat exchanger tube in petrochemical plant. Heat exchanger tube found bulging and burst with vertical crack during plant cold start – up period. These incidents make a delay in plant cold start-up process thus increase the shut down period exceeding estimation days before. Opportunity lost to the plant up to RM 2 million per day excluded maintenance work and retubing cost for the new heat exchanger tubes. The aim of this project is to perform failure analysis on bulging and burst heat exchanger tube as well as determine root cause of the failure incident itself. Besides, this failure analysis project functioned to recommend a few recommendations on future failure prevention in industry. The research methodology that being conducted in this project is failure analysis steps in order to enhance the outstanding result and interpretation of failure sample investigation. The methodology started with background data collection, possible root cause analysis, preliminary examinations, hardness testing, analysis of metallographic and fractographic specimen followed by conclusion on root cause of the bulging and burst tube. Preliminary examination revealed the indication of heat exchanger tube wall bulging and thinning effect. The metallographic analysis by scanning electron microscope and optical microscope exposed the elongation of deform grain at the failed area. The elongation of the grain affected the grain boundaries form long horizontal shape in a thin size and move towards to each other simultaneously with plastic deformation process. Metallographic sample analysis revealed the formation of voids and cavities. As the coalescence of voids and cavities become connected and propagates along grain boundaries leading to intergranular crack fracture. Based on failure analysis that being performed, creep has been identified as a root cause of the bulging and burst heat exchanger tubes. Pressure, temperature, time and constant load of heat exchanger operating parameter are the underlying factors that led to the heat exchanger tubes bulging and burst. This project will be beneficial to both parties; future failure prevention in industry and crucial for university learning purpose.

ACKNOWLEDGEMENT

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CHAPTER 1

INTRODUCTION

1.1 Background Study

Heat exchanger tube failure sample is a tube and shell heat exchanger types operating in the vertical position. This heat exchanger basically functioned to heat up the hydrocarbon which is n - Butane. The leakage of this heat exchanger tube happened during cold start-up period of approximately 8 days on March 2009 during the plant emergency shutdown. Basically there were two types of tubes operating inside this heat exchanger which were 12.8mm OD sparger tube and 1" OD tube. The 12.8mm OD sparger tube was inside the 1" OD tube. Saturated steam flows inside the sparger tube and came out at the end and then flow inside the 1"OD tube. The material for this heat exchanger tube is SA – 179 grades A low carbon steel [1].

The 1" OD tube was used to heat up hydrocarbon inside the shell. This heat exchanger was suspected leak due to the moisture from condensate steam carry over into the hydrocarbon system. This incident will affect the quality and production of the hydrocarbon itself. Leak test was planned to detect the leak tube. 35 tubes at very outer layer of tube bundle were found bulging with vertical crack after pull out the vessel. All defect tubes were at top portion of the tube and some of tube also found bulging without crack. No leak test was carrying out after pull out vessel due to the defect was clearly revealed after opening the vessel. 35 number of tubes found bulging with vertical crack / burst. Refer to Appendix 1 – 5 for heat exchanger tube failure sample details.

The bulging and burst of this heat exchanger tube is a first time occurrence since commissioning in 1991. The leakage of this heat exchanger tube happened during plant cold start-up period of approximately 8 days in March 2009 in conjunction with the plant emergency shutdown. This heat exchanger operated in a vertical position. It was suspected leak due to the condensate steam carry over into the hydrocarbon system. All defect tubes were at top portion of the tube and some of tube also found bulging without crack as shown in Figure 1.1 and 2.1. 35 out of 138 total tubes found bulging and burst with vertical crack after the vessels were opened. The heat exchanger tubes failure sample material is SA-179 low carbon steel. SA-179 carbon steel types referred to the specification material for seamless cold-drawn low-carbon steel that being used widely in industry for heat-exchanger and condenser tubes.

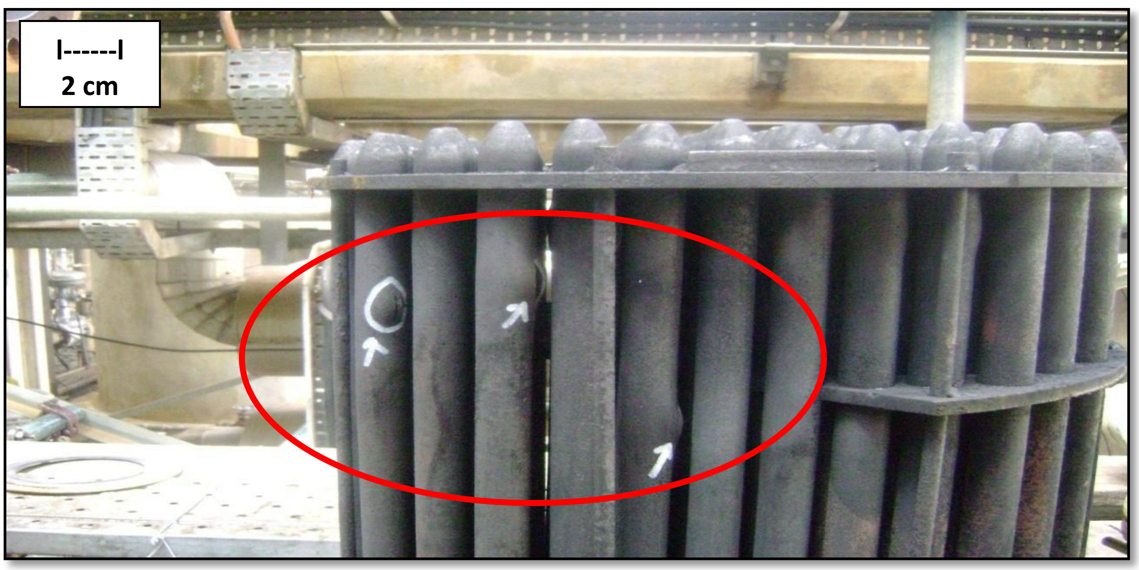

Figure 1.1: Bulging and burst tube at the top portion of the heat exchanger

1.2 Problem Statement

1.2.1 Problem Identification

Heat exchanger tube was found bulging and burst with vertical crack during plant cold start – up period. These incidents make a delay in plant cold start-up process thus increase the shut down period exceed the estimation days before. Opportunity lost to the plant up to RM 2 million per day excluded the retubing cost for the new heat exchanger tubes.

1.2.2 Significance of The Project

Upon completion of the project, this failure analysis interpretation will be both beneficial to the industry and university. The prevention of incident or failure can be implemented in future onwards in industry especially based on the recommendation made by root cause analysis. This project also discussed regarding the microstructure condition, analysis of failure sample, mechanical testing or examination and etcetera thus will be beneficial to both parties; future failure prevention in industry and for university learning process.

1.3 Objective of Study

The main objective of this project is to perform failure analysis of bulging and burst heat exchanger tube as well as determine the root cause analysis (RCA) on the failure incident itself. Besides, this failure analysis project functioned to recommend a few recommendations on future failure prevention in industry.

1.4 Scope of Study

In order to achieve this objective, research and scope of study that need to be carried out by collecting all technical details regarding the failure background and sample bulging and burst heat exchange tube. The study mainly discussed regarding the failure analysis that consist of preliminary examinations, microstructure condition, chemical analysis composition, analysis of metallographic sample and mechanical testing such as hardness test of the bulging and burst heat exchange tube samples. Besides, the study also discussed regarding the carbon steel microstructure, mechanical properties and etcetera.

1.5 The Relevancy and Feasibility of Project

This project is relevant to the study of engineering failure analysis as well as the study of material failure mode interpretation, microstructure, metallographic and fractographic analysis, utilizes failure analysis tools such as scanning electron microscope, hardness testing, chemical analysis and etcetera. The project is feasible and relevant as it will be beneficial to both parties: future failure prevention in oil and gas industry and university learning purpose.

CHAPTER 2

LITERATURE REVIEW

2.1 Heat Exchanger Details

Table 2.1 and Figure 2.2 shows heat exchanger data sheet and schematic drawing. Heat exchanger tube bulging and burst with narrow longitudinal split as shown in Figure 2.1.

Table 2.1: Heat exchanger data sheet [1]

Items	Shell side	Tube side
Design pressure (kPa)	1606	1071
Operating pressure (kPa)	1225	570
Design temperature (°C)	121	195
Operating temperature (°C)	87	150
Fluid in circulation	Hydrocarbon (n-Butane)	LP steam
Material	SA – 106 Grade B	SA – 179 low carbon steel

