Failure Analysis on the Wire Rope for Lifting Equipment

by

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
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Approved by,

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(AP Dr Patthi Bin Hussain)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

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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.

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SUHAIMI BIN SHAZALI

ABSTRACT

The failure analysis o the wire rope for the lifting equipment is the project based on the real life case study. The lifting equipment is the pedestal crane that widely used at the offshore facilities. This report contains the detail explanation on the project. The objective of this project are to find the factors that lead to the failure and to find the best practice on handling wire rope for safety and to reduce the downtime of the pedestal crane due to wire rope failure. The methodology conducted to complete the analysis divided into four main sections which are research, sample preparation, experiments and testing and final analysis and conclusion. The failure analysis conducted is based on the failure analysis procedure that involved non destructive testing, mechanical testing, macroscopic and microscopic examination, metallography, and energy dispersive x-ray. The results from the experiments and testing indicated that corrosion on the internal part of wire rope reduce the wire rope strength by 53.81%, the wire rope experienced ductile fracture, the damage of the wire rope start with the wear and corrosion of the zinc coating before finally failed. As a conclusion, the failed of the wire rope occurred due to the corrosion that reduces the strength of the wire rope.

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The first gratitude goes to the most humble and supportive supervisor, Assoc. Prof Dr. Pathi Hussain. His continuous guidance and coaching helps the author to complete the project. The gratitude also goes to the Final Year Project Coordinator, Prof Dr. Vijay R Raghavan and Assoc. Prof. Dr Puteri Sri Melor Bte Megat Yussoff for giving continuous reminder and information on the final year project course.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

At offshore facilities, pedestal crane is the main lifting equipment. Pedestal crane has two three main wire ropes. The wire ropes are pendant line, main hoist wire rope and auxiliary hoist. For the pendant line it used as a static rope to hold the boom. Main hoist wire rope is used for lifting much heavier load compare to the auxiliary hoist. Both of the main hoist wire rope and auxiliary hoist are dynamic. These wire ropes are moving during the lifting process.

Figure 1.1: Pedestal Crane at offshore platform.

Figure 1.1 shows the pedestal crane on the offshore platform. The failure analysis on wire rope was focused on one of the incident that happened at one platform in Peninsular Malaysia block. The failure occurred on the main hoist wire rope.

Wire ropes should be grease or lubricate properly for longer life time and to protect it from corrosion. There were several types of lubrication process practices such as:

1. Pouring of lubricant onto rope as it passes over a sheave and Wipe off excess.
2. Swab the rope when not in motion with lubricant soaked rags.
3. Brush or spray with lubricant.
4. Pressure lubrication.

Since wire rope is combination of several strands there is a possibility for the grease did not penetrate to core of the wire rope. This could cause a corrosion to favor occur at the internal part of the wire rope. Once the corrosion starts it reduces the strength of the wire rope. At some point, when load applied to the wire rope, the wire rope will snap instantly at the weak point. Apart of internal corrosion, environmental effect also can be one of the reasons for the wire rope to fail. At some of the offshore facilities, pedestal crane parked near fan exhaust that can heat treated the wire rope and dry up the grease.

Wire rope is stored on drum after lifting process. Wire rope rotated around the drum and boom is parked on the parking position at the offshore facilities. During the process of storing the wire rope on the drum, the wire rope can be damaged if the arrangement of the wire rope is not proper. The damages on the wire rope known as kink or swell. These types of damage also reduce the life time of the wire rope and may lead to the unwanted incident. Normally crane operator will check the arrangement of the wire rope before lifting and after lifting process. If any of the arrangement is not right the wire rope is unrolled and rolls back into the proper arrangement. The figure of the drum can be observed in Figure 1.2, refer to table 1.1 for the name of each component on the crane.

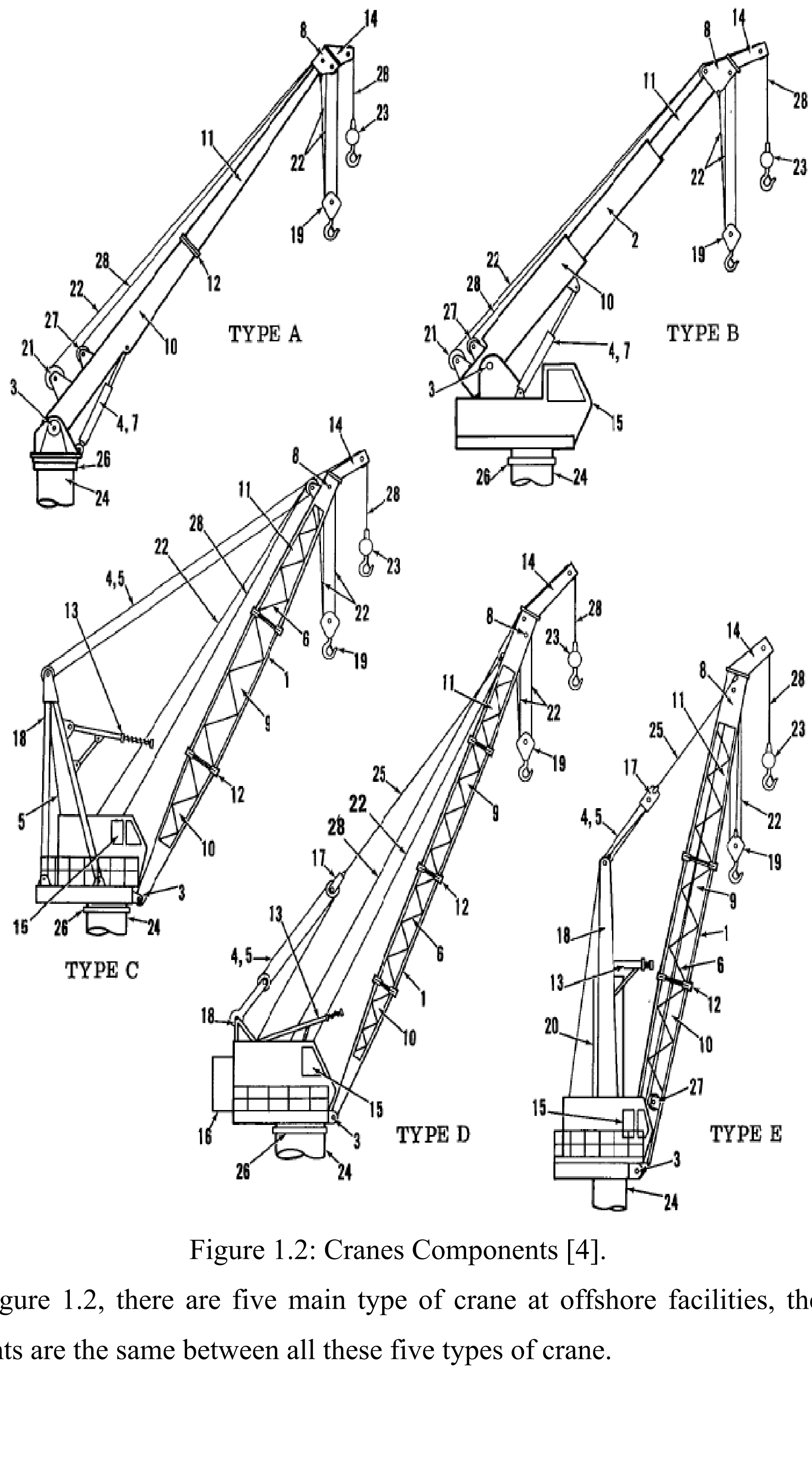


Figure 1.2: Cranes Components [4].

As per Figure 1.2, there are five main type of crane at offshore facilities, the mainly components are the same between all these five types of crane.

Table 1.1: Cranes components [4].

No.	Component	Type, See Figure 1. 2				
		A	B	C	D	E
1	Boom Chord	-	-	X	X	X
2	Boom Extension	-	X	-	-	-
3	Boom Foot Pin	X	X	X	X	X
4	Boom Hoist Mechanism	X	X	X	X	X
5	Boom Hoist Wire Rope or Boom Line	-	-	X	X	X
6	Boom Lacing	-	-	X	X	X
7	Boom Lift Cylinder	X	X	-	-	-
8	Boom Point Sheave Assembly or Boom Head	X	X	X	X	X
9	Boom Section, Insert	-	-	X	X	X
10	Boom Section, Lower, Base or Butt	X	X	X	X	X
11	Boom Section, Upper, Point or Tip	X	X	X	X	X
12	Boom Splice	X	-	X	X	X
13	Boom Stop	-	-	X	X	X
14	Boom Tip Extension or Jib	X	X	X	X	X
15	Cab	-	X	X	X	X
16	Counterweight	-	-	-	X	-
17	Floating Harness or Bridle	-	-	-	X	X
18	Gantry, Mast or A-Frame	-	-	X	X	X
19	Hook Block	X	X	X	X	X
20	King Post or Center Post	-	-	-	-	X
21	Main Hoist Drum	X	X	-	-	-
22	Main Hoist Rope or Load Line	X	X	X	X	X
23	Overhaul Ball	X	X	X	X	X
24	Pedestal or Base	X	X	X	X	X
25	Pendant Line	-	-	-	X	X
26	Swing Circle Assembly	X	X	X	X	-
27	Whip Line or Auxiliary Hoist Drum	X	X	-	-	X
28	Whip Line or Auxiliary Hoist Rope	X	X	X	X	X

1.2 Problem Statement

The incidents of failed wire rope on the pedestal crane used at offshore facilities are normally occurred. The incident can affect the working condition and also can lead to equipment damage and time loss. Based on the observation on the failed wire rope, there were corrosion occurred at the internal part of the wire rope. The material used to manufactures the wire rope is galvanized carbon steel that claims to have high corrosion resistance. The failure analysis conducted to find the root problem that leads to the failure of the wire rope. The analysis then would help on determining the best practice on handling wire rope to prevent recurrences of the same type of incident.

1.2 Objective Scope of Work

The objectives of the failure analysis on the wire rope for pedestal crane are per below.

- To find the factors that lead to the failure.
- To find the best practice on handling wire rope for safety and to reduce the downtime of the pedestal crane due to wire rope failure.

The failure analysis conducted based on the failure analysis procedure. Few experiments conducted o the specimen to get the required data. The scope of study focused on the material aspect. Experiments such as non destructive testing, tensile test, macroscopic examination, microscopic examination, metallographic, Scanning Electron Microscopy (SEM) and Energy Dispersive Spectrum X-Ray (EDX) conducted to complete the analysis.

CHAPTER 2

LITERATURE REVIEW

2.0 LITERATURE REVIEW

This chapter will be discussed on the information on the wire rope, galvanized carbon steel, corrosion and failure analysis. The information will be useful to complete the project on the failure analysis of the wire rope for lifting equipment.

2.1 Wire Rope

Wire rope is flexible, multi-wired members usually consisting of a core member around the number of multi-wired strands are “laid” or helically wound [4]. Wire used to manufacture wire rope shall be made from:

- Acid or basic open-hearth steel
- Basic oxygen steel
- Electric furnace steel

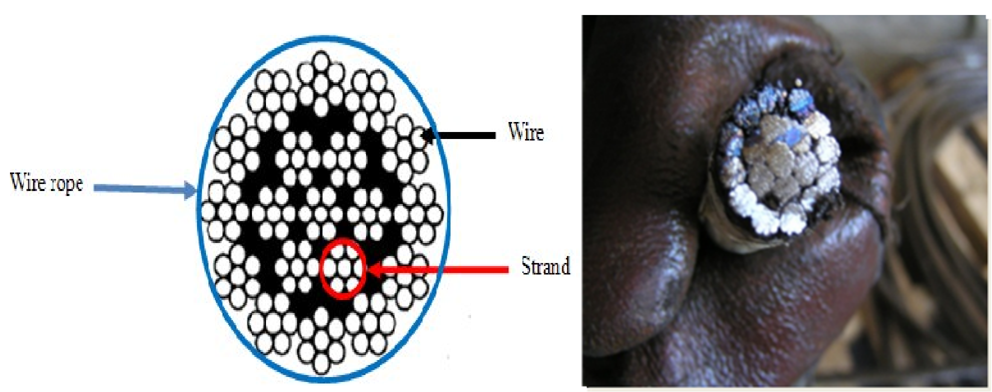


Figure 2.1 Wire rope components for galvanized 19X7

The single wire produce will be tested before used to manufacture wire rope. The tests performed on the wire are tensile and torsional. The wire should pass the requirement before proceed to the manufacturing the wire rope (before fabrication test) and the after fabrication test should be perform on the wire rope.

