FAILURE ANALYSIS OF CONVEYOR CHAIN LINKS: A CASE STUDY AT TOP GLOVE SDN. BHD.

NUR ISMALINA BINTI HARIS

A project report is submitted as partial fulfillment of the requirements for the award of the degree of

Master of Mechanical Engineering

Faculty of Mechanical and Manufacturing Engineering
Universiti Tun Hussein Onn Malaysia

JULAI 2013

ABSTRACT

This case study is to investigate the causes of failure of chain system through characterization on the failure component. The failures that occur are relate to welding because this dipping latex industry use customized chain that have to be welded at joining with outer chain links. The analysis revealed that the weld defect such as crater leads the crack propagation and added with cyclic loading that cause the fatigue failure. The fatigue failure occurs due to this inherited crack at the outer circumference of the weld within chain attachment and outer chain link plate. This type of defect also can be categories as designing-in defect. Fatigue crack propagation was evident by progressive beach marks and the scanning electron microscopy (SEM) analysis revealed the types of microstructure that resulting at heat affected zone (HAZ). Hardness testing by using Rockwell Tester found the different hardness profile at three areas that are weld metal, base metal and heat affected zone. The maximum hardness values were found at heat affected zone and weld metal. Finite element method (FEM) that is Ansys Workbench was used to review the different size of outer link plate thickness that affected to the stress distribution. It was found that stress can be minimized with increasing the plate thickness.

ABSTRAK

Kajian kes ini adalah untuk menyiasat punca-punca kegagalan sistem rantaian melalui ciri-ciri komponen kegagalan. Punca kegagalan yang terjadi lebih menjurus kepada faktor kimpalan kerana industri pembuatan produk berasaskan getah ini menggunakan rantaian khas yang perlu dikimpal pada sambungan dengan plat rantaian luar. Analisis membuktikan bahawa kecacatan kimpalan iaitu kehadiran kawah kimpalan telah menyebabkan keretakkan berganda ditambah pula dengan beban berulang yang menyebabkan kegagalan lesu. Jenis kecacatan ini juga boleh di kategorikan sebagai kegagalan rekabentuk. Kegagalan lesu ini dibuktikan dengan terdapatnya tanda *beach* dan penggunaan *scanning electron microscopy* menunjukkan jenis mikrostruktur yang terdapat pada kawasan zon terkesan haba. Ujian kekerasan menggunakan penguji Rockwell menunjukkan profil yang berbeza pada tiga lokasi iaitu bahan kimpal, bahan asas dan zon terkesan haba. Nilai kekerasan maksimum didapati pada bahan kimpal dan zon terkesan haba. Kaedah unsur terhingga iaitu Ansys *Workbench*, telah digunakan untuk menguji sama ada perbezaan ketebalan plat luar mempengaruhi pengurangan agihan tegasan. Ia telah dibuktikan bahawa ketebalan plat mempengaruhi agihan tegasan dan semakin tebal plat itu maka semakin berkurangan agihan tegasan.

TABLE OF CONTENTS

	TITLE	**i**
	DECLARATION	**ii**
	DEDICATION	**iii**
	ACKNOWLEDMENTS	**iv**
	ABSTRACT	**v**
	ABSTRAK	**vi**
	TABLE OF CONTENTS	**vii**
	LIST OF FIGURES	**x**
	LIST OF TABLES	**xiii**
	SYMBLOS/ABBREVIATIONS	**xiv**
CHAPTER 1	**INTRODUCTION**	
	1.1 Background to the case study	1
	1.2 Objective	4
	1.3 Scope of study	4
	1.4 Importance of study	4
	1.5 Report Outline	5