Figure 2.1: Heat exchanger tube fail sample

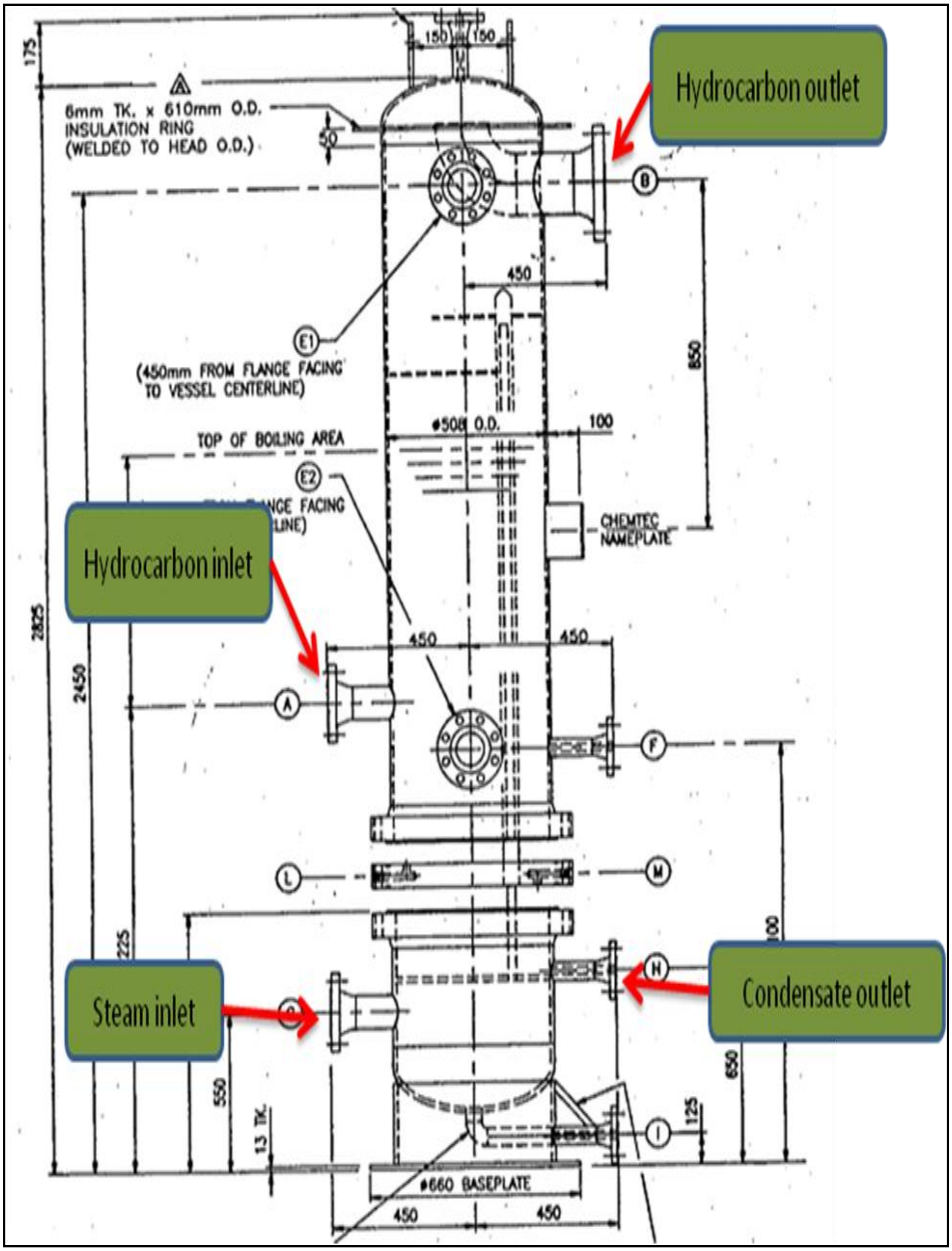

Figure 2.2: Schematic drawing of heat exchanger [1]

2.2 Root Cause Analysis

Root cause analysis based on the Ishikawa method has been conducted as shown in Figure 2.3.

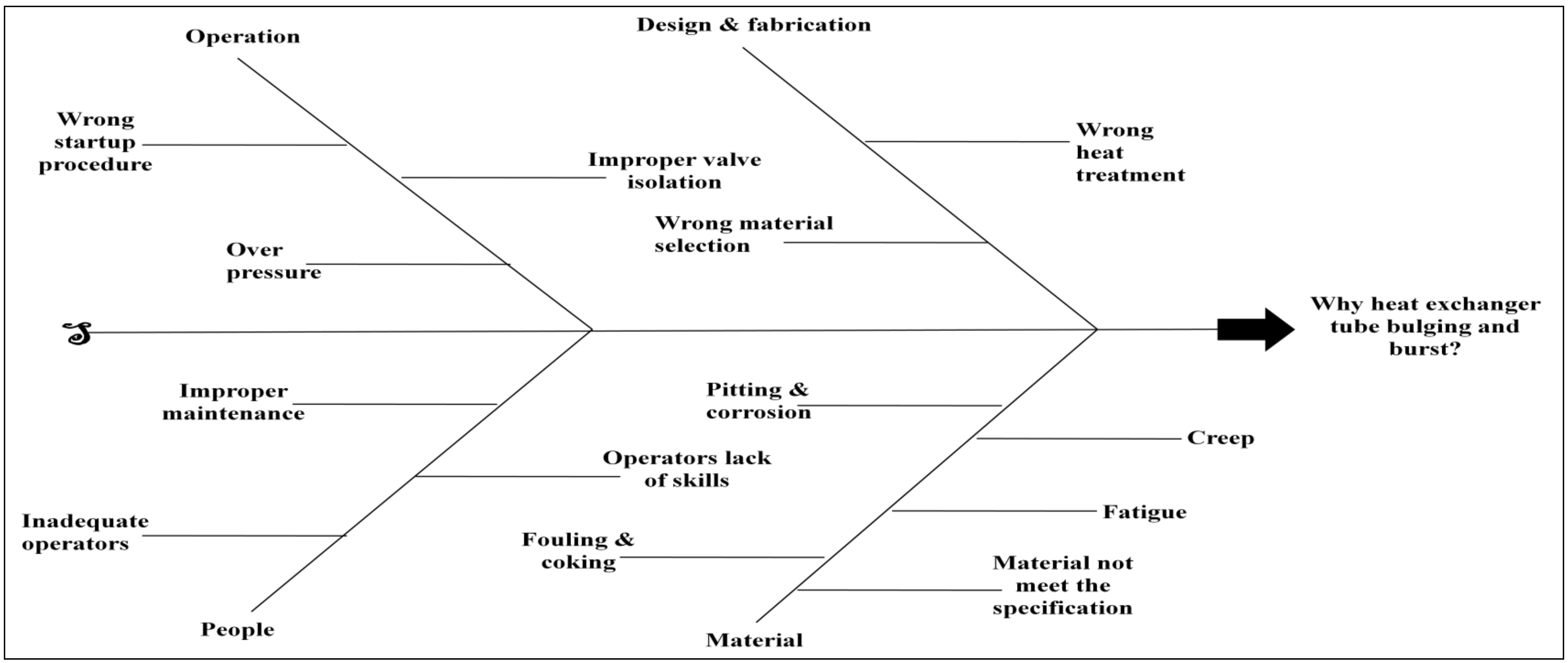

Figure 2.3: Root cause analysis (fish bone diagram)

2.3 Journals Summary

Table 2.2 shows few of journals summary regarding the failure analysis that has been conducted in conjunction to the bulging and burst tube scenario world wide.

Table 2.2: Journals summary

No	Journal title	Summary
1	Failure analysis on a primary superheater tube of a power plant [2]	This paper presents the failure analysis on the SA213-T12 superheater tube by visual inspection, in situ measurements of hardness and finite element analyses is presented. A primary superheater tube has failed with a wide open burst after running at around 28,194 hours. Localized short-term overheating of the tube due to localized and concentrated flue gas flow resulted in a failure of the primary superheater tube.
2	Failure analysis on high temperature superheater Inconel 800 tube [3]	This paper presents failure analysis on a super alloy Inconel 800 superheater tube in Kapar Power Station Malaysia. and its root cause. The failed high temperature superheater (HTSH) tube was found snapped into two parts, heavily distorted shape and bent at several points. Microstructures of the failed tube showed that creep crack initiated at both external and internal surfaces of the tube and propagated as grain boundary creep cavities coalesced to form intergranular cracks. Creep rupture is revealed as the cause of failure of the superheater tube.

3	Failure analysis of air pre-heater tubes of a petrochemicals plant [4]	Heat resistant alloy tubes used in the higher temperature range of 1150–1273K depends on the protective scale integrity for prevention of corrosion induced premature failures in a mixed gas environment with potential corrodents for oxidation, carburization and sulphidation attack. Cast HK40+Nb alloy tubes of an air pre-heater unit of a petrochemical industry failed prematurely after 13,000 hours in service. Failed parts showed crack/punctures below the corrosion product filled pits. Factors like excessive temperature cycling, overheating, presence of impurities either in the pre- heating gas mixture or that got introduced while in operation were found to be the reasons for breach of protective scale integrity leading to un warranted corrosion attack resulting in thinning of tube material and internal corrosion penetration which finally led to premature failure.
4	Failure analysis of heat exchanger tubes [5]	Primary waste heat exchanger tubes of material ASTM A213 grade T11 failed after operation of only three and a half months. The heat exchanger was of the bayonet type with boiler water inside the tubes and secondary reformer outlet process gas at the shell side. The failed, used and new heat exchanger tubes were subjected to stereo/optical microscopy, chemical analysis and hardness testing. The cause of the failure was thoroughly investigated using optical/scanning electron micro-scope equipped with energy dispersive spectrometer. The study revealed that the material was exposed to thermal cycling and excessive local heating. These conditions lead to thermal fatigue of the material with consequent failure.

2.4 Overview on Failure Analysis

Failure analysis is the process of collecting and analyzing data to determine the cause of a failure and how to prevent it from recurring. It relies on collecting failed components for subsequent examination causes of failure [6]. There are several specific level of failures which are physical, human, latent and root. Physical failure occurred due to environmental or chemical effect such as corrosion, thinning, pitting and etcetera. Besides, the human failure affected by human error itself for example equipment mishandling, improper maintenance, inadequate inspection and others.

Meanwhile, the latent failure occurred due to people that handle the equipment lack of ability, qualifications and skills such as inadequate inspector training. There are several steps and procedure that must be followed in conducting failure analysis process. The first step starts with background data and information collection regarding the failure together with sample material selection. Better understanding of the conditions under which the part was operating and site visit is necessary if possible. The second step is to conduct preliminary examination such as visual examination, cataloguing and recording the physical evidence.

Samples should be examined, photographed and sketched taking particular care to identify and record any area of particular importance such as fracture surfaces and surface defects. Samples should be examined and recorded before any surface cleaning undertaken [7]. The third step is to decide on a course of action lead to failure. There are several resources that an investigator can draw on to determine the cause of failure such as non destructive testing (NDT), mechanical testing, macroscopic and microscopic examinations.

Then the process proceeds with selection, preparation, examination and analysis of metallographic specimens followed by chemical analysis, stress analysis, fracture mechanics and failure simulation. The final and most difficult step in any investigation is coming up with conclusion and recommendations. The failure analysis process ended with report writing and documentation regarding failure background, sample photograph, findings, testing results and etcetera [7].

2.5 Overview on Material Failure Modes

Failure defines as a component unable to adequate or performs its intended function. In simple words, failure referred to a component that is loss of function, loss of service life and a system that is inoperable. There are many different kinds of mechanical failure occurred consist of overload, impact, fatigue, creep, rupture, stress relaxation, stress corrosion cracking, corrosion fatigue, buckling, yielding and etcetera. Each produces a different type of fracture surface, and other indicators near the fracture surface.

Corrosion failure can be defined as the disintegration of a material into its constituent atoms due to chemical reactions with its surroundings [8]. These types of failure can be concentrated locally to form a pitting, thinning and surface cracking or it can extend across a wide area to produce general deterioration to the material [8]. The overload failures occurred due to insufficient material strength or under design, stress concentration and material defects as well as material alteration because of temperature and environment effect. The applied stress maybe tension, compression, torsion and bending or shear stress.

In engineering material, two failure modes possible which are ductile and brittle fractures and the classification are based on the ability of material to experience plastic deformation. Ductile fracture typically exhibit substantial plastic deformation with high energy absorption before fracture and vice versa compare to the brittle material. Ductile fracture occurs from the nucleation, growth, and coalescence of micro voids during deformation [8]. Fatigue is a form of failure that occurs in structure subjected to dynamic and fluctuating stress or cyclic loading. This type of failure is possible to occur at a stress level considerably lower than the tensile or yield strength for a static load.