Selection of the specimen after the fabrication should be done on the manufactured wire rope. The specimen should be selected from unused and undamaged wire rope section of 3.05m for the individual wire test. From each strand there shall be selected and tested curtained wire as follows [4].The total number to be tested shall be equal to the number of wires in any one strand.

- They shall be selected from all strands of the rope.
- The specimens shall be selected from all locations or position so that they would constitute a complete composite strand exactly similar to a regular strand in the rope.
- The specimen for all "like positioned" wire toe selected so as to use as nearly as possible to equal number from each strand.

Note: "like positioned" wires means wires are symmetrically placed in a strand.

Selection of test specimens before fabrication, wire prior to rope fabrication will be adequate to ensure the after fabrication wire rope breaking strength and wire requirements can be met.

2.2 Galvanized Carbon Steel

The failure analysis will be done on the failed wire rope that made from galvanized carbon steel. Galvanized carbon steel is carbon steel coated with layer of zinc. Galvanized or Zinc coated steel offer superior corrosion resistance compared to standard carbon steel without the expense of stainless steel. Carbon steel is steel where the main alloying constituent is carbon. Steel with low carbon content has properties similar to iron. The carbons content in steel effect the properties of the carbon steel. The percentage of carbon determine the properties of the iron, if the percentage of carbon increase in iron, the iron become more hard and strong but less ductile. In general, higher carbon content lowers the melting point and its temperature resistance. Carbon content influences the yield strength of steel because carbon molecules fit into the interstitial crystal lattice sites of the body-centered cubic (BCC) arrangement of the iron molecules [2]. The interstitial carbon reduces the mobility of dislocations, which in turn has a hardening effect on the iron. To get dislocations to move, a high enough stress level must be applied in order for the dislocations to occur. This is because the interstitial carbon atoms cause some of the iron BCC lattice cells to distort [2].

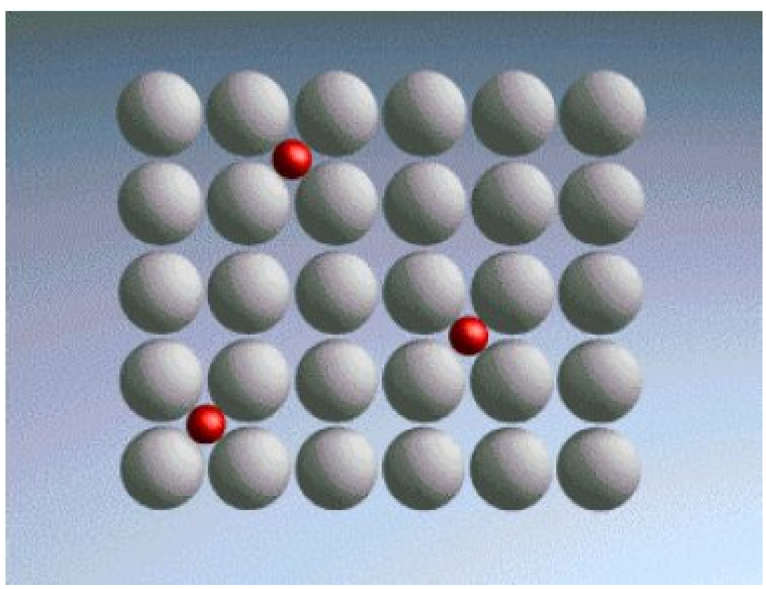


Figure 2.4: Interstitial carbon atom (red) [2].

Among the types of the carbon steel are [2]:

- Mild (low carbon) steel: approximately 0.05–0.15% carbon content for low carbon steel and 0.16-0.29% carbon content for mild steel (e.g. AISI 1018 steel). Mild steel has a relatively low tensile strength, but it is cheap and malleable; surface hardness can be increased through carburizing.
- Medium carbon steel: approximately 0.30–0.59% carbon content (e.g. AISI 1040 steel). Balances ductility and strength and has good wear resistance; used for large parts, forging and automotive components.
- High carbon steel: approximately 0.6–0.99% carbon content. Very strong, used for springs and high-strength wires.
- Ultra-high carbon steel: approximately 1.0–2.0% carbon content. Steels can be tempered to great hardness. Used for special purposes like (non-industrial-purpose) knives, axles or punches. Most steels with more than 1.2% carbon content are made using powder metallurgy and usually fall in the category of high alloy carbon steels.

The wire rope coated with the zinc depends on the diameter itself. The drawn galvanized carbon steel wire rope produced by applied the coating at the intermediate stage of the wire drawing process. The coating process can be either by the [4]:

- Electro-deposition – also known as the electroplating process occurs due to the movement of charged ions in a solution (often water based) under an electric field produces thin layer of metal alloys.
- Hot galvanizing process – process of dipping the wire into the molten zinc.

Table 2.1: weight of zinc coating in drawn galvanized wire rope [4]

(1)	(2)	(3)	(4)
Diameter of Wire		Minimum Weight of Zinc Coating	
in.	mm	oz./ft^2	kg/m^2
0.018 to 0.028	0.46 to 0.71	0.10	0.03
0.029 to 0.060	0.74 to 1.52	0.20	0.06
0.061 to 0.090	1.55 to 2.29	0.30	0.09
0.091 to 0.140	2.31 to 3.56	0.40	0.12

2.3 Corrosion

Corrosion is the degradation of material when its react with the environment. Theoretically every material will corrode. Galvanized carbon steel at the rough environment is much more corrosion resistance compare to the non coated carbon steel. The galvanized carbon steel can withstand corrosion for many years depend on the thickness of the coating. Zinc coatings prevent corrosion of the protected metal by forming a physical barrier and by acting as a sacrificial anode if this barrier is damaged. When exposed to the atmosphere, zinc reacts with oxygen to form zinc oxide, which further reacts with water molecules in the air to form zinc hydroxide. Finally zinc hydroxide reacts with carbon dioxide in the atmosphere to yield a thin, impermeable, tenacious and quite insoluble dull grey layer of zinc carbonate which adheres extremely well to the underlying zinc, so protecting it from further corrosion.

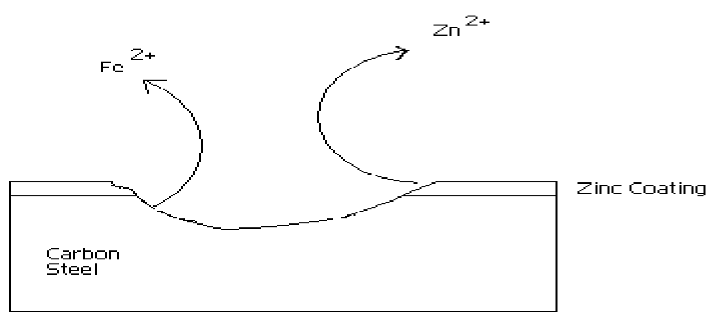


Figure 2.2: Corrosion of carbon steel.

Figure 2.2 indicated that oxidation of iron and zinc releasing electron producing ions iron and zinc. As the coating of zinc finished due to wear or corrosion the carbon steel will start to corrode. Without any protection the metal than will failed. Increasing the amount of the stress will further speed up the process of the material to fail due to uneven stress distribution. Stress tends to concentrate at the place where the corrosion of the material occurs.

2.4 Failure Analysis

Failure analysis is an investigation carried out to determine the causes of failure of a certain product or equivalently the mistake in the continuous process of engineering design-manufacturing-performance in order to prevent recurrence in the future [6]. There are other valuable purposes of failure analysis investigation which are:

- Developing a product that improves in reliability and durability.
- The result of failure analysis also used as the basis for litigation and insurance claims.
- Development of new materials or improvement in existing materials properties.

The failure analysis on the wire rope for lifting equipment covered:

- Background data and sample collection
- Preliminary examination
- Non-destructive testing (NDT)
- Mechanical testing
- Macroscopic examination
- Microscopic examination
- Metallographic
- Final analysis, conclusion and report writing.

Background data and sample collection is the process to collect all pertinent details. The data such as manufacturing details, service history, sequence of events leading to failure, photographic record of the failed component, selection of samples and identification of any abnormal conditions before the failure. Background data and sample collection to find any record that could be the factors that lead to the failure of the wire rope.

Preliminary examination is process to capture the environment of the incident just after the accident take place. The pictures should be taken before cleaning, to solidify the evident the picture taken should be at various angles perspective. Based on the preliminary examination, the hypothesis of the incident will be determined.

Non destructive testing (NDT) is the application of technical method to examine material or component without impairing future usefulness and serviceability in order to detect, locate, measure, interpret and evaluate discontinuities. For the wire rope the suitable NDT would be visual inspection using the vernier caliper.

After the NDT mechanical testing can be applied to the specimens to find the required data. As for the wire rope either torsional or tension test can be performed. The wire rope normally measured or classified by its strength to lift the certain amount of load. Thus the tension test will be suitable for the strength analysis on the wire rope.

For the macroscopic examination and microscopic examination, the fractography should be performed on the fracture surface to determine the types of the failure occur on the specimen and how the product failed. The macroscopic examination should be performed below 100X magnification. The type of failure can be observed either brittle failure or ductile failure.

Ductile facture [7]

- Much plastic formation
- 45 degree angles
- Appear fibrous to eye
- Micro –voids in the microscope
- Cross section area reduced by necking
- Crack grow is slow

Brittle fracture [7]

- Little plastic deformation
- Flat fracture perpendicular to the component surface
- Appears granular to eye and reflective to light
- Cross section is not reduce by necking
- Cracks grow rapidly, often with a loud noise

Under simple tension for the ductile materials fracture occur on plane of maximum shear stress at 45 degree to the cylinder axis. The brittle materials, fracture occurs on a plane normal to the cylinder axis. Under torsion, for the ductile material fracture occurs on a plane shear stress and the fracture surface is perpendicular shear stress to cylinder axis. The brittle materials, fracture path is spiral and inclined at 45 degree to the cylinder axis if the material is brittle.

Beside the overload failure that leads to either brittle or ductile failure as mention above, there other failure mode that typically result in brittle or ductile fracture which are:

- Fatigue: cracks grow due to cyclic loading until the remaining ligament can no longer sustained the load (the remaining ligament fails either in brittle or ductile manner) [7].
- Creep: the plastic deformation due to creep may reduce the cross- section subject to load, resulting in either brittle or ductile fracture [7].
- Corrosion: chemical attack on the particular mirostructural features result in failure [7].

Metallography is the process of preparing a metal surface to reveal microstructure information [7]. The methodology of the metallography is:

1. Sectioning
2. Mounting of the sample
3. Grinding
4. Polishing
5. Etching
6. Microscopy
7. Image recording.

The images obtained from the metallography can reveal the phases present in the microstructure, phase consistent expected from the phase diagram, shape of phase or grain structure and lastly any unusual in the structure like of porosity or defect.