CHAPTER 2 TERMINOLOGY OF CHAIN CONVEYOR AND FAILURE ANALYSIS

2.1 Conveyor system 6

2.2 Chain conveyor 7

2.3 Roller chain conveyor 9

2.4 Study of the chain conveyor 11

2.5 Failure of conveyor 12

CHAPTER 3 LITERATURE REVIEW

3.1 Failure analysis of chain conveyor 14

3.2 Conclusion to the chapter 16

CHAPTER 4 METHODOLOGY

4.1 Failure analysis methodology flow chart 20

4.2 Introduction of failure event 21

4.2.1 Visual Examination 21

4.2.2 Perform non-destructive testing

4.2.2.1 Scanning electron fractography 22

4.2.2.2 Chemical analysis 24

4.2.2.3 Sample selection and preparation for Scanning electron microscope 24

4.2.2.4 Sample selection and preparation for Energy Dispersive Spectrometry 25

4.2.3 Metallographic analysis 25

4.2.4 Hardness testing 27

4.3 Validate the failure by using FEM in Ansys Workbench v14 27

4.3.1 Steps in Ansys Workbench v14 to perform FEM 28

4.4 Data analysis, conclusion and report 30

CHAPTER 5 DATA ANALYSIS AND VALIDATION OF FAILURE

5.1 Visual Examination 31

5.1.1 Identify the type of chain that received 31

5.1.2 Analyze type of failure sample 34

5.2 Chemical composition 37

5.2.1 Carbon Equivalent 38

5.3 Hardness Measurement 39

5.4 Metallographic analysis 41

5.4.1 Phase transformation after welding and Heat affected zone (HAZ) 43

5.5 Discussion and validation of data 45

5.5.1 Design of chain 45

5.5.2 Proposed improvement of chain (Overcome the failure) 50

CHAPTER 6 CONCLUSION & RECOMMENDATION 54

REFERENCES 56

LIST OF FIGURES

1.1	Framework of this case study	3
2.1(a)	Floor type conveyor	8
2.1(b)	Overhead type conveyor	8
2.2	Basic structure of a conveyor chain (Otoshi, 1997)	10
2.3	Five components of chain conveyor (Diamond, 1999)	10
2.4	Section view of a roller chain with exaggerated clearances (Kerremans, Rolly, Baets, Pauw, Sukumaran, & Delgado, 2011)	13
3.1	Visual Examination revealed a crack-like surface defect (M. Sujata, 2006)	16
3.2	Optical micrograph showing Oxides entrapment in the material near the surface (M. Sujata, 2006)	16
3.3	Cracking zone at chain bracket (Momčilović, Hut, Milović, & Atanasovska, 2011)	17
3.4	Stresses zone in the chain link (Bošnjak, Arsic, Nenad, Odanovic, & Dordevic, 2011)	18

3.5	Mating surface A with areas labelled 1–4 represent: (1) fatigue origins, (2) fatigue progressive marks and final rupture by (3) void formation and (4) step-like brittle rupture (Khaled Al-Fadhalah, Ahmed Elkhory, Majed Majeed, 2010)	19
4.1	Ductile and Brittle Fractures (Kopeliovich, 2012)	22
4.2	Chevrons pointing to the crack origin	22
4.3	SEM with EDX: TM3000 Hitachi at *UniMAP*	23
4.4	Material mechanical properties	29
4.5(a)	Mesh in Ansys Mechanical	29
4.5(b)	Boundary Conditions	29
4.6	Post processing; Von Mises Stress and Deformation	30
5.1(a)	Sample of roller chain link without failure at top and side view	32
5.1(b)	Sample failure chain part A	32
5.1(c)	Sample failure chain part B	32
5.2	Sample of roller chain link plates	33
5.3	Special latex dipping chains (Keng Lek Engineering, 2012)	34
5.4	Pores at weld between chain attachment and outer link plate	35
5.5(a)	Fracture starting point at weld area	36
5.5(b)	Overlapping of the crack	36
5.6	Shows beach marks caused by fatigue	36
5.7	Bending at U-bracket and bolt	37
5.8	SAE-AISI carbon steel nomenclature (ASM International, 1990)	38

5.9	Position to analyse hardness profiles at failure part	40
5.10	Weld metal, heat affected zone and base metal hardness profiles on surface as indicated in Figure 5.9.	41
5.11	Iron-carbon phases	42
5.12	Micrograph of low carbon steel. Etched 2% nital	43
5.13	Widmanstatten ferrite	44
5.14	Coarse grained HAZ at weldment	44
5.15	Chain links 3d model in Ansys workbench (Mechanical)	46
5.16	Loads applied at point A, B, C and D	46
5.17	Result shows stress distribution in chain links	47
5.18	Stress distribution at weld area	47
5.19	S/N curves for welded and unwelded specimens (Mathers, 2013)	49
5.20	Effects of joint classification on fatigue life (Mathers, 2013)	49
5.21	Stress distribution at outer link plate	51
5.22(a)	Stress distribution in outer link plate 6mm	51
5.22(b)	Stress distribution in outer link plate 7mm	52
5.22(c)	Stress distribution in outer link plate 7.5mm	52
5.22(d)	Stress distribution in outer link plate 8mm	52
5.23	Equivalent Von-Mises Stress graph	53
6.1	Improvement weld fillet in fatigue life (Mathers, 2013)	55

LIST OF TABLES

2.1	Different kind of applications for chain, belt and roller (Otoshi, 1997)	7
2.2	Function and criteria of chain conveyor	11
4.1	Etching Reagent for Iron and Steel (Carbon, Low, and Medium-Alloy Steels)	26
4.2	Rockwell Hardness Testing Reference Guide	27
5.1	Dimensions of chain parts	33
5.2	Chemical composition of the chain link material (0.19 wt. %C)	37
5.3	Hardness distribution of sample	40
5.4	Static structural analysis data in Ansys	45
5.5	Outer link plate thickness and Von-Mises Stress	53

SYMBOLS/ABBREVIATIONS

%C	-	Percentage of Carbon
e_{23}	-	small clearance resulting in eccentricity at pin and bushing
e_{34}	-	small eccentricity at bushing and roller
F_t	-	Tensile Force
N_{02}	-	Normal Force
C	-	Carbon
Si	-	Silicon
Mn	-	Mangan
P	-	Phosphorus
S	-	Sulphur
Al	-	Aluminium
N	-	Nitrogen
Nb	-	Niobium
Ti	-	Titanium
AISI	-	American Iron and Steel Institute
ANSI	-	American Standard National Institute

ASTM	-	American Society for Testing and Materials
BM	-	Base Metal
CAD	-	Computer Aided Design
EDS	-	Energy Dispersive Spectrometry
EDX	-	Energy Dispersive X-Ray
FEM	-	Finite Elements Methods
HAZ	-	Heat Affected Zone
ISO	-	International Organization for Standardization
JIS	-	Japanese Industrial Standard
NDT	-	Nondestructive testing
PLC	-	Programmable Logic Controller
SAE	-	Society of Automotive Engineers
SEM	-	Scanning Electron Microscope
UniMAP	-	Universiti Malaysia Perlis
WM	-	Weld Metal
wt.	-	weight

CHAPTER 1

INTRODUCTION

This chapter explains the case study background, aims and objectives, scope of study, importance of study and expected outcomes.