Buckling is a failure mode characterized by a sudden failure of a structural member subjected to high compressive stresses, where the actual compressive stress at the point of failure is less than the ultimate compressive stresses that the material is capable of withstanding. Creep defines as time dependant and permanent deformation of material when subjected to constant load or stress. Creep is the tendency of a solid material to slowly move or deform permanently under the influence of stresses. This type of failure occurred as a result of long term exposure to an elevated temperature and stress [8].

CHAPTER 3

METHODOLOGY

3.1 Research Methodology on Heat Exchanger Tube Failure Analysis Process

Figure 3.1 shows failure analysis process on bulging and burst heat exchanger tube.

Background data collection and sample material selection of the bulging and burst tube

↓

Preliminary examination (tube sample diameter and thickness measurement) and root causes analysis

↓

Non Destructive Testing and Mechanical Testing

↓

Macroscopic and microscopic examinations on the bulging and burst heat exchanger tube

↓

Selection, preparation, examination and analysis of metallographic /fractographic specimens

↓

Final analysis, conclusion, recommendation and report writing

Figure 3.1: Failure analysis process

The methodology involves in this failure analysis project starts with background data and information collection regarding the failure together with sample material selection. In this step, all the background of the incident, failure picture, the equipment data sheet (operating and design parameters) is gathered. Then, the possible root cause analysis (RCA) is performed by fish bone or Ishikawa diagrams that consist of all the failure information. The second step is to conduct preliminary examination such as visual examination, diameter and thickness measurement, cataloguing and recording all the physical evidence.

Then proceed with non destructive testing (NDT) and mechanical testing such as dye penetrant testing for NDT and perform hardness test for mechanical testing. The third step is selection, preparation, examination and analysis of metallographic specimens. Two samples were prepared which are failed and normal ones. For the sample preparation a few steps involve which are sectioning, mounting, grinding, polishing and etching. Then the examination and analysis process is followed. In this step, the scanning electron microscope (SEM) and optical microscope (OM) is used for microstructure tube sample examination as well as the fractographic analysis.

The last steps end by conclusion, recommendation and report writing regarding the failure analysis findings and investigation. The conclusions of this failure analysis must be supported by the lab test examination and analysis. The recommendation functioned for future failure prevention. Refer to Gantt chart attached in appendix 8 and 9 for the work progress to support the methodology of this failure analysis project.

3.2 Metallographic Sample Preparation

Heat exchanger tubes bulging and burst tube has been undergone sample preparation for Optical Microscope (OM) and Scanning Electron Micrograph (SEM) examination together with analysis. A few steps for sample preparation have been performed starting with sectioning, mounting, grinding, polishing and etching as shown in Figure 3.2. Sectioning functioned to remove the representative sample and this process performed by abrasive cutter [9]. For this heat exchanger tubes, sectioning has been done on two samples which are failed and away (normal) areas for the comparison analysis as express in Figure 3.3. Hot mounting process was proceed after the sectioning. This step is important due to a few factors such as for ease of handling of difficult shapes/sizes of samples and for edged protection [9].

Thermosetting polymeric powder is placed in a mould with the sample to which heat and pressure is applied. Grinding process has been conducted on the mounting sample surface after the mounting process done. This step functioned to minimize thickness of damaged layer from to the sectioning process [9]. Grinding process done using rotating discs covered with silicon carbide (SiC) paper with various grade (180, 240, 320, 400, 600 grit) in appearance of cooling water as lubricant. During the grinding process the flatness of sample surface is maintained before proceed to the polishing process [9].

Sample preparation process proceeds by polishing. Polishing consist of rotating discs covered with soft cloth impregnated with micro-particles of diamond or other media and lubricant. Polishing functioned to produce a scratch-free mirror-like finish on the sample. Then, the etching process was performed to the sample. Etching basically functioned to remove final thin layer of material deformation. Besides, etching also crucial to attack particular sites on the sample surface with the “highest energy” that led to various features to be able distinguish in reflected light microscopy. 2% Nital has been used as an etchant for this heat exchanger tubes sample etching.

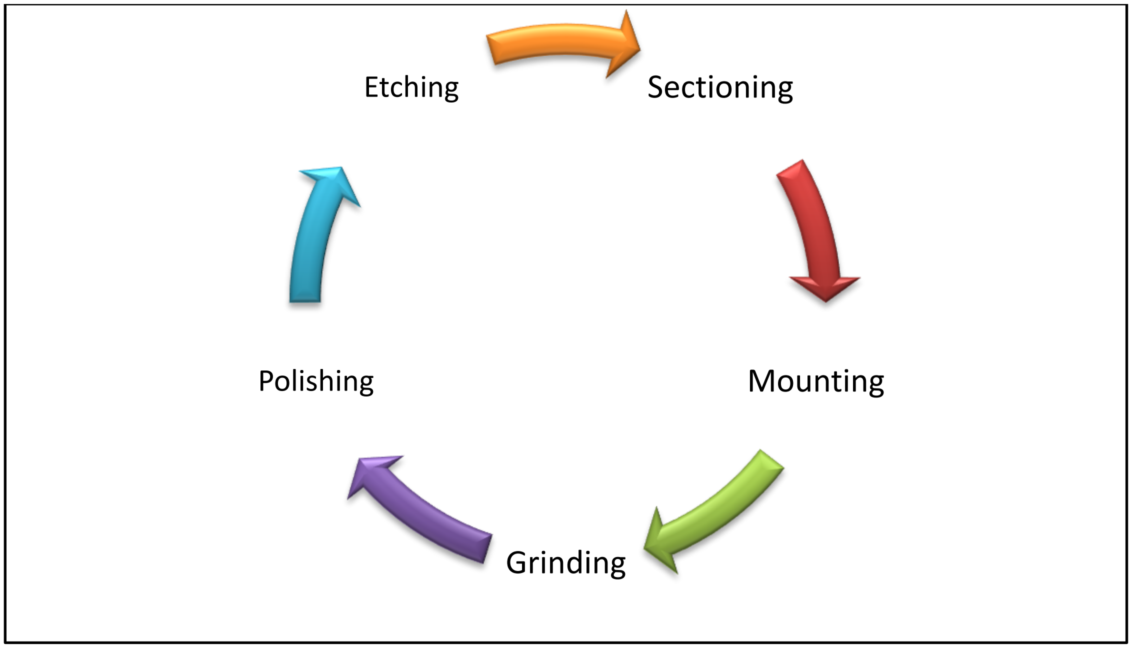

Figure 3.2: Metallographic sample preparation cycle [9]

Figure 3.3: Metallographic sample preparation (failed and normal sample)

3.3 Tools, Equipment, Hardware and Software

3.3.1 Tools and Equipment

The tools and equipment which are required in this failure analysis project such as scanning electron microscope (LEO 1430 VP), optical microscope (LEICA Microsystems 251794), abrasive cutter (BUEHLER 102145-400), mounting machine (BUEHLER 20-1415), grinding machine (BUEHLER 95-2829), polishing machine (IMPTECT 302 DVT),Micro Hardness Tester (LECO LM247), camera, stationeries and hand tools such as knife, sand paper, wrench and etcetera.

3.3.2 Hardware and Software

Hardware and software required in this project for example Microsoft Office Word for documentation or report writing and Microsoft Power Point for visualizing technical oral presentation.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Data Gathering and Analysis

Based on the standards and codes specific carbon steel ASME/ASTM material specifications, SA-179 carbon steel types represent the specification material for seamless cold-drawn low-carbon steel. Table 4.1 and 4.2 shows chemical composition and mechanical properties of carbon steel SA-179.

4.11 Material Chemical Composition.

Table 4.1: Chemical composition for SA – 179 [10]

Composition / Material	Carbon (C)	Manganese (Mn)	Phosphorus (P)	Sulfur (S)
SA – 179	0.06 – 0.18	0.27 – 0.63	0.035	0.035

4.12 Material Mechanical Properties

Table 4.2: Mechanical properties for SA – 179 [10]

Properties / Material	Tensile Strength (MPa)	Yield Strength (MPa)	Min Elongation (2 in./ 50mm), %
SA – 179	325	180	35

4.2 Preliminary examination

4.21 Visual examination of general physical feature of heat exchanger tube sample:

- Outer diameter shows thin loose corrosion product with reddish and brownish in color as shown in Figure 4.1
- Inner diameter shows black dark in color, clean surface with no deposit/scale
- Narrow longitudinal split, 25 mm length and 3.1 mm widest opening of the burst area

4.22 Diameter measurement of heat exchanger tube sample

Table 4.3: Diameter measurement of heat exchanger tube sample

Location	Diameter (mm)	
	Outer	Inner
A (away from burst area)	25.4	21.4
B (near burst area)	26.5	23.6
C (burst area)	31.5	27.5

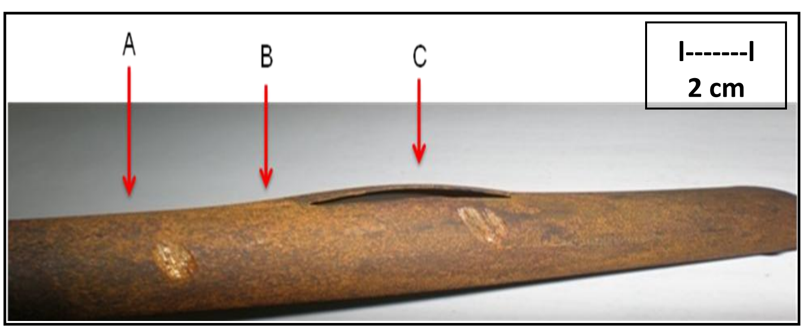

Figure 4.1: Heat exchanger tube for sample measurement

4.23 Thickness measurement of heat exchanger tube sample

Table 4.4: Thickness measurement of heat exchanger tube sample

Location	Thickness (mm)
A(away from burst area)	2.10
B (near burst area)	1.65
C (burst area)	1.10

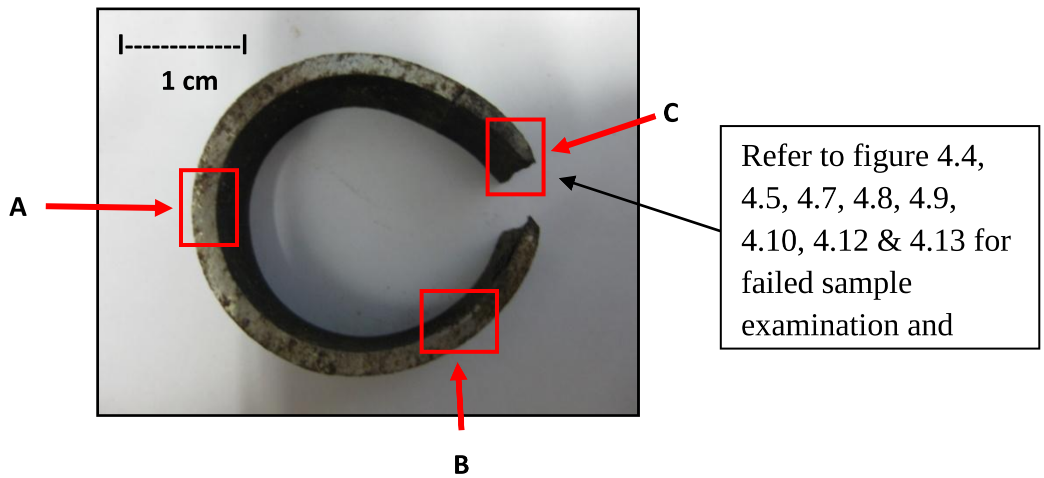

Figure 4.2: Cross section of the burst tube

Based on the diameter measurement on the heat exchanger tube sample that has been measured, there is a huge increment number of diameter measurement at the burst area compare to the normal one as shown in Table 4.3 and Figure 4.1. These phenomena happened due to the bulging effect take place before the heat exchanger tube burst thus the diameter measurement increase rapidly. Besides that, the thickness measurement of the tube wall at the burst area reduces rapidly as shown in Table 4.4 and Figure 4.2. Here, the thinning effect occurred at the tube wall as well as the diameter tube increased. This bulging and thinning process run simultaneously until exceed certain allowable load and force that cannot be sustained by tube wall before this heat exchanger tube burst. These processes affect size and shape of the tube wall grain boundaries.