CHAPTER 3

METHODOLOGY

3.0 METHODOLOGY

This chapter discuss on the methods and procedures conducted to complete the failure analysis on the wire rope. The failure analysis was completed based on the four main stages which are research, sample preparation, experimentation and testing and lastly final report and analysis. The project is divided into four sections which are:

1. Research

   The research will include the manufacturing process of the wire rope. The study on the failure analysis, to improve the understanding on the analysis and procedure carried out to make sure that the specimen handling is correct and any evidences are secured. The familiarization on the equipments that should be used for the experiments and analysis also continue at this stage.

2. Sample preparation

   The sample of failed wire rope obtained from the PETRONAS Carigali Sdn. Bhd. (PCSB) Peninsular Malaysia Operation, (PMO). The fresh sample obtained was prepared for the analysis. Pictures was taken on the fresh specimen for the macroscopic analysis. Some of parts of the specimen near the failed area was cut out for the samples preparation for the experiments such as Scanning Electron Microscopic (SEM) and microscopic view on the specimen.

3. Experimentation and testing

   The experiments conducted for the project are:

   - Non-destructive testing (Visual Inspection)
   - Tensile test
   - Macroscopic
   - Microscopic
   - Metallographic
   - Energy Dispersive X-ray (EDX)

4. Final analysis and conclusion

   The final report was the last stage on the study. The result of all experiments/testing compile and the overall conclusion was produce based on the data obtained from experiments and testing.

For the project milestone and process flow refers to the appendix.

3.1 Non Destructive Testing

The suitable approach for the nondestructive testing is visual inspection. Visual inspection conducted to the specimen without destroying the construction of the wire rope.

Based on the API 2D standard the methods of inspections that was done on the wire rope are:

1. Reduction of rope diameter below the nominal diameter due to wear of outside wires, loss of core support or internal or external corrosion. Core failure in rotation-resistant rope may be difficult to observe. Typical methods to check core failure are:
   a. Diameter measurement; diameter is reduced with core deterioration using vernier caliper.
   b. Length of lay measurement; core failure results in an increase in the lay length.
2. The number of broken outside wires and the concentration of the broken wires. Attention should be given to valley breaks where the breaks are at the strand to contact points.
3. Worn outside wires.
4. Corroded or broken wires at the end connections. Corroded, cracked, bent, worn or improperly applied end connections.
5. Kinking, crushing, cutting or unstranding.
6. Improper spooling on hoist drum such as:
   - Strand Crushing
   - Core Protrusion
   - Abrasion
   - Excessive Strand Gaps
   - Loose and Uneven Spooling

7. Heavy wear and/or broken wires occur in rope sections in contact with certain components of the crane. Care shall be exercised in inspecting the rope at these points. Inspection shall include, but not be limited to, the following areas:
   a. Equalizer sheaves or saddles also referred to as fixed guides, or other sheaves.
   b. End connections including socket or end attachments to running ropes, boom pendants and other standing ropes.
   c. Sections of the rope where the rope is continually running over sheaves within the various hoist systems. This inspection is of particular importance where boom angle and load block changes are frequent and limited to short distances.
   d. At crossover and flange points of the rope on the hoist drums.

For this study, all the methods above covered except for number 6 and 7. The correct way of diameter measurement is per Figure 3.1.

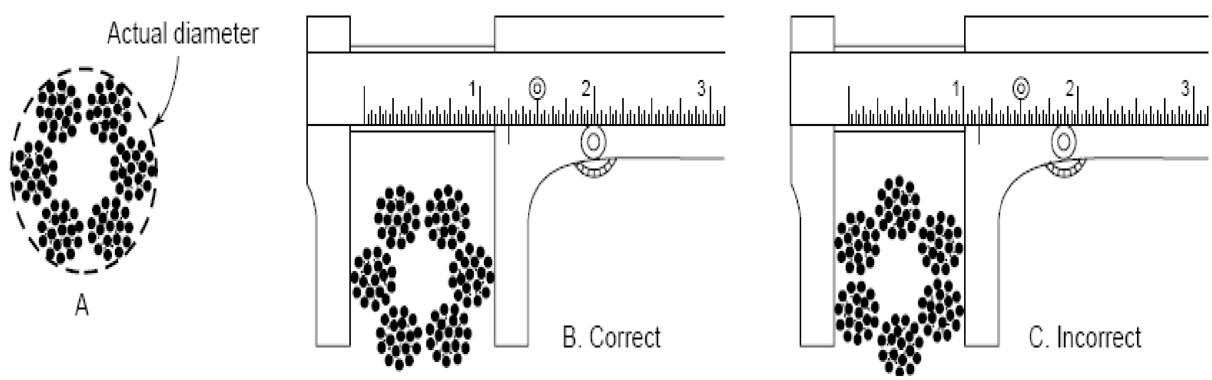


Figure 3.1: Diameter measurement using vernier caliper

3.2 Mechanical Testing

The mechanical testing conducted on the corroded part of the wire rope and good part of the wire rope. The experiment known as the “pull test” and conducted using the pull test bench. The purpose of this experiment is to compare the strength of two different specimens. Theoretically the good wire rope can withstand much greater load compared to the corroded part. The results obtained from this experiment shows and prove that the corrosion on the wire rope will affect the strength of the wire rope. The data also was compared with the properties of 19X7 galvanized carbon steel that indicated in the API 9A. The sample should be prepared in the way the machine can hold the wire rope without slipping. Both ends of the specimens should me gripped with ferrule. The ferrule is as per indicate in Figure 3.4.

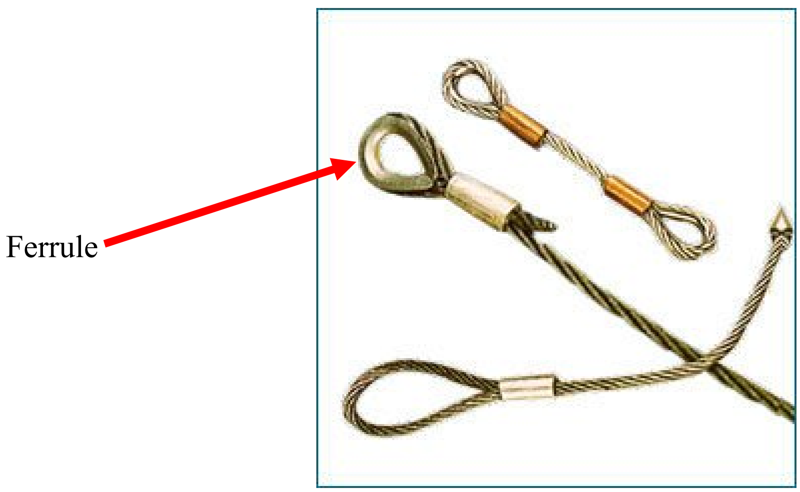


Figure 3.4: Ferrule on the wire rope

The samples prepared for both corroded and normal wire rope, the length of both specimens used for the testing should be 5ft.

3.3 Macroscopic and Microscopic Examination

The preparation of the fracture surface should be done before can be used in the scanning electron microscopic for microscopic and macroscopic examination. The fracture surface secured from the total specimen buy cutting into the appropriate size without damaging the fracture surface. The fracture surface then mounted using the cold mounting process to ensure that the fracture surface in vertical position so the fracture surface can be captured under scanning electron microscopic. SEMs can be operated to capture image at different magnification. For the fractography, the image captured at 50X magnification. SEM emitted a fine, high energy electron beam to the surface causing the emission of electrons from the surface. The emitted electrons produced an electrical signal converted as image in computer screen.

Figure 3.2: Mounted fractography samples

Figure 3.2 indicate the mounted sample of fracture surface of the wire rope used for the SEM. Using scanning electron microscopic (SEM) the image can be obtained using secondary or back scattered electron. For the fracture surface the image obtained by secondary electron. The secondary electron imaged via electrons from upper most layer of material producing topographical type image. Areas on the surface emitting a small amount of electrons, such as a crack hole appear dark. For the area that emit a large amount of electrons such as flat surface or peak will appear bright.

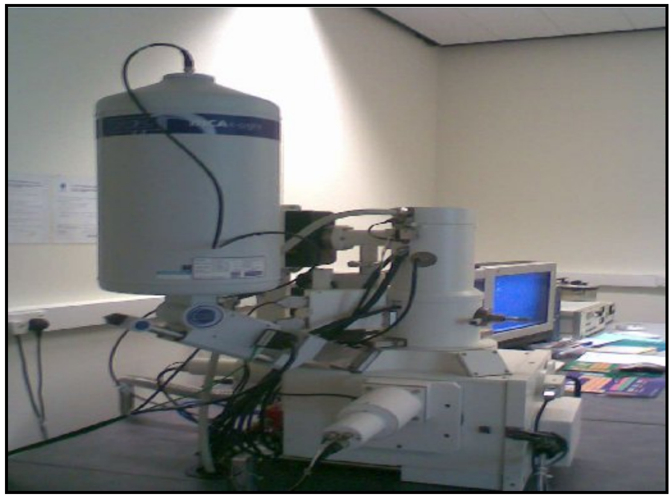


Figure 3.3: Scanning Electron Microscope

Besides using the SEM (Figure 3.3) for the specimens of the wire rope strand the corroded part and normal part observed using optical microscope. By using optical microscope the rust on the surface will appear yellow and for the normal surface will appear silver.

Figure 3.4: Optical microscope

The optical microscope as per Figure 3.4 used at different magnification for example 50X, 100X, 200X and 500X.

3.4 Metallography

The metallography conducted on the wire rope specimen to reveal it microstructure information. The methodology of the metallography is:

- Sectioning
- Mounting of samples (cold mounting for the wire rope)
- Grinding
- Polishing
- Etching
- Microscopy
- Image recording

Sectioning is the process of removal of representative samples, noting of section relative to prominent features. For wire rope samples, specimens are taken from regions immediately adjacent to the failure surface. The wire rope is a tough and hard material, the sectioning process conducted using abrasive cutter as indicate in Figure 3.5.

Figure 3.5: Abrasive cutter

The wire rope is small to be able to hold when grinding, polishing and to capture image under optical microscope. The suitable mounting for the wire rope is cold mounting. The cold mounting prepared cold using two components hardener and epoxy. The equipment consists of cylindrical ring which serves as a mould and flat piece of plastic which serves as the base indicate in Figure 3.6.

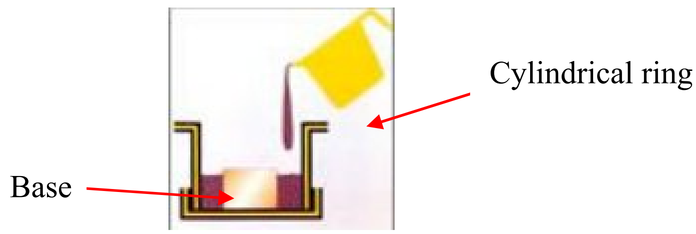


Figure 3.6: Cold mounting casing

After the cutting process there will be cutting mark on the surface. The cutting mark will clearly observe under optical microscope. The cutting mark on the surface can be removed by grinding and polishing. Grinding using difference grit of sand paper will eliminate the cutting marks and scratches on the mounted specimen using the machine indicate in Figure 3.7. The grinding process start with sand paper grit 60 followed by 120, 240, 320, 400, 600, 800 and lastly 1200. On last grade of sand paper, the sample grind until it produce shine surface (scratch less).

Figure 3.7: Grinder and polisher

The grinding process the followed by polishing using the machine in Figure 3.7, the sample the polish on 6μ and 1μ polishes paper. The sample polishes to remove any remaining scratches from the grinding process before. After the sample produce mirror like surface the sample then washed by using water to remove any contaminant on the surface. Figure 3.8 indicate the sample of the wire rope that mounted and polished.

Figure 3.8: Mounted specimen using cold mounting

Etching for the wire rope is necessary because the microstructure cannot be revealed without etchant. Since the wire rope is made from the galvanized carbon steel the suitable etchant is 2% nital. After etching, the mounted specimen then placed under optical microscope to observe the microstructure. The microstructure of the specimen can be observed at 50X, 100X, 200X and 500X magnifications. The higher magnification did not represent the best view.