1.1 Background to the case study

The most significant development made in the industrial world is conveyors (Singh & Singh, 2012). Conveyor is one types of material handling that existed for over 100 years. By referring to Material Handling Equipment Distributors Association or commonly known as (MHEDA, 2001), since 1795 people already used belt conveyor as a transport of bulk material from one location to another. In the 20^{th} century, conveyors become popular with more tough and versatile. In 1902, steel conveyor belt had been manufactured by Swedish company, Sandvik. Then, around 1908, first pattern of roller conveyor received from a man named Hymle Goddard of the Logan Company. In 1910 pioneered by Henry Ford, he developed an assembly line that consist conveyor to carry the product with mass production in automotive industries (Allen, 2010). The industrial revolution in process then becomes shines when most of automotive companies began using conveyors in 1919 due to the successes of Henry Ford's innovation in assembly line.

Conveyors provide lots of benefit that cannot be undisputed. Imagine that how many times will be wasted if the workers need to walk by holding the item from one location to another location. This situation can be handled by using conveyor to bring the item to the desired location throughout a plant. Furthermore, conveyor can be used to transport the object for a long distance such as the longest belt conveyor in the world is in Western Sahara with 100 km long to transport the phosphate from the Bu Craa mine to the coast at El Aaiun (Lewis, 2011).

But, what will happen if the conveyor fails to operate as usual? How about the production for that day if the conveyor suddenly fails to function without giving warning to the company?

So, this project is a case study to investigate the types of failure that causes the conveyor has to be shut down its routine operation. This investigation only cover conveyor chain types and the interested area to investigate is chain links because that area is one of the most stressed zones (Momčilović, Hut, Milović, & Atanasovska, 2011). Top Glove Corporation Berhad have been selected to do this investigation because their chain conveyor with 5 km long suddenly breaks down and this undesirable situation disrupts the production lines.

Referring to their web (Glove, 2008), Top Glove Corporation Berhad is a rubber manufacturer that established since 1991. Started only with one factory and three production lines, Top Glove has grown by leaps and bounds to become the world's largest rubber glove manufacturer. In line with its objective of capturing a larger share in the world market, the company has undertaken a rapid expansion of its capacity. Its manufacturing facilities which spread across Malaysia, Thailand and China grew from 5 in 2001 to 23 presently. Top Glove exports to approximately 1,000 customers in over 185 countries through its sales and marketing offices in Malaysia, the United States and Germany. As at 2 November 2012, there are 458 numbers of production lines with 40 billion total production capacities. This figure shows that Top Glove produce 109,589,041.096 pcs/day through 23 factories.

But, what will happen to this successful production if their conveyor suddenly breaks down? What the impact of the entire operation if waiting until the repairs complete. The Top Glove will lose their profit per day, wasting their time, the production line need to be shut down and lost their customer too.

So, this project will use analytical technique for investigation of the failures. The procedures of the failure analysis also will be reviewed and execute the techniques in the investigation for the failure components. Besides, this project will see the system in terms of chain design and operation for improvements. This case study framework already summarized as shown in Figure 1.1 below.