4.3 Mechanical Testing

4.3.1 Hardness Testing

Hardness testing by Vickers method with 300 gram force has been performed to both samples at five different locations. From the test data, the average hardness reading for the failed samples seems higher compared to the normal ones as shown in Table 4.5. These phenomenons occurred mainly due to the plastic deformation that has been established during the bulging tubes process together with deformation of grain throughout the recrystallization process.

Table 4.5: Hardness testing (Vickers method)

No	Failed area (HV)	Normal/Away area (HV)
1	207.80	160.40
2	203.20	171.70
3	215.40	131.00
4	219.70	180.00
5	228.00	178.20
Average	214.82	164.26

4.4 Examination and Analysis of Metallographic Specimens

4.4.1 Optical Microscope (OM) Examination and Analysis

There are huge different comparisons of microstructure in between 2 samples, normal ones and failed area after being examined by optical microscope (OM). With referring to Figure 4.3, the normal sample seems to have a consistent in grain boundaries sizes and shape compared to the failed sample. The pearlite seems to agglomerate and precipitated along grain boundaries for both samples. The failed sample was observed to elongate and formed closer to grain boundaries but different in size and shape as shown in Figure 4.4 & 4.5. The elongations of grains form the long horizontal grain with a thin size. This point is a weak point due to loss of grain boundaries bonding strength. The indication of the heat exchanger tube microstructure plastic deformation has been observed.

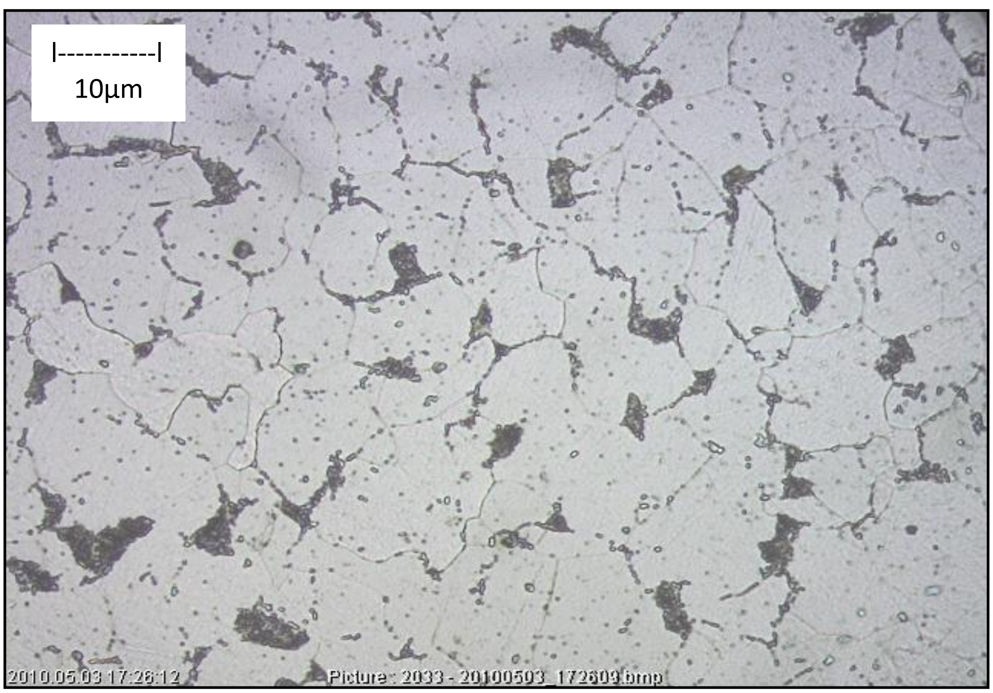

Figure 4.3: Away (normal) area by optical microscope with 50X magnification

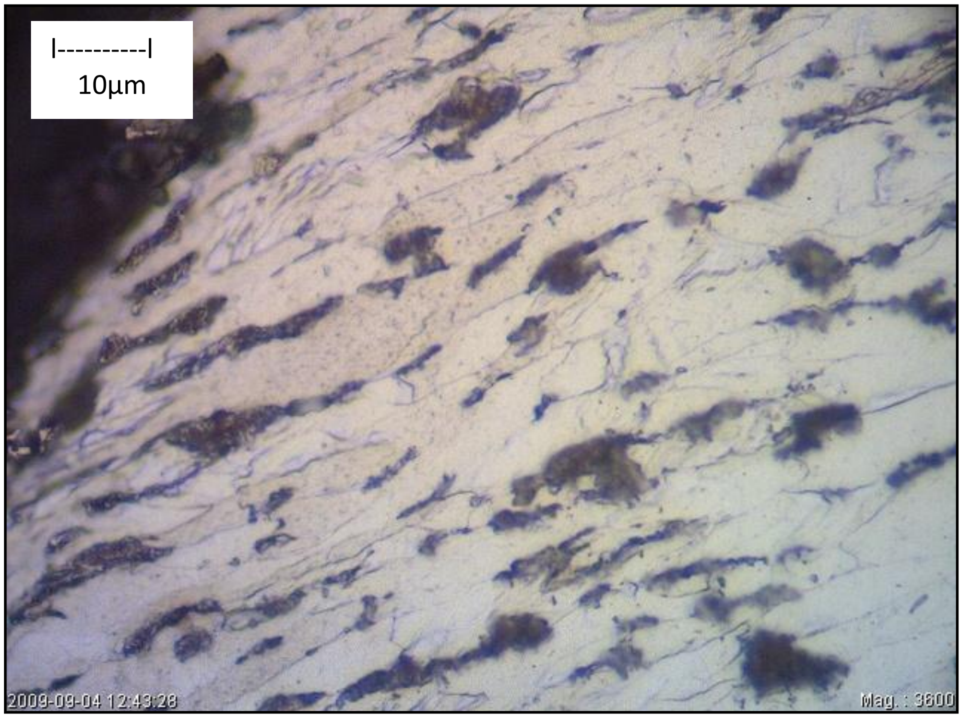

Figure 4.4: Elongated deform grain (failed area) by optical microscope with 50X magnification

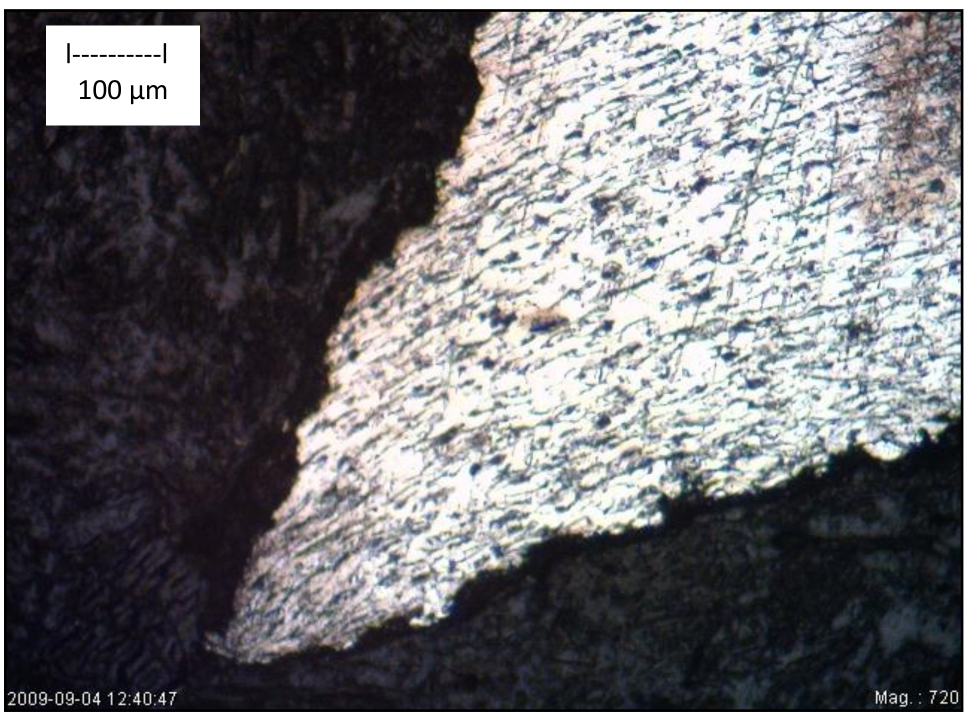

Figure 4.5: Elongated deform grain (failed area) by optical microscope with 10X magnification

4.4.2 Scanning Electron Microscope (SEM) Examination and Analysis

Metallographic sample examination has been performed by scanning electron microscope (SEM). The normal area observed to have consistent shape and size of grain boundaries as shown in Figure 4.6. There is no indication of affected grain. Pearlite seems to agglomerate and precipitate along the grain boundaries for both normal and failed sample. For the failed area, the grains observed to elongate and form the long horizontal shape in a thin size together with the occurrence of plastic deformation indicate by Figure 4.7. The grain observed to move towards and become closer to each other. Recrystallization of the grain / microstructure has been pragmatic. Besides, the micro voids and cavities formation along the grain boundaries has been observed as express in Figure 4.8 & 4.9. These micro voids and cavities formation revealed the indication of creep failure. Nucleation and growth of cavities to coalescence increase the rate of creep failure.