3.5 Electron Dispersive X-Ray (EDX)

The EDX conducted using SEM machine to determine the element present in the wire rope. The EDX conducted on both corroded part and normal part of the wire rope. The result from the EDX will solidified the conclusion made based on the observation image view on the optical microscope. EDX is an analytical technique used for the elemental analysis or chemical characterization of a sample. As a type of spectroscopy, it relies on the investigation of a sample through interactions between electromagnetic radiation and matter, analyzing x-rays emitted by the matter in response to being hit with charged particles. Its characterization capabilities are due in large part to the fundamental principle that each element has a unique atomic structure allowing x-rays that are characteristic of an element's atomic structure to be identified uniquely from each other. The sample contains ground state (or unexcited) electrons in discrete energy levels or electron shells bound to the nucleus. The incident beam may excite an electron in an inner shell, ejecting it from the shell while creating an electron hole where the electron was. An electron from an outer, higher-energy shell then fills the hole, and the difference in energy between the higher-energy shell and the lower energy shell may be released in the form of an X-ray [7]. The number and energy of the X-rays emitted from a specimen can be measured by an energy dispersive spectrometer. As the energy of the X-rays is characteristic of the difference in energy between the two shells, and of the atomic structure of the element from which they were emitted, this allows the elemental composition of the specimen to be measured [7].

CHAPTER 4

RESULT AND DISCUSSION

4.0 RESULT AND DISCUSSION

The failure analysis on the wire rope for the lifting equipment result can be divided into six main sections which are background and data collection, preliminary examination, non destructive testing, mechanical testing, macroscopic and microscopic examination, metallography and lastly EDX.

4.1 Background and Data Collection

The results obtain for the background and data collections are [4]:

1) Manufacturing date based on SAP, for the main hoist wire rope, no record found of replacement since 2000 (record start).
2) The crane is rated at Safe Weight Limit 10 ton but de-rated to 5 ton due to engine deficiency in Sept 07 by 3rd party inspector. It was manufactured by FMC Link Belt in 1984.
3) Material for the wire rope is galvanized carbon steel based on the information given by Handal Offshore services SDN. BHD., company that servicing offshore crane.
4) The diameter of the wire rope is 5/8".
5) The pedestal crane never been overall overhauled.
6) The last inspection and testing done is on 5th September 2007 by Velosi (Service Company). Based on the inspection the wire rope were found to have sign of corrosion and recommended to be greased properly.

7) Based on the last four cycles of Planned Preventive Maintenance (PPM) there where only minor finding on the wire rope, whereby on August 2007 the wire rope found having a swell at the drum first layer. The swell is approximately 1 meter length [4].
8) On 14th March 08 MV Setia Wira (vessel) was requested to pick up backload of construction scrap materials from Duyong-A to Kemaman Supply Based (KSB). At 1512 hours during hoisting of the 2nd backload of 4' x 20' cargo basket the main hoist wire rope failed. The cargo basket and the load block fell onto the boat bulkway port side slightly damaging it and then fell into the sea. The operation was stopped immediately and the incident was reported to the relevant parties.

The chronology during the incident day is as per table below.

Table 4.1: Chronology activities before wire rope failed [4].

Date/Time	Description of activity/incident
March 14, 2008 Wind speed: 12 knots Swell: 1.0 m	Lifting of construction materials for the shutdown activities.
0800 hours	PTW released for lifting operation at Duyong-A.
0830 hours	Crane inspection conducted by crane operator.
0845 hours	Vessel MV Setia Wira alongside for lifting Tote tank filled with fresh water approximately 500gallon.
1230 hours	Two lifting operation for HyperWave personal transferring from boat to platform (7 persons).

1430 hours	- Lifting operation started with Petronas Carigali Sdn. Bhd. Operational personal transfer from boat to platform (3 persons). - Crane operator informed roustabout to backload MV Setia Wira (7 times lifting process).
1500 hours	First offloading of cargo basket size 4' x 20', containing disposed materials from previous shutdown activities such as pipe spools, used valves (Full basket capacity)
1508 hours	Second offloading continued cargo basket 4' x 20', also containing disposed materials with full basket capacity (actual load unknown due to faulty Safety Load Indicator).
1510 hours	During lifting observed the wire rope twisted to each other (4 part lines). Stop hoisting and correct the twist using the cargo basket tag line.
1512 hours	- During lowering the cargo basket into MV Setia Wira, the main hoist wire snapped, fall & hit the bulkwalk (Port Side). The load and the load block fell into the sea. - Immediately crane operator informed platform supervisor.
1530 hours	Crane secured.

Note that Duyong-A is name of the platform and MV Setial Wira is a boat name.

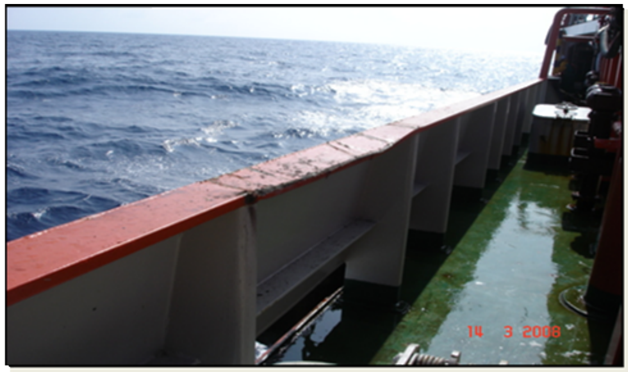


Figure 4.1: Affect on the MV Setia Wira

The background and data can be divided into five main part as per listed below.

Equipment

1. Found severe corrosion at the core of the snapped wire rope
    - The wire rope failed at the rest point of the load block
2. Safe Load Indicator not functioning since August 2007.

Environment

1. Underneath the boom at rest, have fin fan cooler. Temperature of ambient approximately 40 degrees Celsius. Observation on the wire ropes, this does not have significant effect.

System/Procedure

1. Verification on the work completion and quality is not sufficient
2. Training module for the Crane Operator does not cover how to fill up daily checklist.
3. Lifting Equipment Management System – No specification on time based maintenance (condition based maintenance does not address wire rope core corrosion problem)

Documentation

1. Crane Operator log book – not been consistently used.
2. Planned Preventive Maintenance reports – The 3 monthly is carried out per schedule. Lacking at the first line maintenance based on the observation and interview with the maintenance crew.
3. Current contract with Service Company does not contain price agreement on parts causing delay in corrective maintenance.

Human

1. Competency of the crane operator – 9 years experience with 7 years at Duyong Last competency assessment in Febuary certified as Level 2. License Valid until Feb 2012 (no issue).

2. Competency of the maintenance crew – evidence of lacking in quality.

3. Lack of ownership by the Crane Operator – lack of understanding in stop work policy.

4. Lack of enforcement by the Platform Management on the procedural requirement, Memorandum Of Change (MOC) for Safe Load Indicator (SLI), re-rating of the crane after reinstatement.

For the background data collection, the data obtained used to find any abnormal condition on the equipment before it fail. The sequence of events before the incident find out, either the equipment failed due to human abuse or else. Based on the chronology above, it was observed that several procedures were not followed correctly such as the usage of the safe weight indicator. Even though the safe weight indicator failed, the full capacity of the cargo basket also lifted during the process. This might be one of the reasons that could lead to the failure. Since the design of the wire rope was high strength, the cargo basket believed to be lower than 5 ton based on the crane operator experience.

4.2 Preliminary Examination

There were several pictures taken around the location just after the incident and the environment on the offshore platform where the crane in rest position.

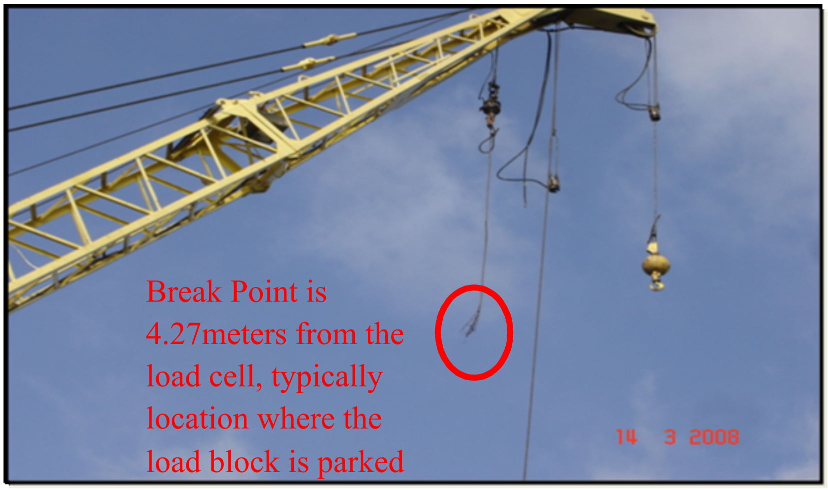


Figure 4.2: The crane boom position just after the incident

Based on Figure 4.2, the breaking point of the wire rope is in the red circle. The break point is 4.27meters from the load cell typically location where the load block is parked.

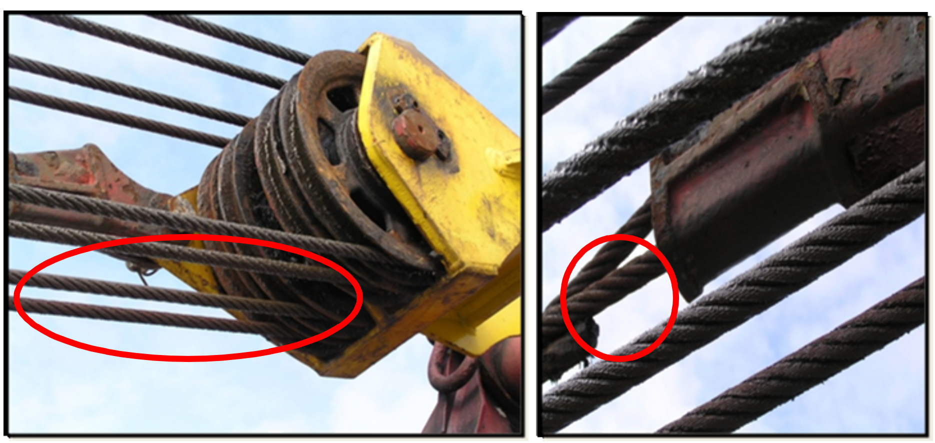


Figure 4.3: The crane anchor

The anchor is the tip point of the boom indicated in Figure 4.3. The red marked shows the portion of the wire rope without grease (improper maintenance on the wire rope).

Figure 4.4: Pendant line on the crane (red arrows)

Based on Figure 4.4, the grease on the pendant line has become brittle and peel off from the wire rope. The grease become brittle due to the reaction with the environment since the pedestal crane did not park under any roof. This also shows that improper maintenance activity conduced to cover the peel off grease with new grease.