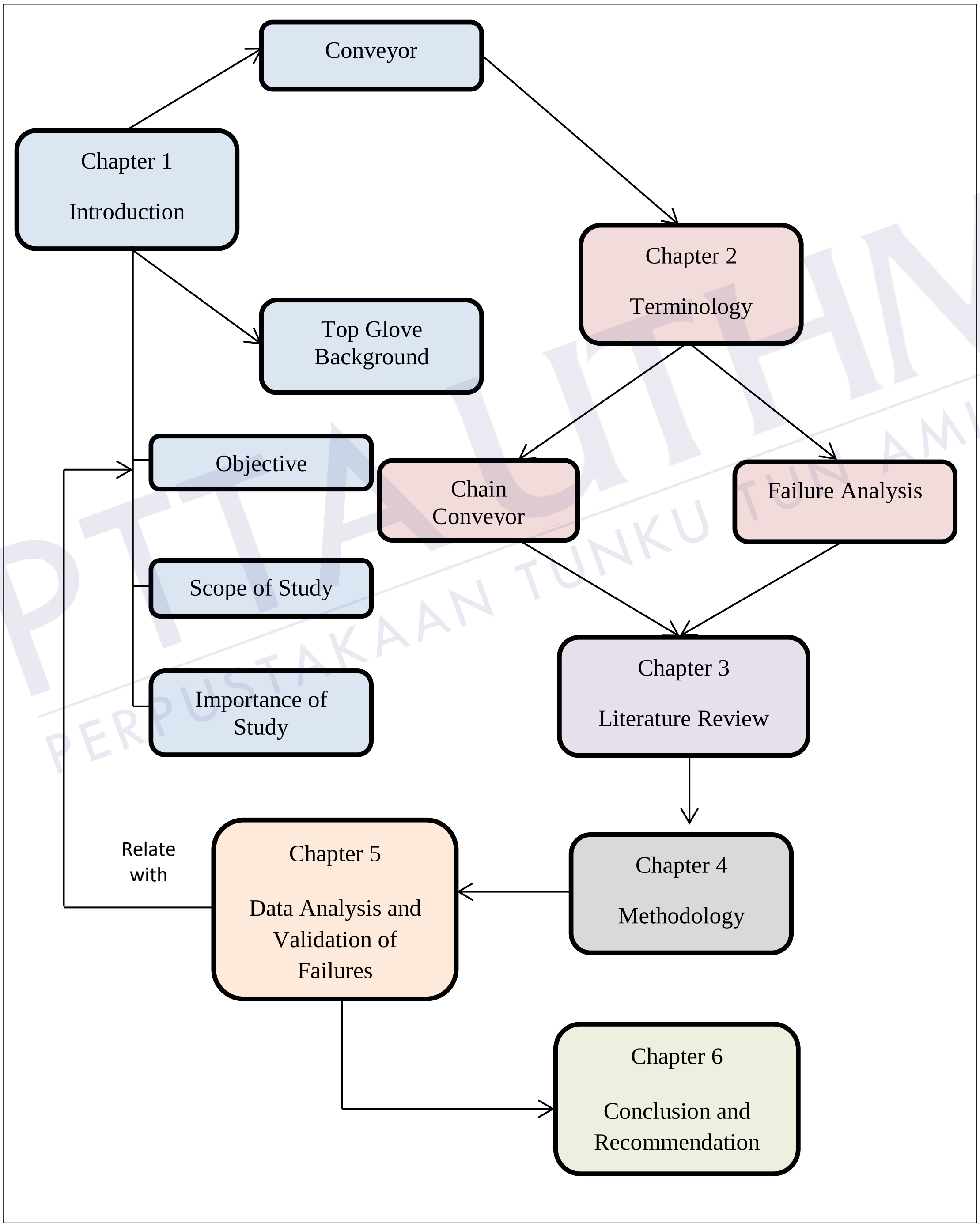


Figure 1.1: Framework of this case study

1.2 Objective

i. To investigate the causes of failure of chain system through characterization on the failure component.

ii. To evaluate the chain system design and operation of the current setup through case study.

iii. To propose for improvement on the chain system based on the finding in (i) and (ii).

1.3 Scope of study

i. The investigation of the failure component and the chain system design will be based on component and system found at the case study area, i.e. Top Glove Sdn. Bhd.

ii. To identify the types of failure that exist at conveyor chain links either designing-in defects, manufacturing-in defects, operating-in defects and environment-in defects (Gagg, 2005; and Bosnjak, Arsic, Zrnic, Rakin, & Pantelic, 2011).

1.4 Importance of study

i. Previous literatures have highlighted the causes of chain failures such as Momcilovic et al. (2011), M.Sujata et. al. (2006) and Bun (2000). According to (Schroeder, 2013), "Metallurgical failure analysis process can help mechanical and design engineers determine whether field or laboratory failures are due to design issues, application issues, or whether problems with material processing are the root cause for failure. When parts or assemblies fail, it can affect the delivery of goods, result in costly repairs, down time, and jeopardize the safety of people near the parts". So, this case study will help the industries i.e. Top Glove Sdn. Bhd. to identify what type root of failure of their chain conveyor and how to prevent the failures for next time.

1.5 Report outline

This report contains four chapters as has been illustrated in Figure 1.1. Chapter 1 introduces background to the case study, objectives, scope of study and importance of study. Chapter 2 elaborates the terminology of conveyor system, chain conveyor application and types of chain conveyor. Failures of conveyor also have been discussed briefly in this chapter.

Meanwhile, Chapter 3 consists the relevance literature reviewed as guidance to the suitable selected Methodology in Chapter 4. Chapter 4 describes step by step or procedures need to be taken to investigate the failure of chain conveyor.

Chapter 5 analyze the evidence that are failures sample of chain from Top Glove Sdn. Bhd. This chapter also will discuss type of failures that exist and how to overcome these failures. While Chapter 6 will conclude the findings and give recommendations for future study.

CHAPTER 2

TERMINOLOGY OF CHAIN CONVEYOR AND FAILURE ANALYSIS

In this chapter, we will describe the general description and terminology of chain conveyor and failure analysis.

2.1 Conveyor system

McGraw Hill Dictionary define conveyor as any materials-handling machine designed to move individual articles such as solids or free-flowing bulk materials over a horizontal, inclined, declined, or vertical path of travel with continuous motion. Meanwhile, a conveyor system is a common piece of mechanical handling equipment that moves materials from one location/point to another during material handling.

Today, there are many kinds of conveying system. Conveyors of various types such as belt conveyors, roller conveyors, wheel conveyors and chain conveyors, suit different kinds of applications such as be shown in Table 2.1 below. They can convey horizontally, vertically, around corners, incline and decline (DEMATIC, 2012).

Table 2.1: Different kind of applications for chain, belt and roller (Otoshi, 1997)

Conveyor Type	Chain	Belt	Roller
Bulk Handling	◎	◎	×
Unit Handling	◎	○	◎
Dust in Conveying Bulky Goods	◎	×/ ○ (○ for closed conveyor)	
Space Required	Small	Large	Large
◎ Excellent ○ Good × Poor			

Conveyor system in material handling can give lots of benefits such as (Barton, 2010):

i. More efficiency than manual handling in the ways of moving products around a production/warehouse facility.

ii. Allow better tracking of products with aid of PLC or SCADA in the conveyor system. So, products are traceable and good for quality control.

iii. Flexible because they can be installed almost everywhere and are much safer than using a forklift or other machine to move material.