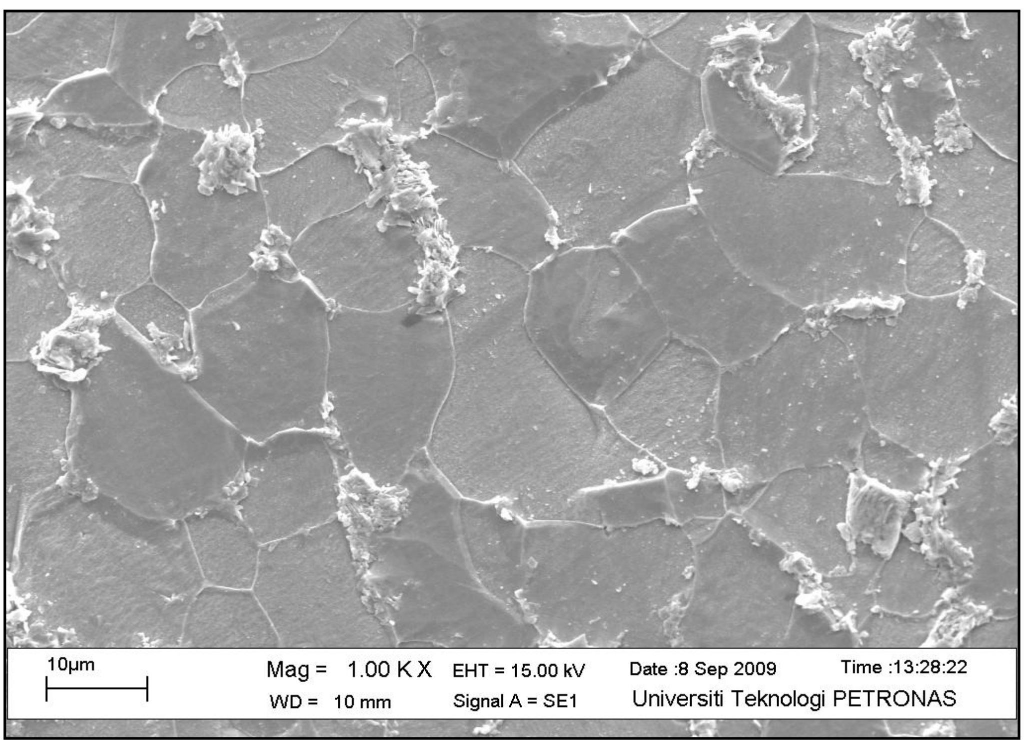

Figure 4.6: Away (normal) area by SEM with 1000X magnification

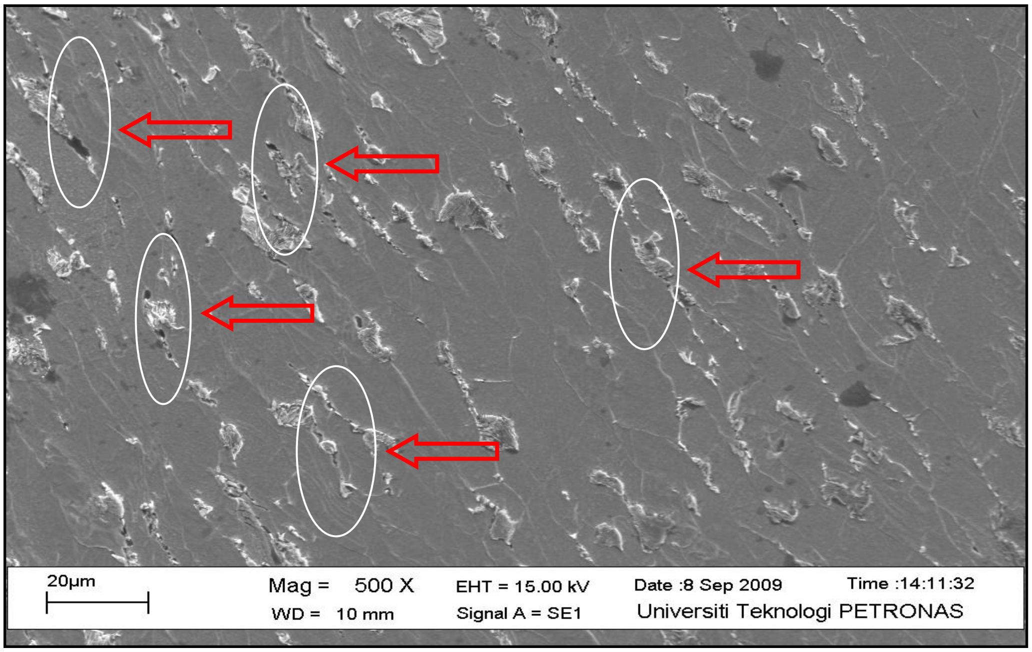

Figure 4.7: Micrograph showing elongated deformed grain and formation of micro voids (failed area) with 500X magnification

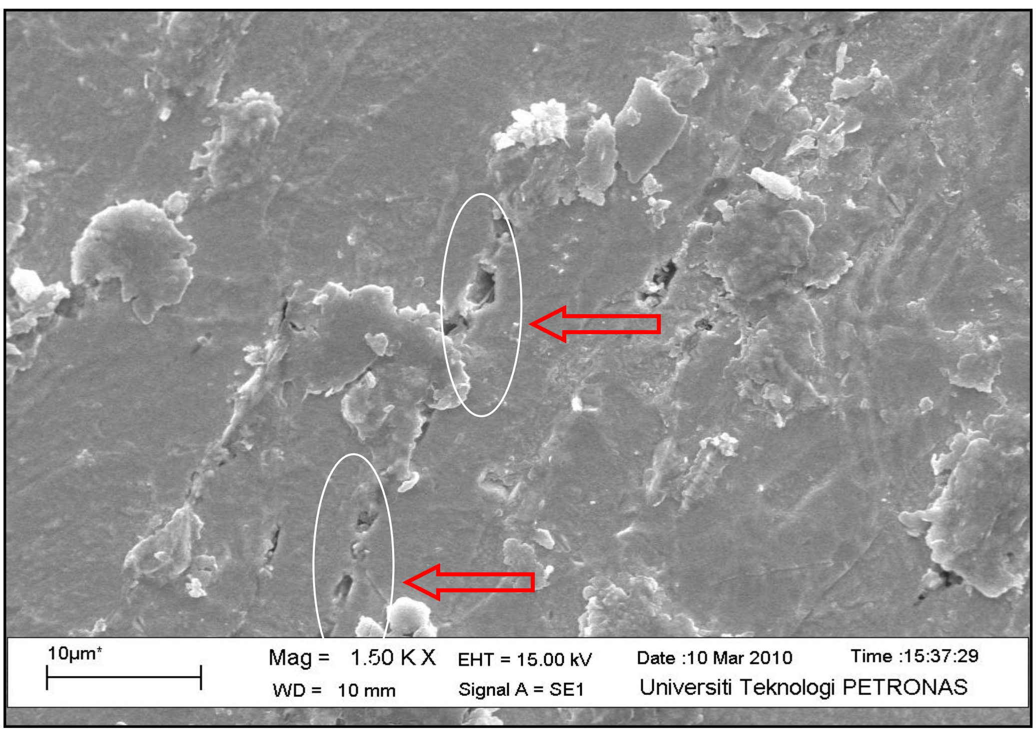

Figure 4.8: Micrograph showing elongated deformed grain and formation of micro voids (failed area) with 1500X magnification

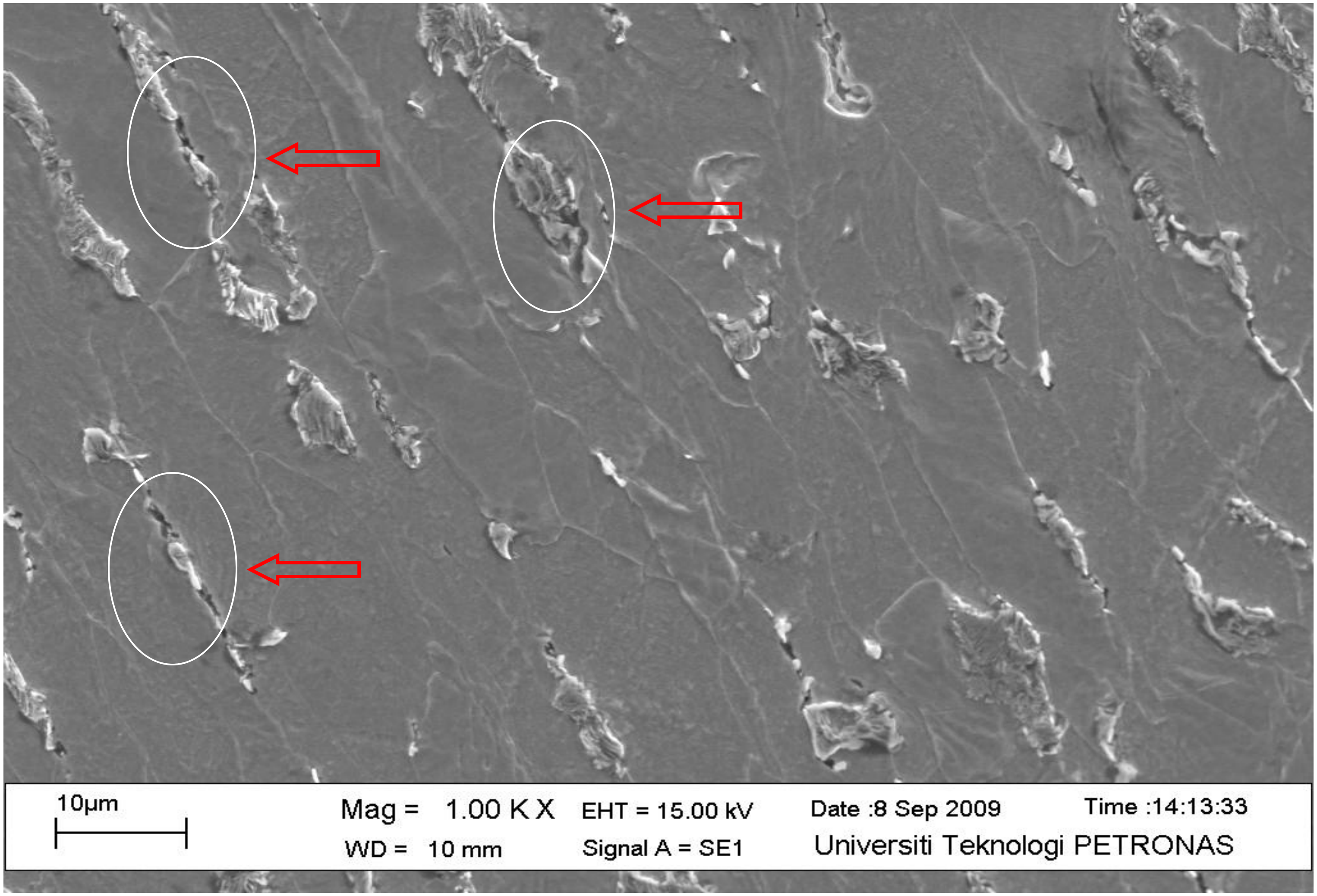

Figure 4.9: Close-up view of elongated deformed grain and micro voids formation (failed area)

4.5 Examination and Analysis of Fractographic Specimens

For the fractographic analysis, the failed area observed to have ductile fracture modes. This analysis was supported by the appearance of the dimple, cavities and micro pores at the fracture surface together with mode of ductile fracture. Micro voids or dimples elongated in direction of loading and cross section is reduced by necking. Besides, failure area with higher magnification of scanning electron microscope divulges the intergranullar crack criterion. This phenomenon occurs due to coalescence and lining of cavities and voids to form intergranullar cracks as shown in Figure 4.10 below.