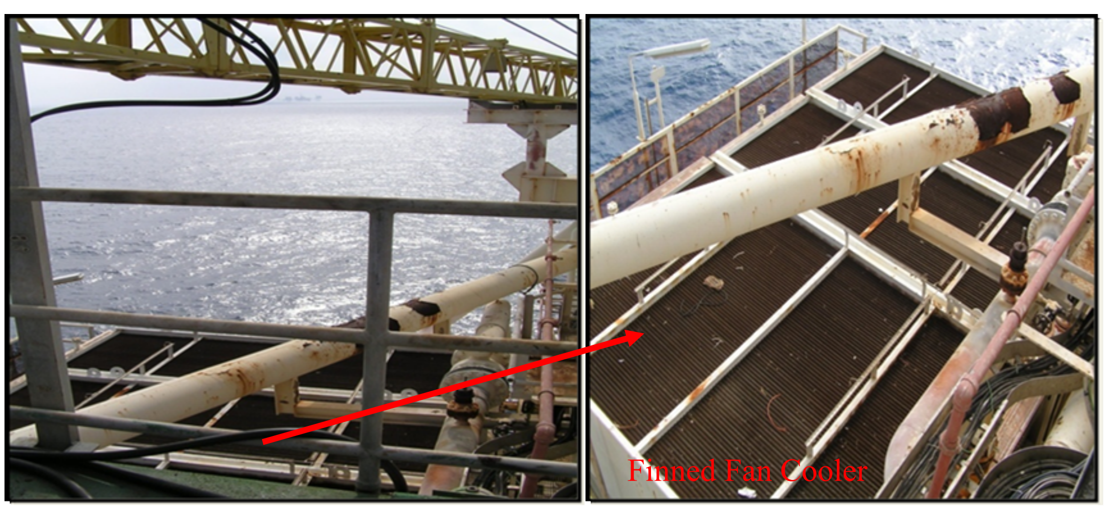


Figure 4.5: Boom on park position

The boom actually park on top of the finned fan cooler as per in Figure 4.5, the ambient temperature of approximately 40 ^{o}C is not significant to affect the strength of wire rope.

4.3 Nondestructive Testing

The nondestructive testing chose for the study are the visual inspection. Based on the observation and diameter measurement the data obtained are:

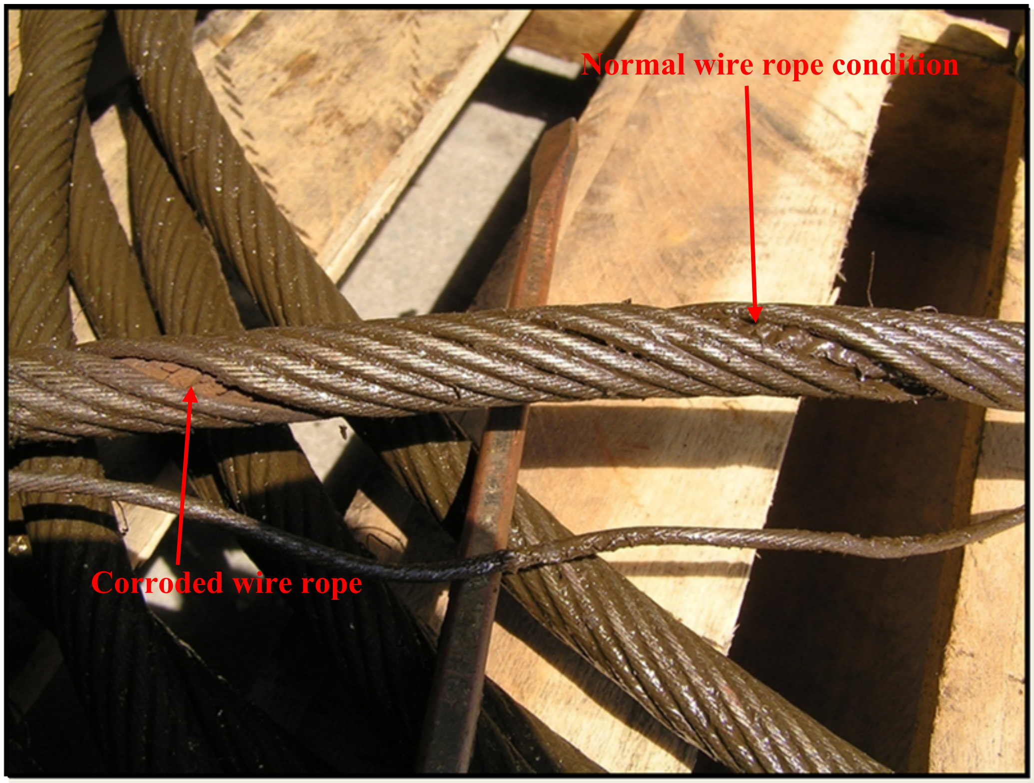


Figure 4.6: Corrosion internal part of the wire rope

At the static portion, observed the grease to be relatively dry. At running portion, the grease can penetrate to the core when the strands are opened by bending when running through sheave. As a result the static portion wire rope core is not protected from the environment. Figure 4.6 clearly show the different between corroded and protected part.

- Specimen type: 19 X 7 drawn galvanized wire rope.
- Total length: 1940mm.
- Nominal diameter: 5/8” or 16mm.

Table 4.2: Diameter of the wire rope at specific distance from datum

Length from datum, mm	Diameter measured, mm
0	22.00
200	16.30
400	16.20
600	16.00
800	16.00
1000	16.00
1200	16.00
1400	16.00
1600	16.02
1800	16.03
End (1940)	17.10

The datum for the measurement is the failed part of the wire rope.

Figure 4.7: Wire rope datum (in the red circle)

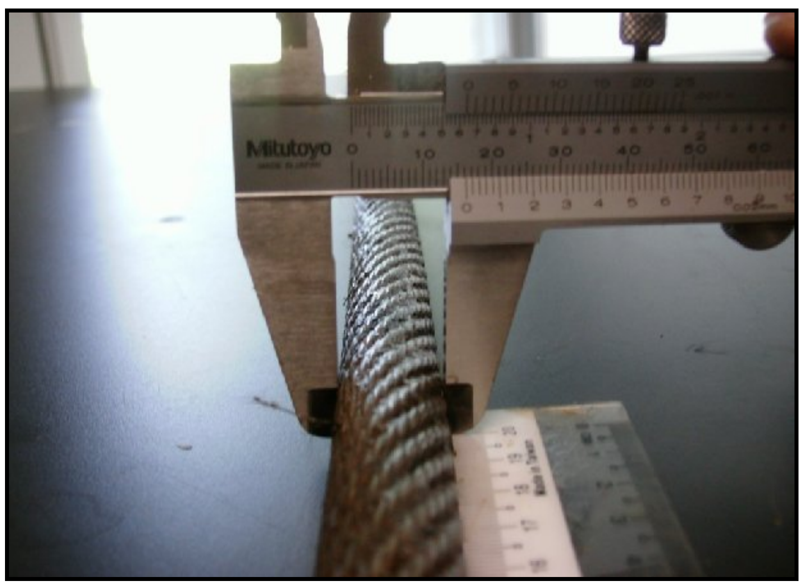


Figure 4.8: Measurement on the wire rope diameter

Based on the data in Table 4.1, the diameters of the wire rope shows reduction as the diameter measured further from the datum and stay constant in the middle of the wire rope length. This indicated that there is corrosion internally or dislocation of the strand lay of the wire rope.

4.4 Mechanical Testing

For the mechanical testing, the tensile test used compares both normal and corroded wire rope.

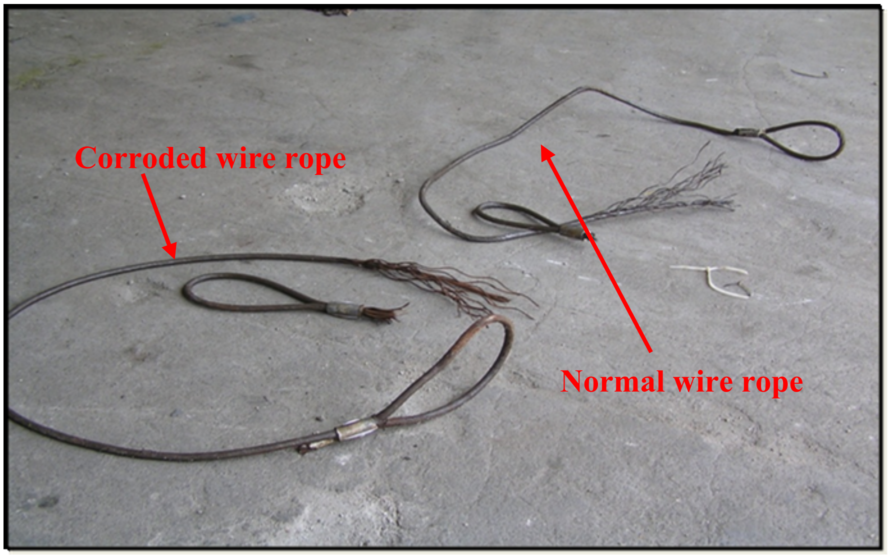


Figure 4.9: Tested specimens

Table 4.3: Properties of the 19X7 wire rope [4]

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
				Nominal Strength*					
Nominal Diameter		Approx. Mass		Improved Plow Steel			Extra Improved Plow Steel		
in.	mm	lb/ft	kg/m	lb	kN	Metric Tonnes	lb	kN	Metric Tonnes
1/2	13	0.45	0.67	19,700	87.6	8.94	21,600	96.1	9.80
9/16	14.5	0.58	0.86	24,800	110	11.2	27,200	121	12.3
5/8	16	0.71	1.06	30,600	136	13.9	33,600	149	15.2
3/4	19	1.02	1.52	43,600	194	19.8	48,000	214	21.8
7/8	22	1.39	2.07	59,000	262	26.8	65,000	289	29.5
1	26	1.82	2.71	76,600	341	34.7	84,400	375	38.3
1 1/8	29	2.30	3.42	96,400	429	43.7	106,200	472	48.2
1 1/4	32	2.84	4.23	118,400	527	53.7	130,200	579	59.1
1 3/8	35	3.43	5.10	142,600	634	64.7	156,800	697	71.1
1 1/2	38	40.8	6.07	168,800	751	76.6	185,600	826	84.2

*These strengths apply only when a test is conducted with both ends fixed. When in use, the strength of these ropes may be significantly reduced if one end is free to rotate.

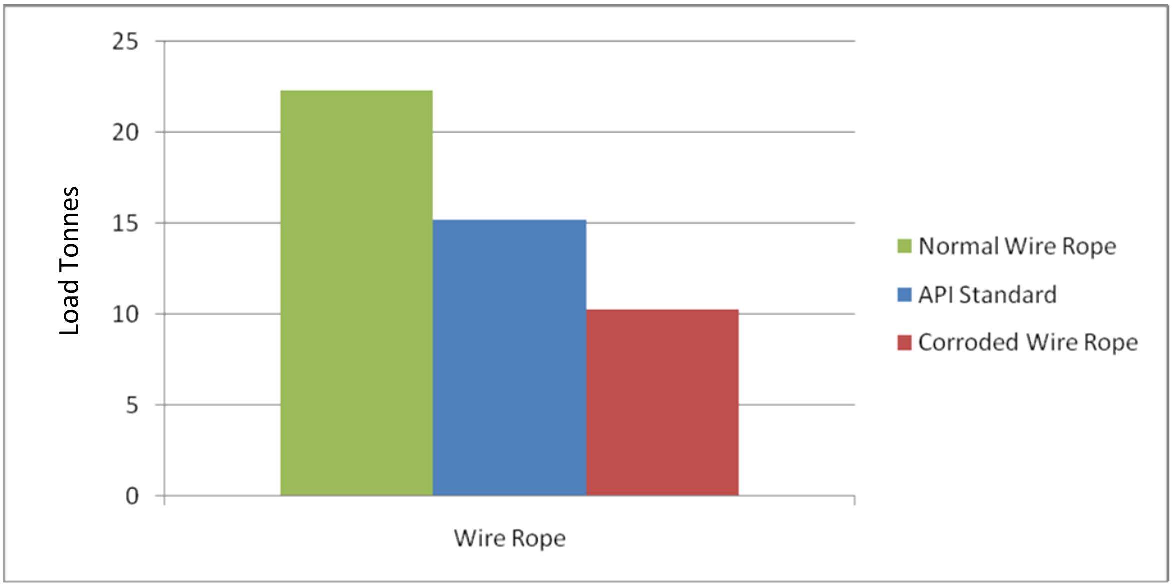


Figure 4.10: Graph load Vs wire rope

These two wire ropes tested with the pull test bench machine. The maximum of the strength before the wire ropes break at the ferrule recorded. The length of the wire rope are 5ft Comparing the data from the testing to the both the strength of the corroded is much lower.