2.2 Chain conveyor

A chain is a machine component that comes with a series of a connected links. It can be used to transmit power or conveyance systems. Usually, there are five types of chains that are cast iron chain, cast steel chain, forged chain, steel chain and plastic chain.

Otoshi (1997) stated that, demand for cast iron chain, cast steel chain and forged chain is now decreasing and only being used for special situations such as a cast iron chain is used for water treatment equipment and forged chain is used in overhead conveyors for automobile industries.

Referring to Table 2.1, chain conveyor has many advantages compared to belt and roller conveyor. These advantages can be summarized as follows:

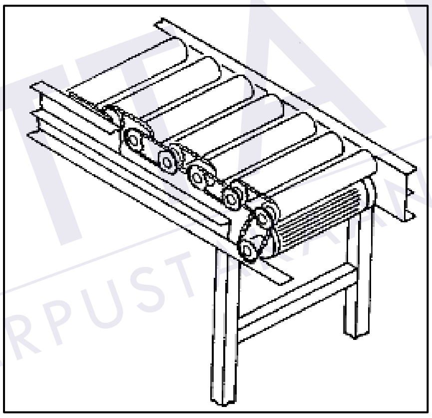
i. Suitable to handle bulk material

ii. Easily integrated into existing production

iii. Take up small space

Jeffrey (2013) & GlobalSpec (2013) stated that because of these advantages, conveyor chain had been applied widely in coal mining, food processing, sewage treatment, timber harvesting, agricultural, bakery, harvesting, and textile machines; car, cement, and chemical plants; and sorting, handling, and material conveyors.

There are floor type and overhead type of chain conveyor as shown in Figure 2.1 (a, b) (DAIFUKU, 2008; MHET, 1999).



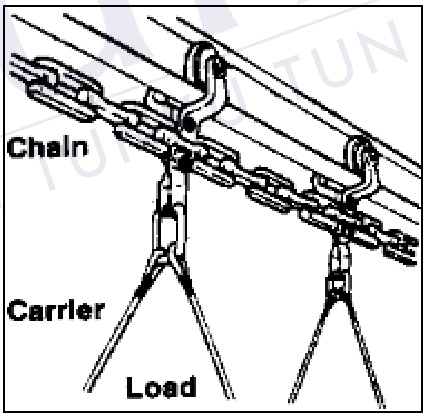


Figure 2.1 (a): Floor type conveyor   Figure 2.1 (b): Overhead type conveyor

2.3 Roller chain conveyor

Nowadays, one of the largest share of chain that being produced is steel chain or commonly called roller chain as shown in Figure 2.2 (Otoshi, 1997). So, for the most part in this case study, we will refer roller chain simply as chain. Chains can be sort according to their uses which can be broadly divided into six types (Otoshi, 1997):

i. Power transmission chain
ii. Small pitch conveyor chain
iii. Precision conveyor chain
iv. Top Chain
v. Free Flow Chain
vi. Large pitch conveyor chain

Diamond Inc. (1999) and Hitachi (2011) stated that the chain conveyors consist of five parts referring to Figure 2.3 and have been summarized its function and criteria as shown in Table 2.2.

Meanwhile, a typical conveyor chain is constructed with two different types of shackles that are the roller link (inner link) and the pin link (outer link) as shown in Figure 2.2 and Figure 2.3 (Kerremans, Rolly, Baets, Pauw, Sukumaran, & Delgado, 2011). Pin link plate and roller link plate are the component that bears the tension placed on the chain. Repeated loading and sometimes accompanied by shock also can causes the failure of plate.

So, plate is one of the important parts that must have great static tensile strength and must hold up the dynamic forces of load. Moreover, the plate must meet environmental resistance such as corrosion and abrasion. This case study will focus why the conveyor chain links has fail.

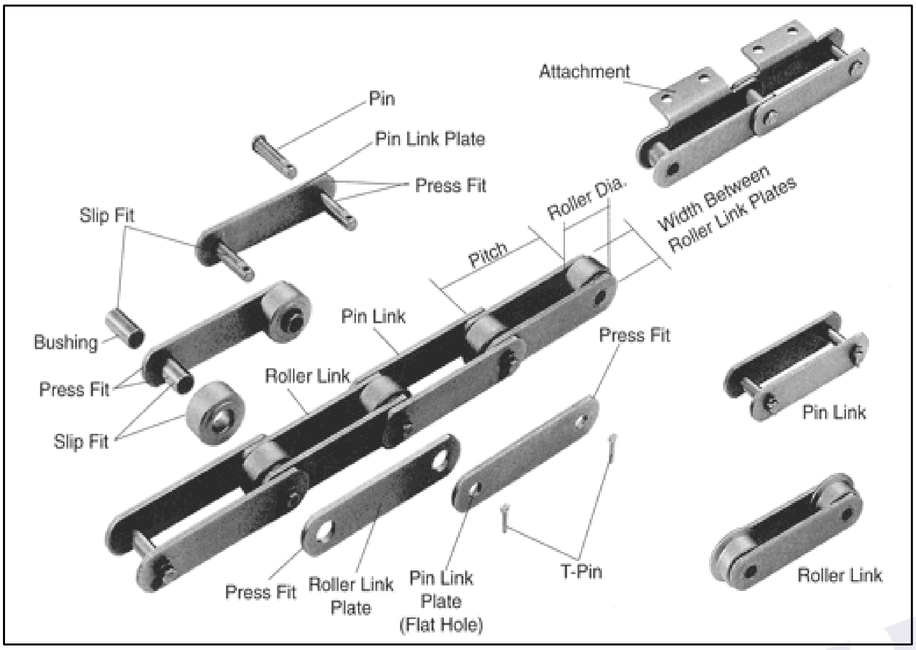


Figure 2.2: Basic structure of a conveyor chain (Otoshi, 1997)