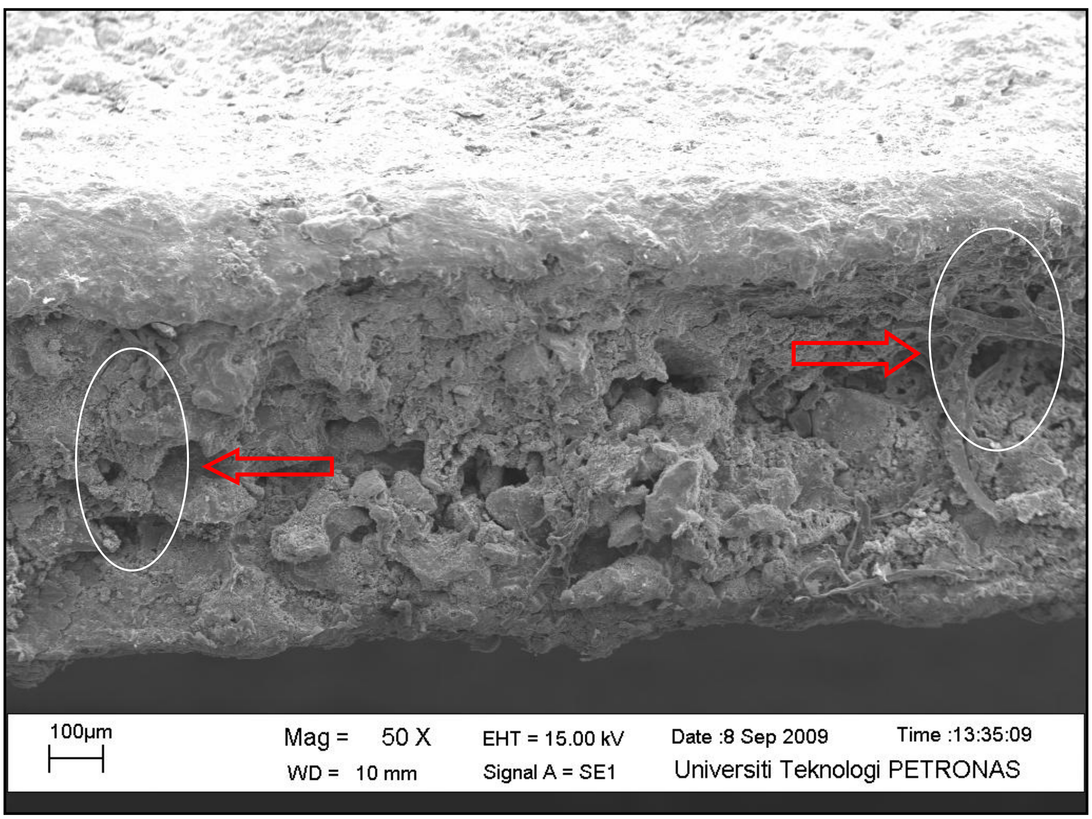

Figure 4.10: Fractographic of fracture surface by SEM showing the intergranullar crack, dimples and micro pores

4.6 Creep Formation

Creep results in slow plastic deformation and ultimate coalescence of micro cavities in metal during overheating revealed evidences of creep damage and rupture as indicated by lining of creep cavities to form intergranullar cracks. In polycrystalline metal subject to creep at elevated temperatures, the nucleation and growth of cavities to coalescence also play a major role in the failure process. With referring to Figure 4.11, rounded voids are formed by the coalescence of vacancies at grain boundaries in diffusion creep that increase with time constraint. Figure 4.12 shows tertiary creep is associated with the formation of cavities and voids along the grain boundaries. Micro cracks are formed as the voids and cavities coalescence become connected and propagate along grain boundaries leading to intergranular fracture as demonstrated by Figure 4.13.

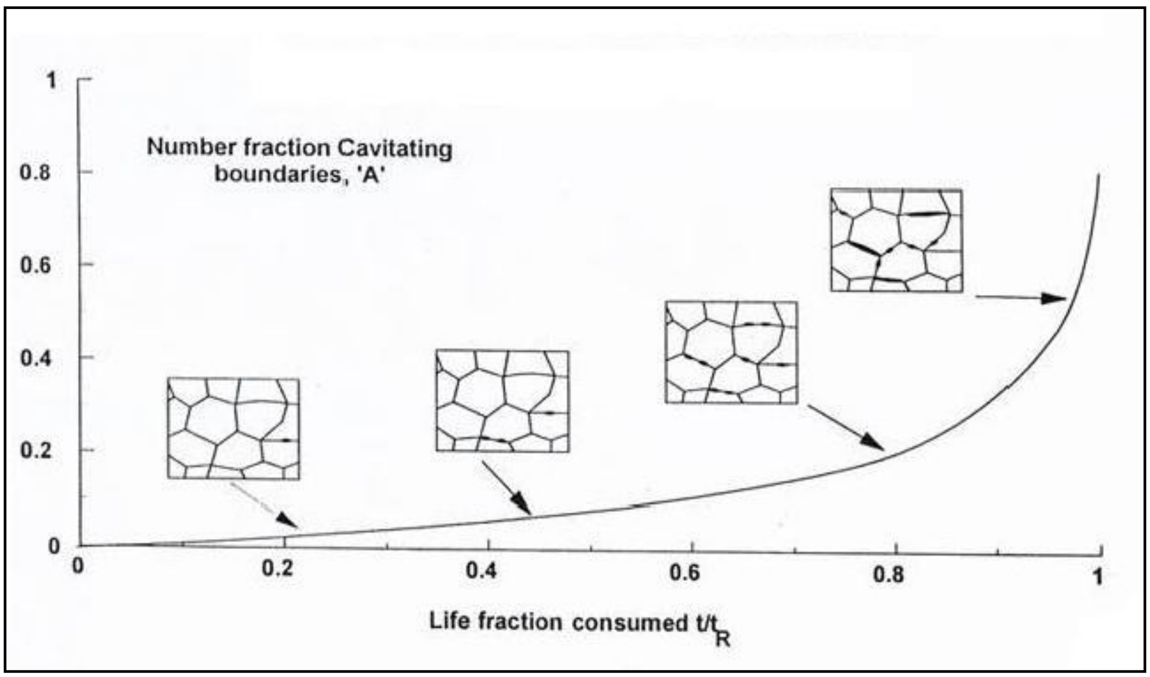

Figure 4.11: Creep damage assessment with cavities versus life fraction [11]