Corroded wire rope = 10.3 tonnes

Normal Wire rope = 22.3 tonnes

API standard for 19X7 = 15.2 tonnes

This indicate that the corrosion reduce the strength of the wire rope reduce by 53.81% from the normal condition of the wire rope.

4.5 Macroscopic and Microscopic Examination

The macroscopic and microscopic examination conducted on the surface, cross sectional and fracture surface of the wire rope were observed.

4.5.1 Surface of Wire Rope

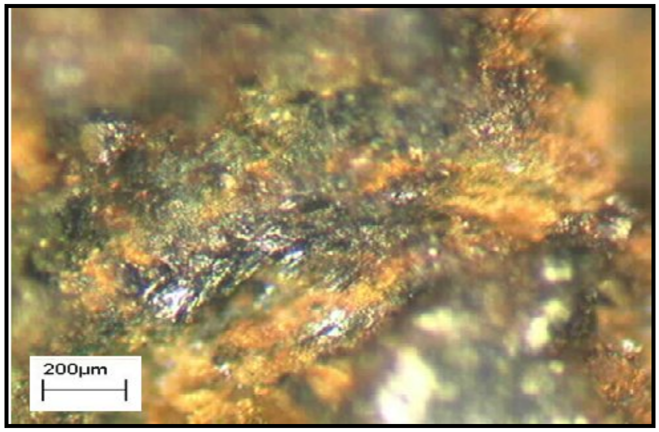


Figure 4.11: Corroded surface at 50X magnification with optical microscope

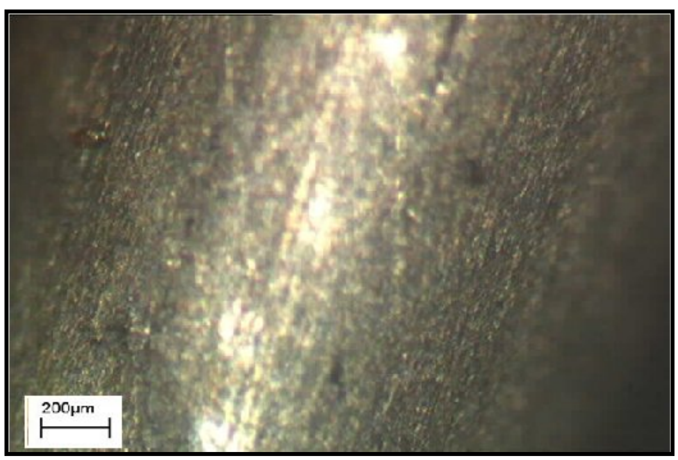


Figure 4.12: Normal surface at 50X magnification with optical microscope

Based on the figure 4.11 the present of the yellow element indicated that the present of the rust which indicates that the wire rope already corroded. Figure 4.12 show how the undamaged surface of the wire rope, there no present of yellow element which shows that the coating of zinc was still protecting the carbon steel.

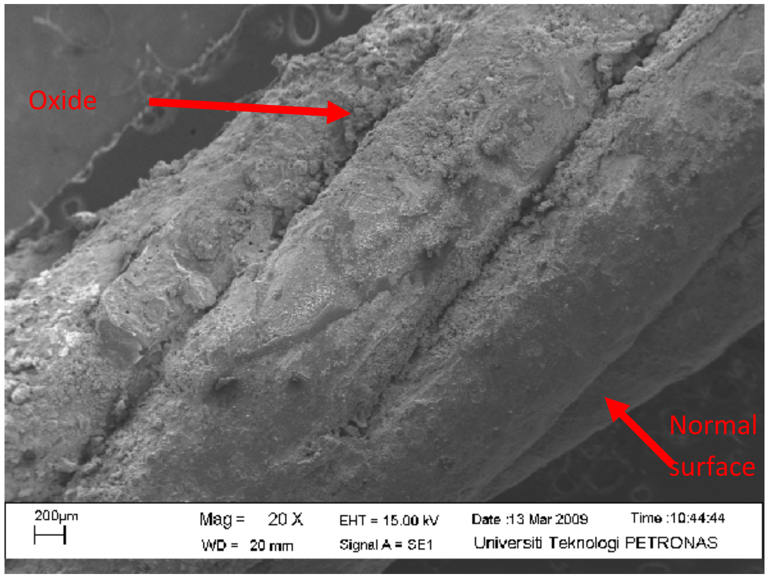


Figure 4.13: Surface Magnification under SEM at 20X magnification for single strand

Figure 4.13 shows the formation of oxide on the surface of the strand as per labeled. Zinc coating designed to sacrificed itself to protect the carbon steel for this wire rope design. As the time of operation increase the zinc may form zinc oxide and wear due to environment and movement of the wire rope. Greasing and lubrication on the wire rope will extend the life. The greasing will act as an inhibitor that will prevent the oxidation and reduction process thus stopping the corrosion. The pattern occurred on this wire is due to the improper greasing apply on the wire rope. The surface without greasing and zinc coating will corrode and the strength of the wire rope will reduce the probability of the wire rope to fail.

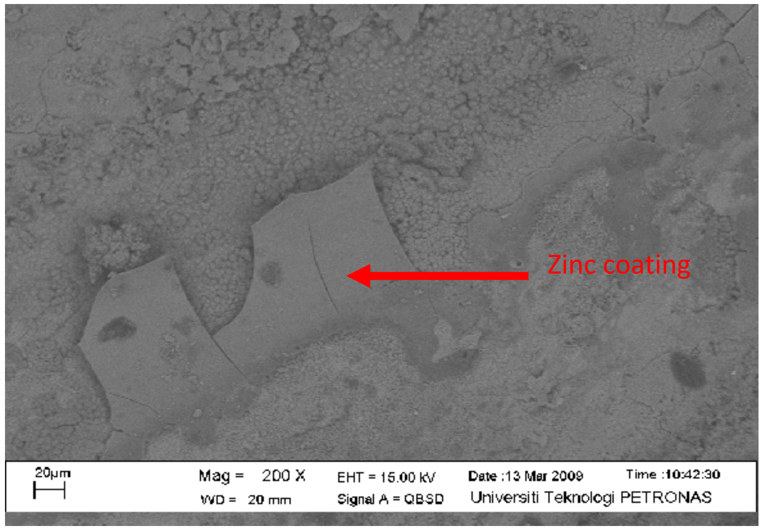


Figure 4.14: Surface Magnification 200X using SEM for single wire

Figure 4.14 show that the remaining of the zinc coating after it reacted with the environment to protect the carbon steel. The zinc peels off from the base metal.

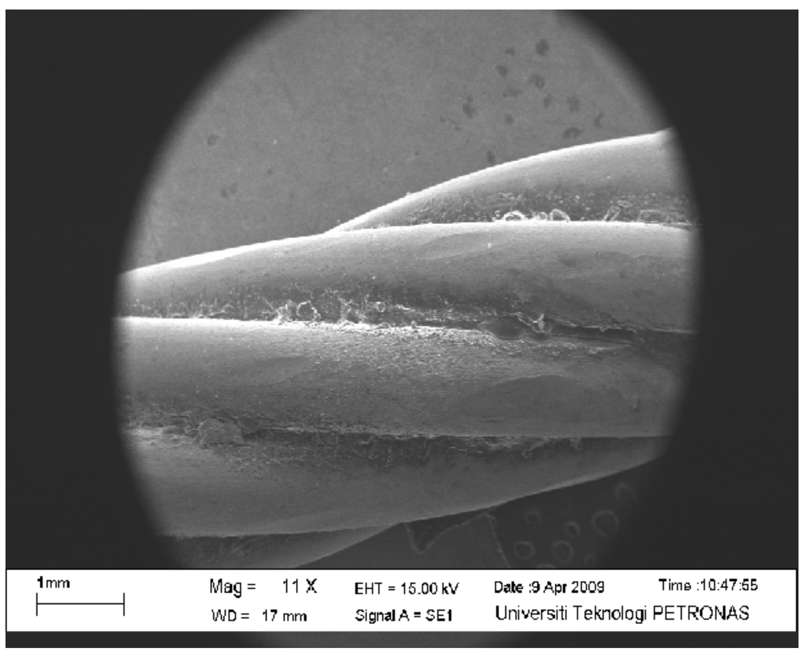


Figure 4.15: Surface magnification 11X for single strand using SEM

Figure 4.15 show the normal strand with zinc coating the surface protected with grease, the zinc coating also remain on the surface of the single wire. There is no sign of oxide formed on the wire surface.

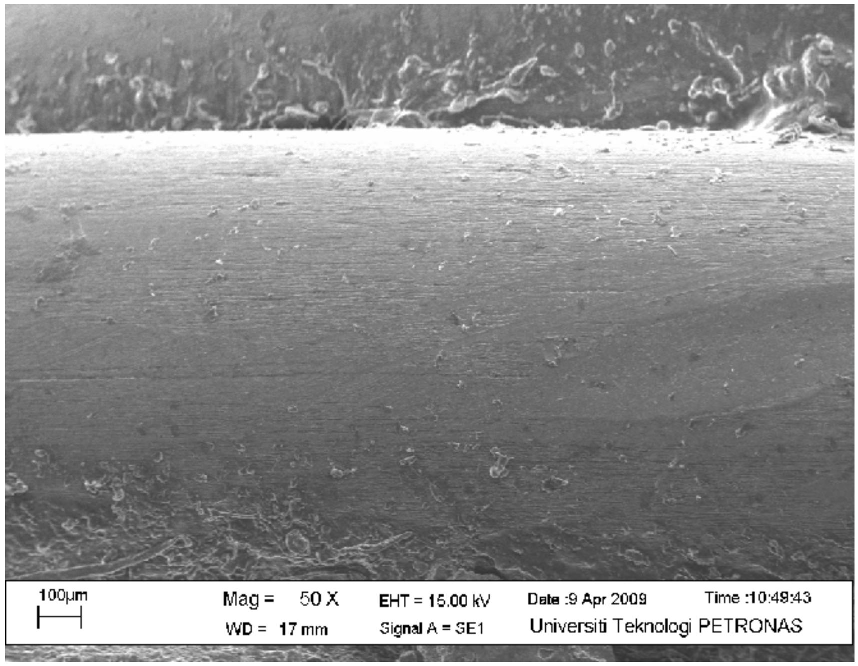


Figure 4.16: Surface magnification 50X using SEM for single wire

The higher magnification view on the surface of normal wire rope show smooth surface. But there is still scratch mark and dent on the surface due to the movement of the strand that will rub each other during manufacturing process. Continuously movement and rubbing process of the wire rope will wear off the surface of the wire rope which protected by zinc coating. As the based metal exposed to the environment without protection the corrosion will occur.

4.5.2 Cross Sectional of Wire Rope

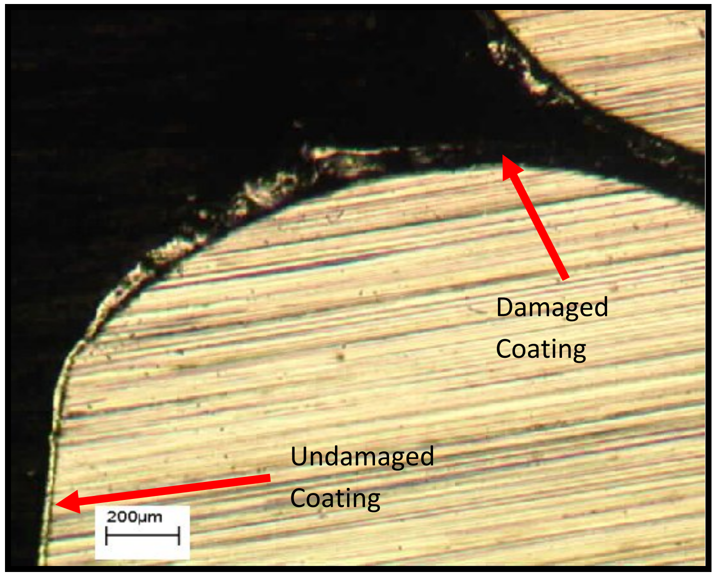


Figure 4.17: Cross sectional of wire at 50X magnification under optical microscope

Figure 4.17 show the zinc coating on the single wire from the corroded strand, here we can observe that some of the coating was already damaged, and the damage is due to degradation of zinc to the environment and wear. The wire without coating and without proper lubrication and greasing can lead to the failed wire rope due to the corrosion.