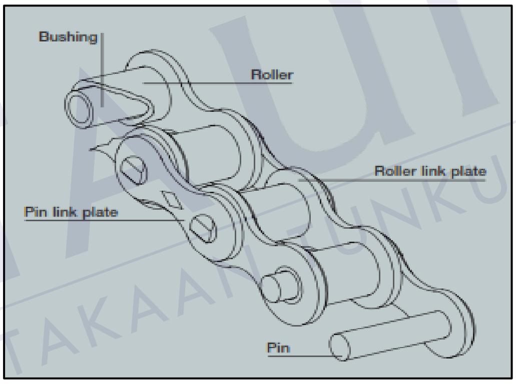


Figure 2.3: Five components of chain conveyor (Diamond, 1999)

Table 2.2: Function and criteria of chain conveyor

Part	Function	Criteria
Plate	Bears the tension placed on the chain	- must have great static tensile strength - must hold up to the dynamic forces of load and shock - must meet environmental resistance requirements
Pin	To shearing and bending forces transmitted by the plate	- needs high tensile and shear strength - resistance to bending - sufficient endurance against shock and wear
Bushing	To shearing and bending stresses transmitted by the plate and roller, and also gets shock loads when the chain engages the sprocket	- must have great tensile strength against shearing - resistant to dynamic shock and wear
Roller	To impact load as it strikes the sprocket teeth during the chain engagement with the sprocket	- resistant to wear - have strength against shock, fatigue, and compression
Cotter pin, Spring Clip, T-Pin	Prevent the outer plate from falling off the pin at the point of connection	- may wear out during high-speed operation, therefore, for this application, these parts require heat treatment

2.4 Study of conveyor chain

2.4.1 Overview of forces acting in conveyor roller chain

This section is study the types of forces that acting in roller chains. According to Kerremans et. al.(2011):

> "When roller chain that transport pallets moving on a track, the weight of the pallets that applied on the pins on the chain will resulting a normal force N_{02}

on each pin. A tensile force F_t is exerted on the chain by the sprocket. Then, this tensile force Ft will be transferred from inner link to the outer link by bushing and pin acting together as a bearing. The normal force N_{02} is transferred from pin to bushing and then from bushing to track through roller. The pin and bushing have a small clearance resulting in eccentricity e_{23}. Analogous, bushing and roller have a small eccentricity e_{34}".

Assume that the chain moving on a track from left to right and small eccentricity e_{34} exaggerated on drawing as shown in Figure 2.4.

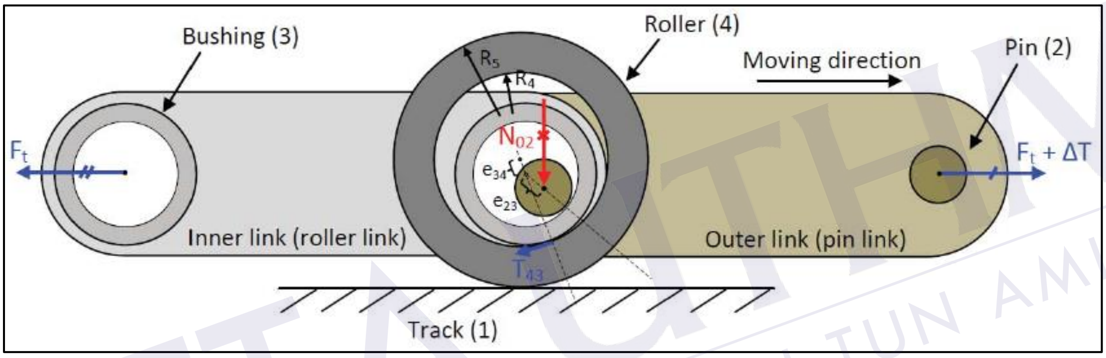


Figure 2.4: Section view of a roller chain with exaggerated clearances (Kerremans, Rolly, Baets, Pauw, Sukumaran, & Delgado, 2011)

2.5 Failure of conveyor

Failure mean is not meeting a desirable or intended objective. There are five general failure categories that are fracture (full section), cracking (partial section), distortion (bending, elongation, and plastic collapse), corrosion (pitting, through wall perforation) and wear (material wastage). Gagg, (2005) and Bošnjak S. et. al. (2011) pointed out in his case study that failures can be cause by:

i. Designing –in defects
ii. Manufacturing-in defects
iii. Operating-in defects
iv. Environment-in defects

Reddy (2004) described in his investigation that there are two types of defects that are generally observed in materials:

i. Inherited defects where the origin is in the ingot
ii. Generated defects that are introduced in the material during various metal working operations and thermal treatments

Meanwhile, failure analysis is the process of collecting and analyzing data to determine the cause of a failure. Referring to Aliya (2003), failure analysis is a process that is performed in order to determine the causes or factors that have led to undesired loss or functionality. The steps to be taken to perform failure analysis in this case study will be discussed in Chapter 3, Methodology section.