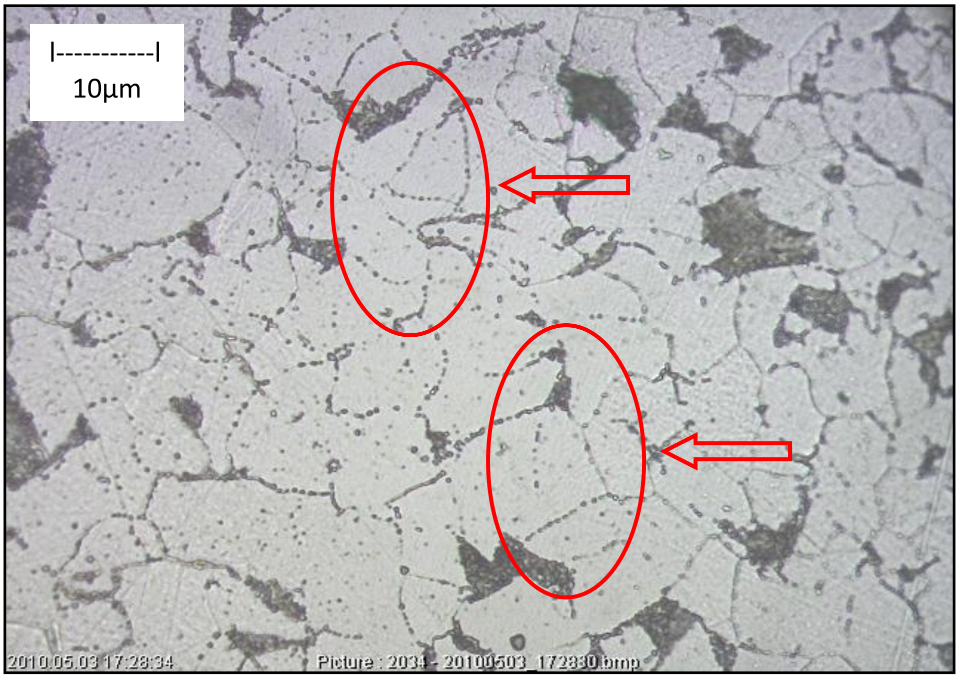

Figure 4.12: Tertiary creep stages with a formation of voids and cavities

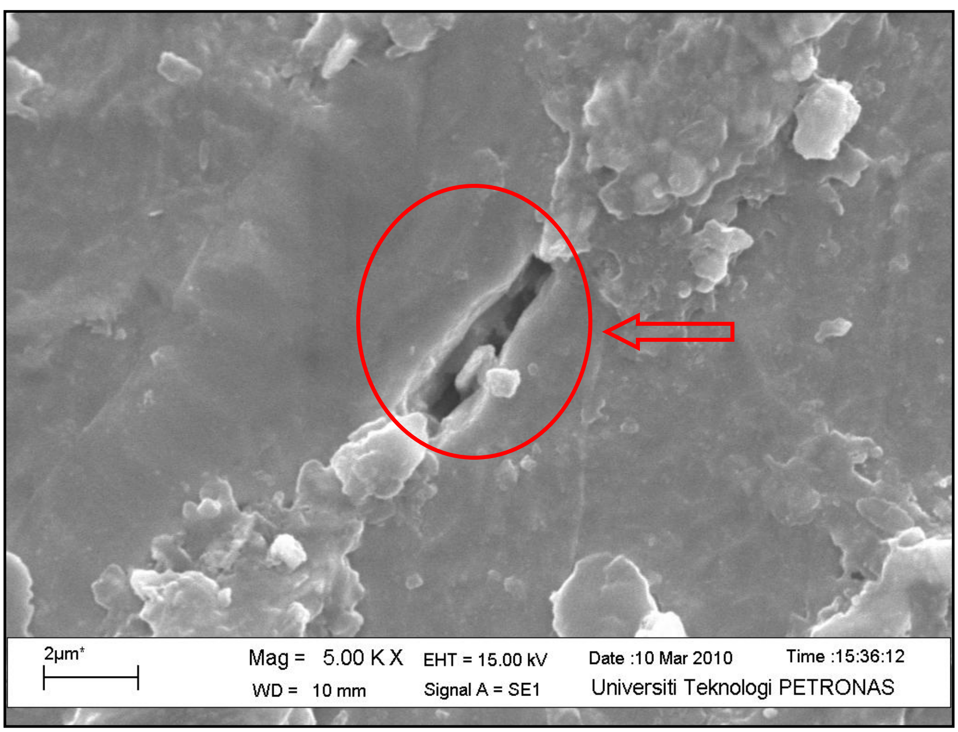

Figure 4.13: Void and cavities lining and connected to form intergranullar crack

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Preliminary examination revealed the indication of heat exchanger tube wall bulging and thinning effect. This analysis supported by the increment diameter and reducing thickness measurement of the burst tube that simultaneously establishes plastic deformation to the tubes microstructure. The metallographic analysis by scanning electron microscope and optical microscope exposed the elongation of deformed grain at the failed area. The elongation of the grain affected the grain boundaries form long horizontal shape in a thin size and move towards to each other simultaneously with plastic deformation process. Creep failure has been observed at the bulging and burst tubes supported by formation of micro voids along grain boundaries. As the voids and cavities coalescence become connected and propagates along grain boundaries leading to intergranular crack fracture. Micro void formation highly suggested occurring due to localized overheating of the heat exchanger tubes itself that increase the rate of creep failure. Based on failure analysis that being performed, creep has been identified as a root cause of the bulging and burst heat exchanger tubes. Pressure, temperature, time and constant load of heat exchanger operating parameter are the underlying factors that led to the heat exchanger tubes bulging and burst. This failure analysis project is relevant to the project objectives which are to perform failure analysis on bulging and burst heat exchanger tubes as well as identify possible root cause of the incident and recommend future failure prevention. In conclusion this failure analysis project will beneficial to both parties: future failure prevention in industry and university learning purpose especially in enhancing the development of country and nation world wide.

5.2 Recommendations

5.21 Double Block Blinding

In correlation during the bulging and burst heat exchanger tubes incident, the automatic isolation valves of inlet steam into the tubes side is confirmed to leak by operation department. The leakage of this isolation valves led steam flowing into the tubes of heat exchanger during the shut down period. For future work expansion, it is highly suggested to execute double block blinding to the inlet and outlet heat exchanger piping system without totally rely on the automatic isolation valves. Blinding functioned as a double protection to the isolation valve and plays a vital role for safety purpose either to equipment or operation for future failure prevention.

5.22 Local Pressure and Temperature Indicator Installation

The indicator of local pressure and temperature either on inlet or outlet tubes and shell of heat exchanger is not acquired by original equipment manufacturer specification. This circumstance creates an obstacle in close scrutinizing the operating parameters of the heat exchanger operation. To overcome this situation, it is highly recommended to execute installation of local thermocouple on heat exchanger tubes and shell inlet or outlet lines. This action crucial in proper monitoring the exposure of thermal and pressure to heat exchanger operating parameter within the range of specifications. The thermocouples will directly connect to the distributed control system at control room that automatically warns a signal when the operating parameter exceeds certain elevated value specifications.

5.23 Non Destructive Examination

Creep failure is slow, continuous and permanent deformation that directly proportional to a specified time constraint. For future work expansion, non destructive examination through the replica stripping technique is highly suggested for execution to the heat exchanger tubes during online operation. Microstructure condition of online heat exchanger tubes can be thoroughly studied and scrutinized. Through this technique, an expert can estimate stages of creep and life time service on the tube without causing any defect to the tubes. Hence, operational people still have a sufficient period of time for preparing and maintaining purpose before catastrophic failure occurred that led to huge opportunity lost to the plant.

5.24 Commissioning of Safety Relief Valve

Safety relief valve functioned to protect equipment by releasing overpressure process gas or fluid until reduce the excess pressure in a safe manner. For future work expansion, it is highly recommended to execute commissioning of pressure relieve and internal relieve valve to the inlet heat exchanger steam tubes lines. Consequently, certified volume of steam will be released when a predetermined maximum pressure is reached, thereby reducing the excess pressure in a safe manner and prevent catastrophic failure to the heat exchanger tubes. Pressure safety valve basically is a valve which automatically discharges a certified amount of fluid to prevent a predetermined safe pressure being exceeded and designed to re – close and prevent the further flow of fluid after normal pressure condition of service have been restored.

5.25 Quality of Sample Preparation

Metallographic and fractographic sample preparation must be executed in orderly manners to obtain clear and convincing results. A properly prepared metallographic sample can be aesthetically pleasing as well as scientifically informative. For future work expansion, ensure the flatness of sample surface is maintained throughout the grinding steps and ensures the scratches from the current step are in a single orientation. Flatness and scratches play a vital role in producing high quality of microstructure image either by optical microscope or scanning electron microscope. Color etching on a sample is highly recommended in order to attain high quality definition of image and differentiate the element of microstructure efficiently. For the sample storage, it is highly suggested to use desiccators and vacuum desiccators to ensure specimen protected from atmospheric corrosion.

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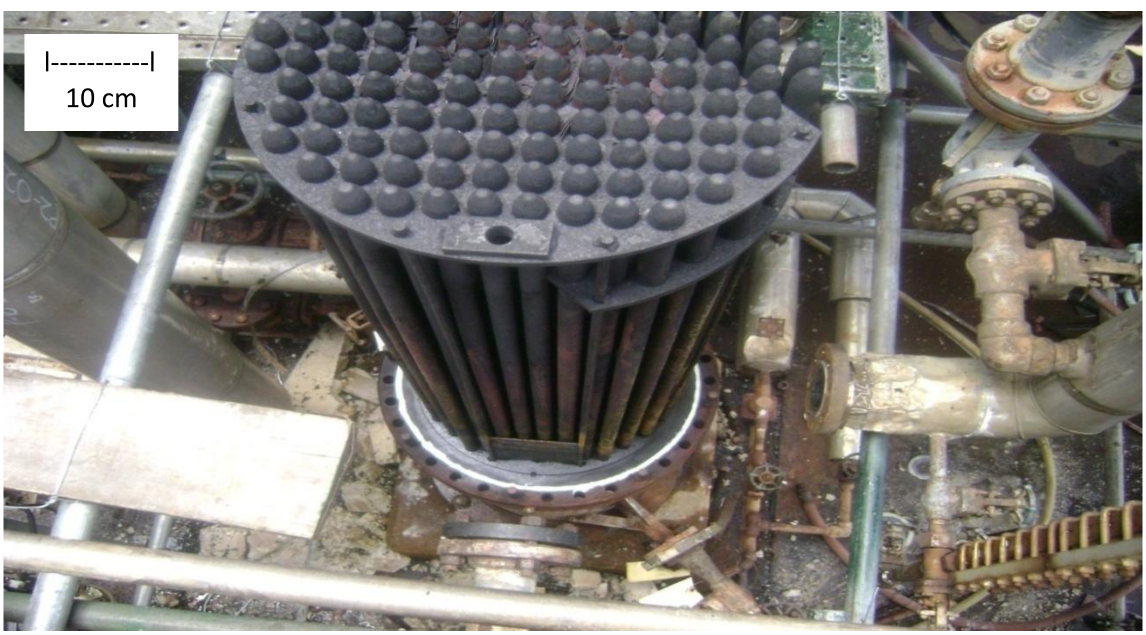
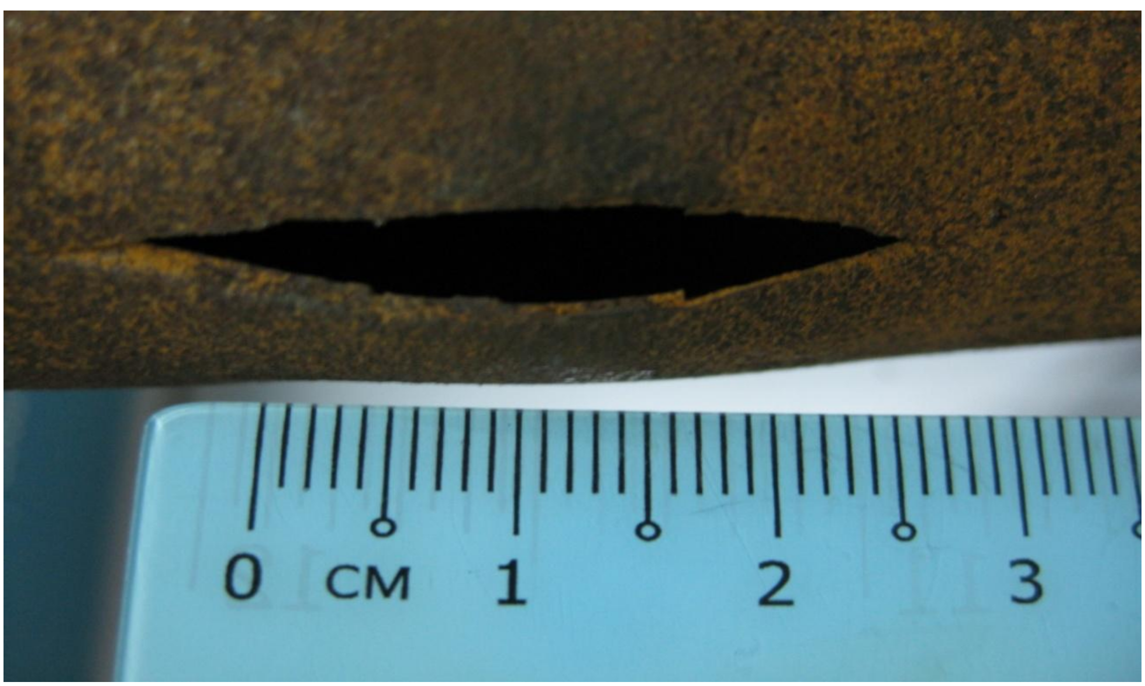
APPENDICES