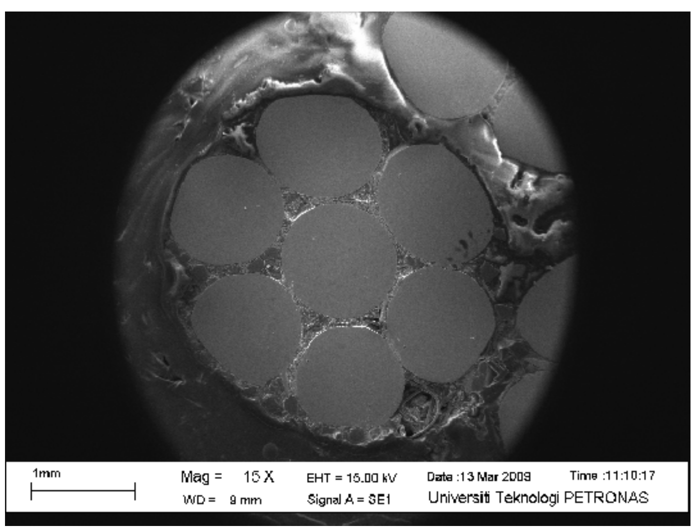


Figure 4.18: Cross sectional of Strand at 15X magnification under SEM

For the figure 4.18, the mounted specimen grinded and polished, there is no layer of zinc observed even though the specimen is the new wire rope. This is because there is imperfection of coating process conducted by the manufacturer, the thickness of the coating process for single wire did not measure closely during the manufacturing because API 9A did not state the thickness of the coating it only mention amount of the weight of coating per length of the wire produce, so there is slight possible that at certain part of the wire rope zinc coating is not enough.

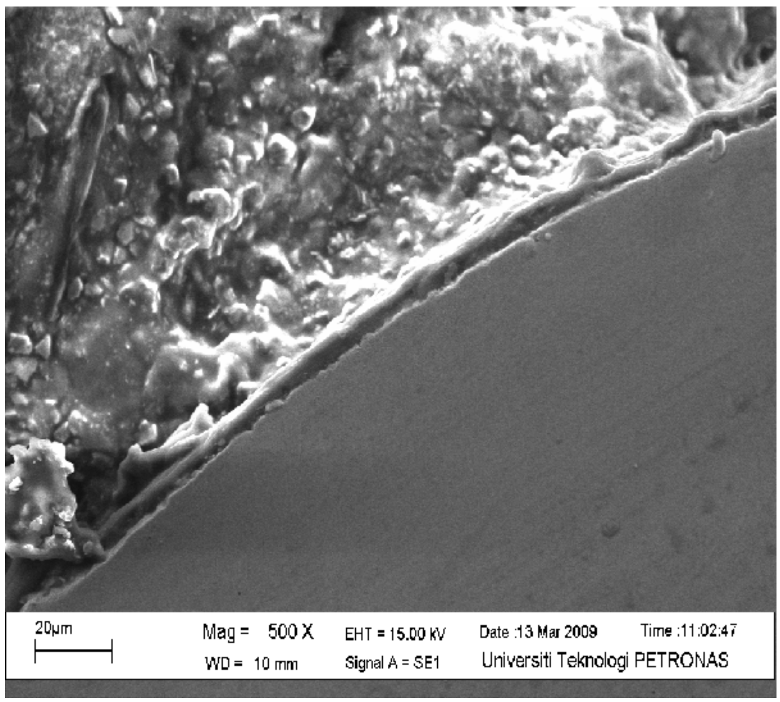


Figure 4.19: Cross sectional of new wire rope at 500X magnification using SEM

After zoom in up to 500X magnification to single new wire as per Figure 4.19, there is still no zinc coatings observed.

4.5.3 Fractography

The fractography image was conducted on the failed specimen, the failed wires randomly picked and observed under SEM to observe the failure mode.

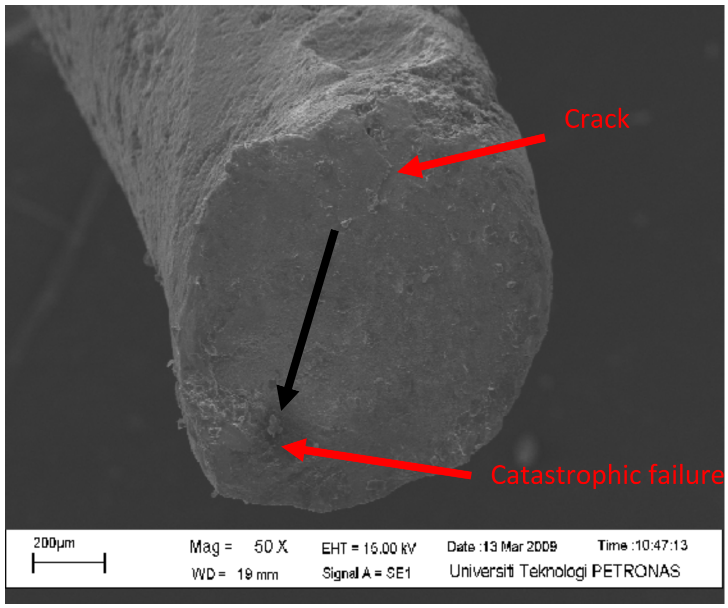


Figure 4.20: Fracture surface on the single wire (a)

Based on the figure 4.20, the fracture surface shows a trend of ductile failure that occurs normally due to tension. The black arrow shows the direction of the failure. There is no mark on the surface showing the propagation of the crack, indicating that this wire failed at single tension load.

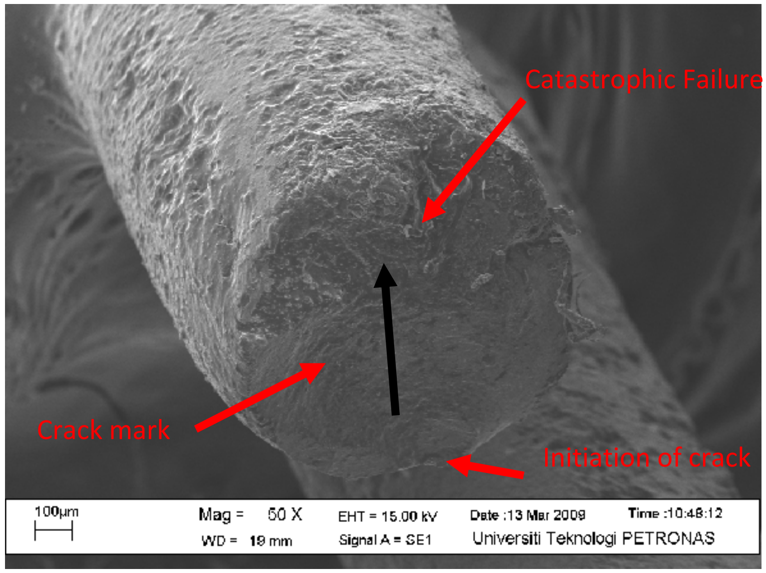


Figure 4.21: Fracture surface on the single wire (b)

Figure 4.21, shows clear mark that indicates the propagation of the crack before the failed of the single wire. The black arrow shows the direction of the crack before the catastrophic failure. The type of the failure is also similar in figure 4.20, which is ductile failure. However, this wire did not fail on single tension loading due to the existence of the marks on the fracture surface.

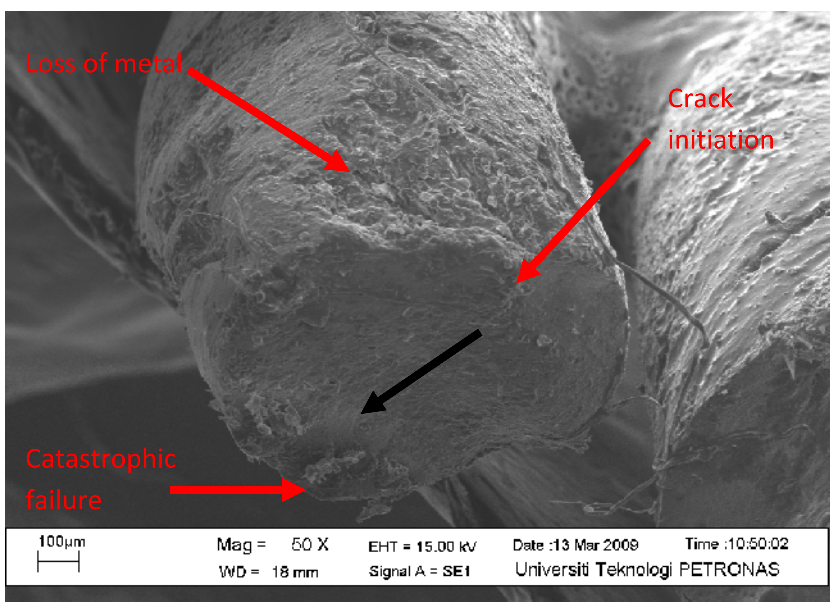
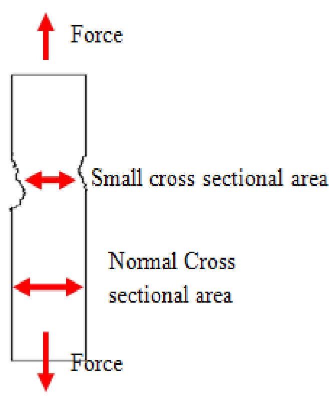


Figure 4.23: Fracture surface on the single wire (c)

Figure 4.23 shows the same type of the failure of the wire, there also loss of metal on the wire which starting the initial crack. The loss of the metal is due to the corrosion on the surface of the wire. The figure also shows no layer of the zinc that should be covered the surface of the wire as per stated in API 2C. The losses of the metal reduce the cross sectional area of the wire, at a tension loading the stress concentrates at the particular area and causing the crack to initiate. As the crack initiate, at the constant loading the crack will propagate (black arrow) until the wire fail. The surface in figure 4.23 also shows the grooving pattern, this pattern exist due to some twisting on the wire before failed.



Stress = Force / Cross Sectional Area

= F/A

Small cross sectional area, greater stress.

Figure 4.24: Illustration of the effect of cross sectional area

The Figure 4.24 illustrates how the concentration of stress occurs on the small cross sectional area.

4.6 Metallography

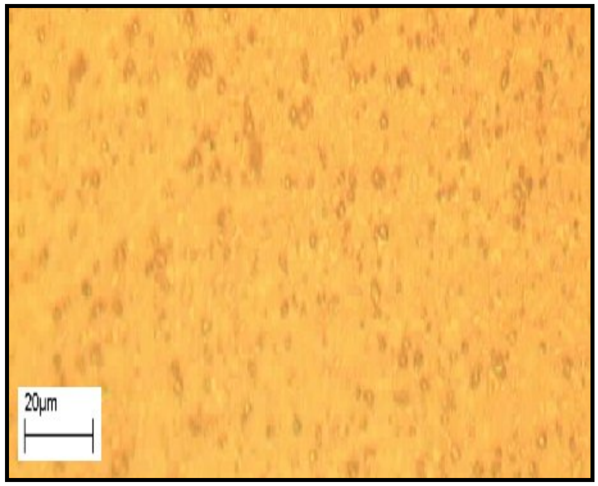


Figure 4.25: Microstructure at 200X using optical microscope

Based on Figure 4.25, the spheroids pattern observed without pores or defect on the wire. Spheroidization is an annealing process used for high carbon steels (Carbon > 0.6%) that will be machined or cold formed subsequently. All these methods result in a structure in which all the Cementite is in the form of small globules (spheroids) dispersed throughout the ferrite matrix. Spheroidization also improves the machinability, making the material soft and more ductile. The wire rope microstructure is acceptable without any stress corrosion cracking or defects.