CHAPTER 3

LITERATURE REVIEW

The literature review has been conducted on failure analysis of conveyor chain and is still continued. This chapter reviews the relevant literature of failure analysis of chain conveyor and can be divided into three categories.

The first category includes failure analysis techniques and tools that commonly used to investigate failure of conveyor. The second category includes types of defects that have been found in conveyor chain. And the last category involves how to prevent the failure of conveyor chain.

3.1 Failure analysis of chain conveyors

The failure analysis process relies on collecting failed components for subsequent examination of the cause or causes of failure using a wide array of methods, especially microscopy and spectroscopy. The NDT or nondestructive testing methods are valuable because the failed products are unaffected by analysis, so inspection always starts using these methods.

Meanwhile, RENESAS Corp. (2006) describe that "failure analysis is an investigation of failure mode and mechanism using optical, electrical, physical, and chemical analysis technique".

Bun (2000) in his investigation of chain conveyor at dewatering system used four tools and technique of failure analysis to find out the causes of the chain failure. He uses visual examination, hardness testing, chemical analysis by using Scanning Electron Microscopy Energy Dispersive Analysis by X-Ray (EDAX) and microstructure examination. These four techniques normally being used by the researchers to collect and analyse the data in the failure field.

Bun (2000) analyse by metallographic examination reveals the shrinkage cavities, high density of gas porosity and cracks in the junction of the cast chain link. The presence of the large cavities and high porosity was formed during solidification in casting. The spherical area that exists is due to bubbles of gas that are ejected as the metal freezes and then trapped before they can leave the liquid.

Based on his investigation, Bun (2000) concluded these manufacturing defects are the dominant source that responsible on the failure. He believed that a comprehensive quality control system in the manufacturing process can reduce the cause of material defects.

Meanwhile, M. Sujata et al (2006) found a shallow crack on the surface of the link using visual examination as shown in Figure 3.1. Under stereo-binocular microscope, he found the fracture surface showed coarse crystalline features .Then, sample containing the crack was cut, mounted, metallographically prepared and observed under an optical microscope.

It can be seen as in Figure 3.2 that the crack-like defects is not perpendicular to the surface. In between the cracks surfaces, M. Sujata et. al (2006) uses Energy Dispersive X-Ray (EDX) analysis in SEM to investigate and he found that the non-metallic inclusions are mainly iron oxide.

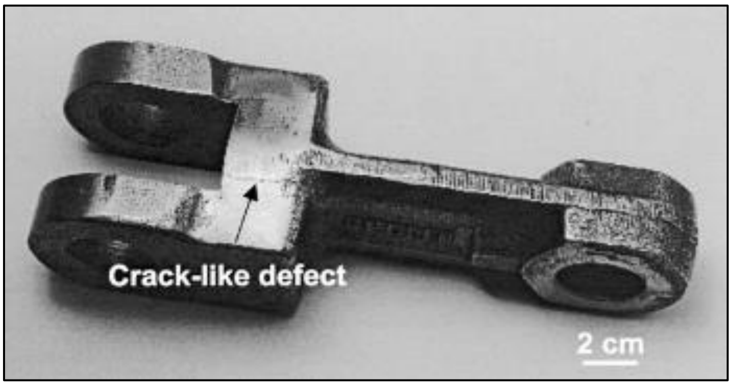


Figure 3.1: Visual Examination revealed a crack-like surface defect (M. Sujata, 2006)

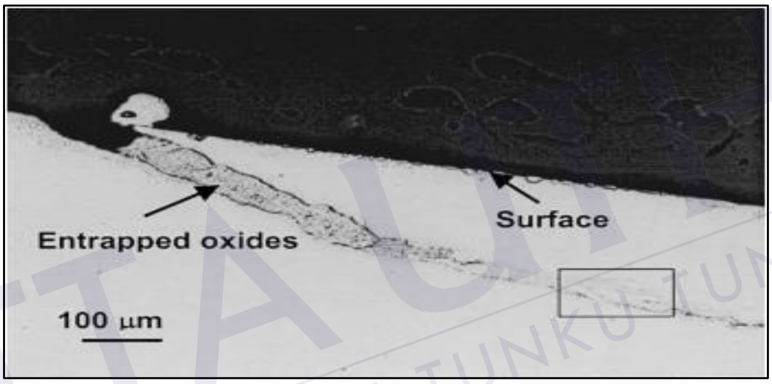


Figure 3.2: Optical micrograph showing Oxides entrapment in the material near the surface (M. Sujata, 2006).

In his study, M.Sujata et. al (2006) gives gas carburising treatment to the components for surface hardening followed by tempering. According to him, hardness survey showed a case depth of about 2.5 mm at the surface containing the crack origin, while the same was found to be 0.4-0.5 mm elsewhere. The fracture surface was grinded and the hardness measurements showed a case depth of 0.4-0.5mm and the localized region where the fracture initiation occurred was 2.5 mm. He believes that this is possible only when there is a surface discontinuity such as presence of a crack prior to the carburising treatment.

Referring to this evident, he concludes that the conveyor chain links have failed due to presence of defects that is manufacturing-in defect such as Bun (2000).

The defects were identified as forging laps or folds and can be summarize as inherited defects. The investigation also showed that surface defects were present in the billet itself. So he recommends that the billet be properly dressed and the surface defects are removed prior to the forging operations.