Appendix 1: Bulging and burst tube

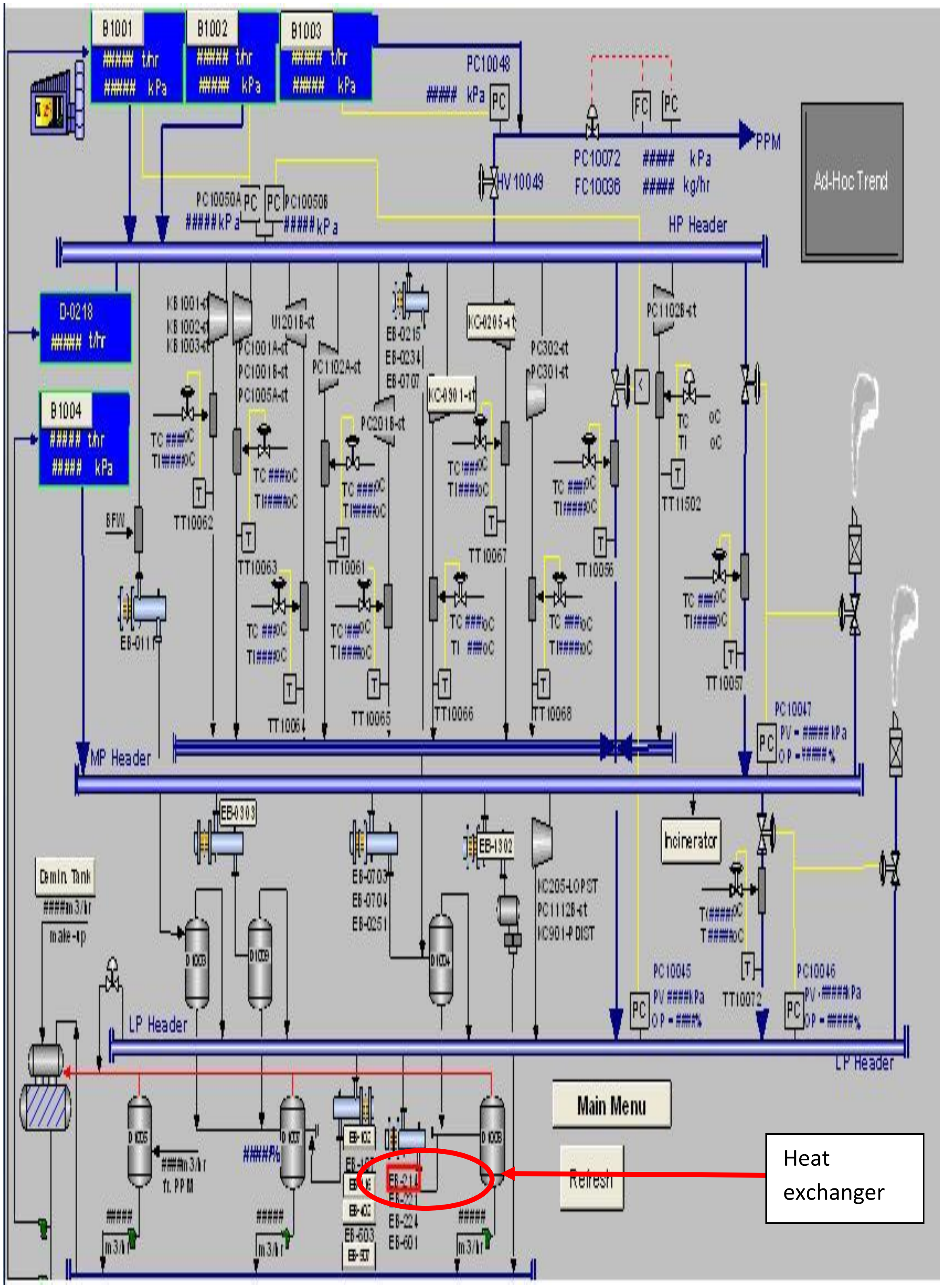


Appendix 2: Heat exchanger tube arrangement at the skid position

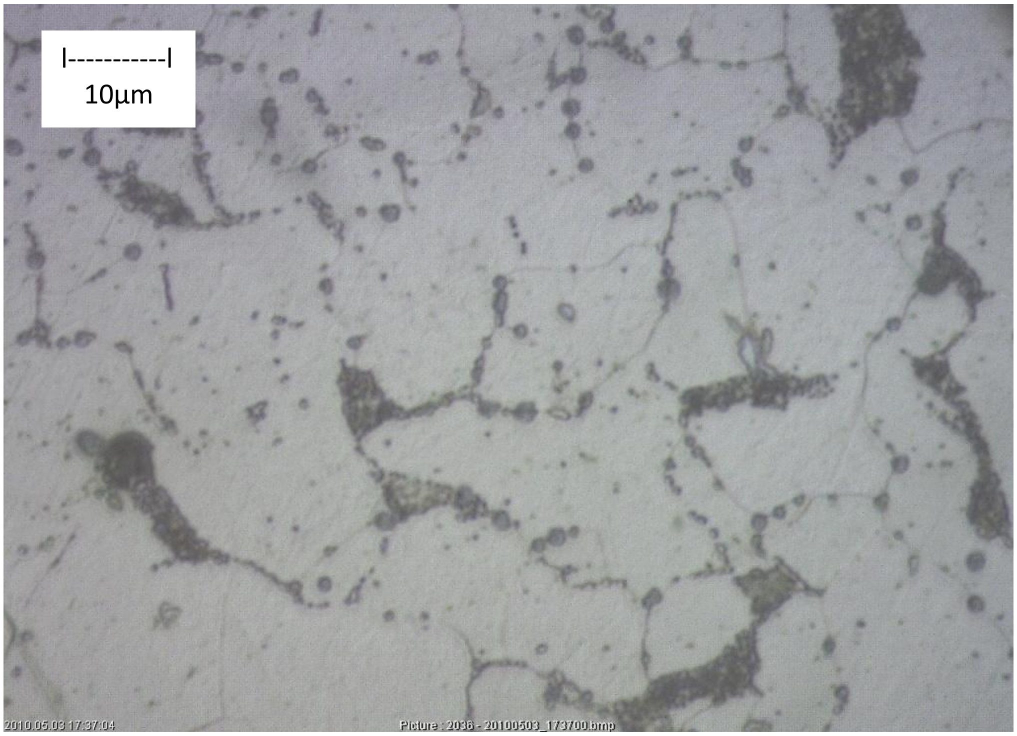
Appendix 3: Heat exchanger tube failure position



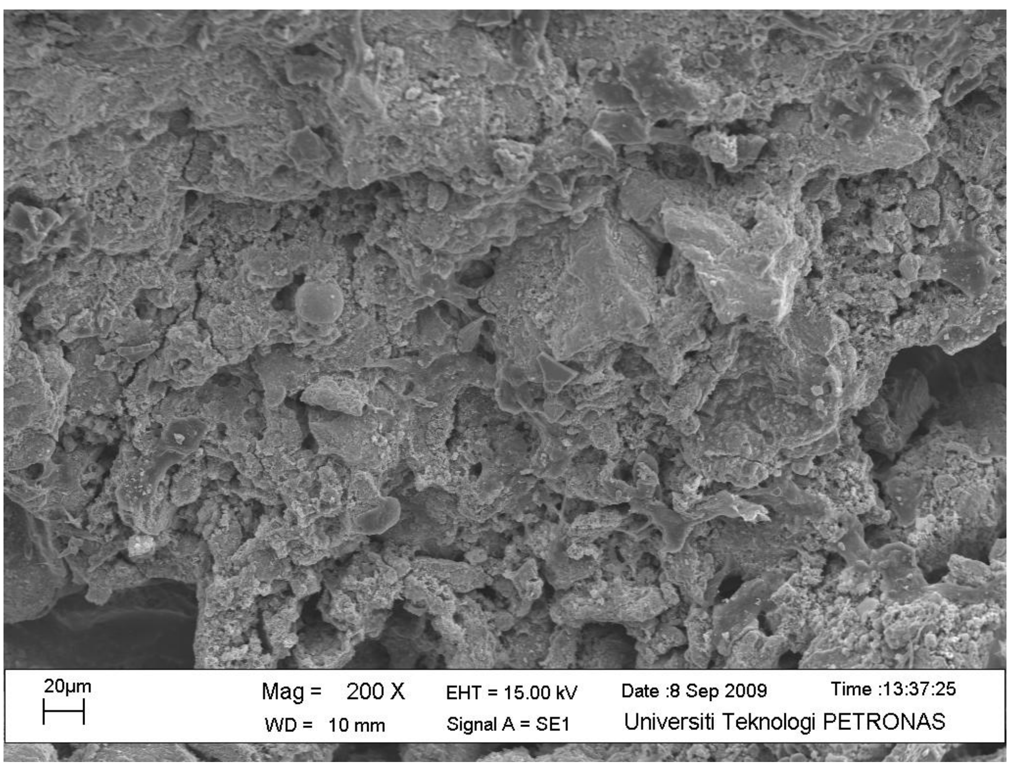
Appendix 4: Close up view of the burst heat exchanger tube



Appendix 5: Steam distribution from boiler to the heat exchanger



Appendix 6: Cavities and micro voids formation along grain boundaries



Appendix 7: Fracture surface on failed area

APPENDIX 8: GANTT CHART FOR FYP 1

No	Progress	1	2	3	4	5	6	7	8	
1	FYP project selection • Failure analysis of heat exchanger tube									
2	Preliminary Research Work • Background data collection • Sample material selection • Literature review on failure analysis									
3	Preliminary report submission				▲					
4	Preliminary examination • Tube sample diameter and thickness measurement, visual inspection on sample condition • Root cause analysis									
5	Progress report submission								▲	
6	Seminar								▲	
7	Laboratory work • Metallographic specimen preparation (normal & failed) • Sectioning, mounting, grinding, polishing, etching • Microstructure examination and analysis by Optical Microscope									
8	Submission of interim report									

APPENDIX 9: GANTT CHART FOR FYP 11

No	Progress	W								
		1	2	3	4	5	6	7	8	
1	Laboratory work									
	• Microstructure examination and analysis by scanning electron microscope (SEM) • Fracture surface examination and analysis by scanning electron microscope (SEM)									
2	Progress report 1 submission				▲					
3	Micro hardness testing (Vickers method)									
	• Compare failed and normal sample • Revealed plastic deformation									
4	Progress report 2 submission								▲	
5	Seminar								▲	
6	Poster exhibition									
7	Submission of Dissertation Report (final draft)									
8	Oral Presentation									
9	Submission of Dissertation Report (Hard bound)									

▲ Suggested Key Milestone

Work Progress/Process