4.7 EDX

The EDX conducted on both failed surface and normal surface to find elements that exist in the material and proof the present of the corrosion on the failed surface compare to normal surface of the wire rope.

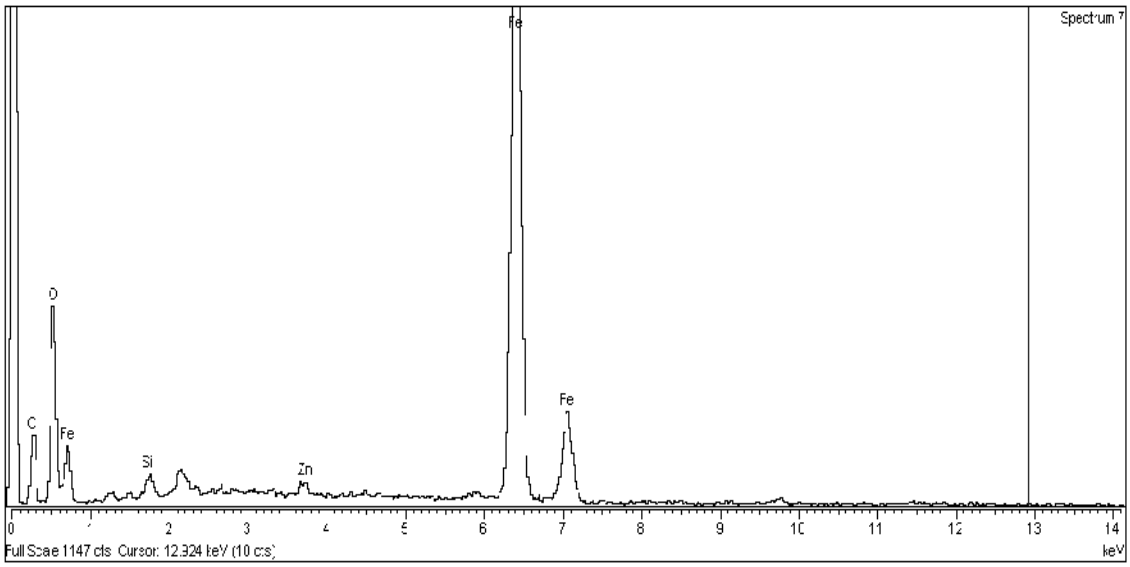


Figure 4.26: EDX on the failed surface

Spectrum processing:

Peaks possibly omitted: 2.139, 9.748 keV

Processing option: All elements analyzed

Number of iterations = 5

Standard:

C $CaCO_3$

O Fe_3O_2

Si SiO_2

Zn ZnO

Fe Fe

Based on the result obtain from Figure 4.26, there is present of the zinc oxide (listed in standard) on the failed sample due to the zinc reacted with the environment to protect the based metal of the wire rope. The present of iron oxide on the surface confirmed the result obtained from the optical microscope (Figure 4.11) that shows the present of the yellow color on the surface.

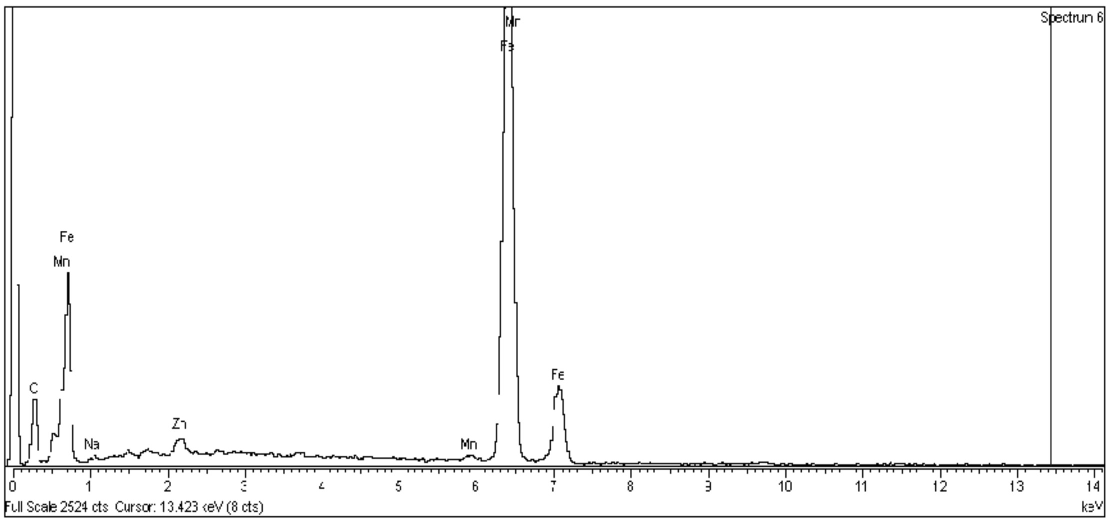


Figure 4.27: EDX on the normal surface

Spectrum processing:

No peaks omitted

Processing option: All elements analyzed (Normalised)

Number of iterations = 4

Standard:

C $CaCO_3$

Na Albite

Mn Mn

Fe Fe

Zn Zn

The data obtained for the normal surface is different from the corroded surface whereby there is no zinc oxide and the iron oxide present. As per Figure 4.12, the surface is properly coated and there is no sign of the corrosion.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Based on the result obtained, the background data show that the last inspection and testing on 5th September 2007 indicates the sign of corrosion. As based on the preliminary examination the failed of the wire rope occurred at 4.27meters from the load cell typically location where the load block was parked. The failed part occurs at the corroded wire rope. The corrosion occurred on the wire rope is due to the loss of the zinc coating as a result of wearing and corrosion of zinc. The insufficient zinc coating on certain part of the wire rope cause the corrosion to occur as the operating time of the wire rope increased. The grease prevents the corrosion on the wire rope if the zinc coating on the wire rope finished. As the corrosion occurred on the certain part of the wire, the wire cross sectional area would reduce due to the loss of the metal. The section with less cross sectional would experience greater stress concentration. At certain amount of load the wire rope failed due to the stress concentration on the corroded area. The wire would fail first and continues with strand and lastly the whole part of the wire rope. The wire rope failure mode initiate from the inner part of the wire rope gave way. As a conclusion, the failed of the wire rope occurred due to the corrosion that reduces the strength of the wire rope.

5.2 Recommendation

- The thickness of the zinc coating should be increase to more than 100%.
- The wire rope should be grease properly after used. Greasing should be applied based on the frequency of the crane used, not on the time based. The Planned Preventive Maintenance should be proceed as usual.
- The wire rope inspection should be done before and after the lifting process.

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APPENDICES

APPENDIX I: Milestone Final Year Project I

APPENDIX II: Milestone Final Year Project II

APPENDIX III: Final Year Project I process flow

APPENDIX IV: Final Year Project II process flow

APPENDIX I: Milestone Final Year Project I

No.	Detail/ Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	Selection of Project Topic	■	■						Mid Semester Break							
2	Preliminary Research Work		■	■	■											
3	Literature Review on Failure Analysis	■	■	■	■	■	■	■		■	■	■	■	■		
4	Submission of Preliminary Report				●											
5	Background Data Collection and Sample Collection	■	■	■	■	■	■	■								
6	Preliminary Examination						■									
7	Submission of Progress Report									●						
8	Seminar (compulsory)									●						
9	FA equipment familiarization		■	■	■						■					
10	Macroscopic Examination											■				
11	Submission of Interim Report Final Draft														●	
12	Oral Presentation															●

● Suggested Milestone

■ Timeline

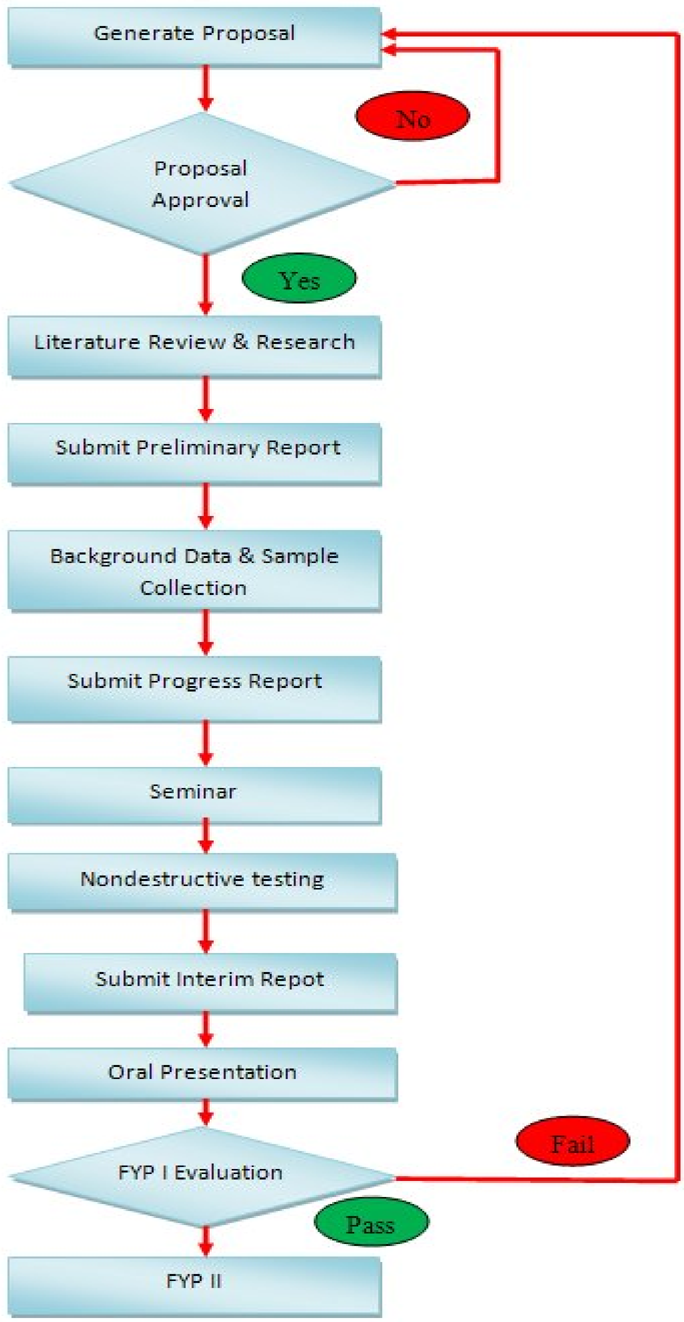
APPENDIX II: Milestone Final Year Project II

No.	Detail/ Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	Mechanical Testing	■	■	■					Mid Semester Break							
2	Submission of Progress Report 1				●											
3	Macroscopic and Microscopic Examination on the damage surface and the fractography				■	■	■	■								
4	Submission of Progress Report 2									●						
5	Seminar (compulsory)									●						
6	Metallographic									■	■	■	■			
7	Final analysis, Conclusion and Improvement										■	■	■			
8	Poster Exhibition											●				
9	Submission of Dissertation (soft bound)													●		
10	Oral Presentation														●	
11	Submission of Project Dissertation (Hard															●

● Suggested Milestone

■ Timeline

APPENDIX III: Final Year Project I process flow



APPENDIX IV: Final Year Project II process flow