Momcilovic et. al (2011) stated that the contact zone between chain link and bracket is one of the most stressed zones as shown in Figure 3.3. The fracture always occurred in that zone. Using Scanning Electron Microscopy analysis, he found the significant presence of oxide on crack surface. Based on his research, he concludes that the origin of cracks in chain brackets is found in the production process, because the wrinkling of the material appears during hot bending.

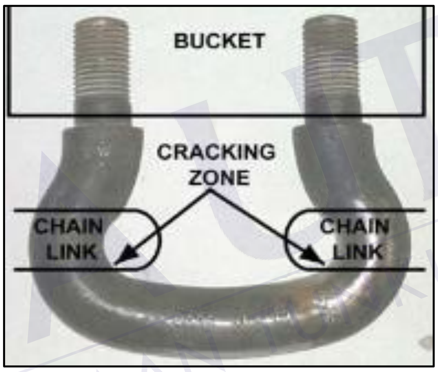


Figure 3.3: Cracking zone at chain bracket (Momčilović, Hut, Milović, & Atanasovska, 2011)

Bošnjak S. et. al. (2011) added his investigation by using finite element method (FEM) to find working stresses in the chain link. Refering to Figure 3.4, he found that the critical zone or fractures zone was around the chain link.

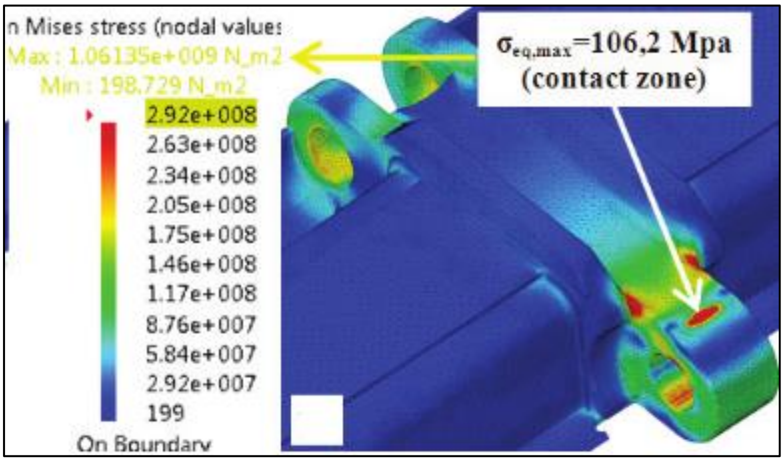


Figure 3.4: Stresses zone in the chain link (Bošnjak, Arsic, Nenad, Odanovic, & Dordevic, 2011)

Then, Bošnjak S. et. al. (2011) investigate the chemical composition of sample and he found that the chemical composition of the chain link material meets the requirements of standard DIN EN 10293 for steel casting.

Tensile testing and impact energy show that the chain link doesn't fulfil the supposed requirements. Tensile test showed that the elongation of the chain link material is more than 40% less than the elongation prescribed by standard and the impact energy is approximately 2.4 times less than the prescribed one in standard DIN EN 10293. By using Vickers hardness testing, the results of the hardness measurements indicate that the required depth of hardening - 10 mm, is not achieved by induction hardening.

Based on the numerical-experimental analysis, Bošnjak S. et. al. (2011) concluded that substantial deviation of the mechanical properties of the material with respect to those prescribed by the standard and the presented failure of the chain link was caused by 'manufacturing-in' defects (Gagg, 2005; and Bosnjak, Arsic, Zrnic, Rakin, & Pantelic, 2011).

Meanwhile, the failure that involve connections such as welding also extensively been studied. Khaled et. al (2010) investigate failure of Grade-80 alloy steel towing chain links. By using optical metallography and SEM analysis, the fatigue failure was found due to generated cracks at outer circumference of the weld.

The fatigue crack propagation was evident by progressive marks and striations such as in Figure 3.5 below. Khaled et. al (2010) conclude that, the evidence of lack of some key alloying elements, welding defects and improper post weld heat treatments of the chain links lead to the failures.

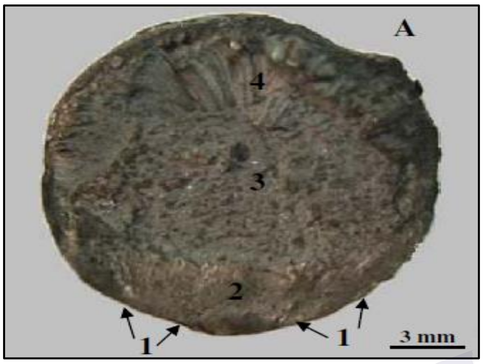


Figure 3.5: Mating surface A with areas labelled 1–4 represent: (1) fatigue origins, (2) fatigue progressive marks and final rupture by (3) void formation and (4) step-like brittle rupture (Khaled Al-Fadhalah, Ahmed Elkhory, Majed Majeed, 2010)

3.2 Conclusion to the chapter

The literature reviews that have been discussed above were divided into three categories. First category is a discussion about the technique or tools that have used to find out the failure of samples. Most of the previous study used Scanning Electron Microscopy, Energy Dispersive X-Ray (EDX) analysis, chemical analysis, tensile testing and hardness testing. Bošnjak S. et. al. (2011) diversify the investigation with finite element method to prove the most stresses zone have been identified around the chain link.

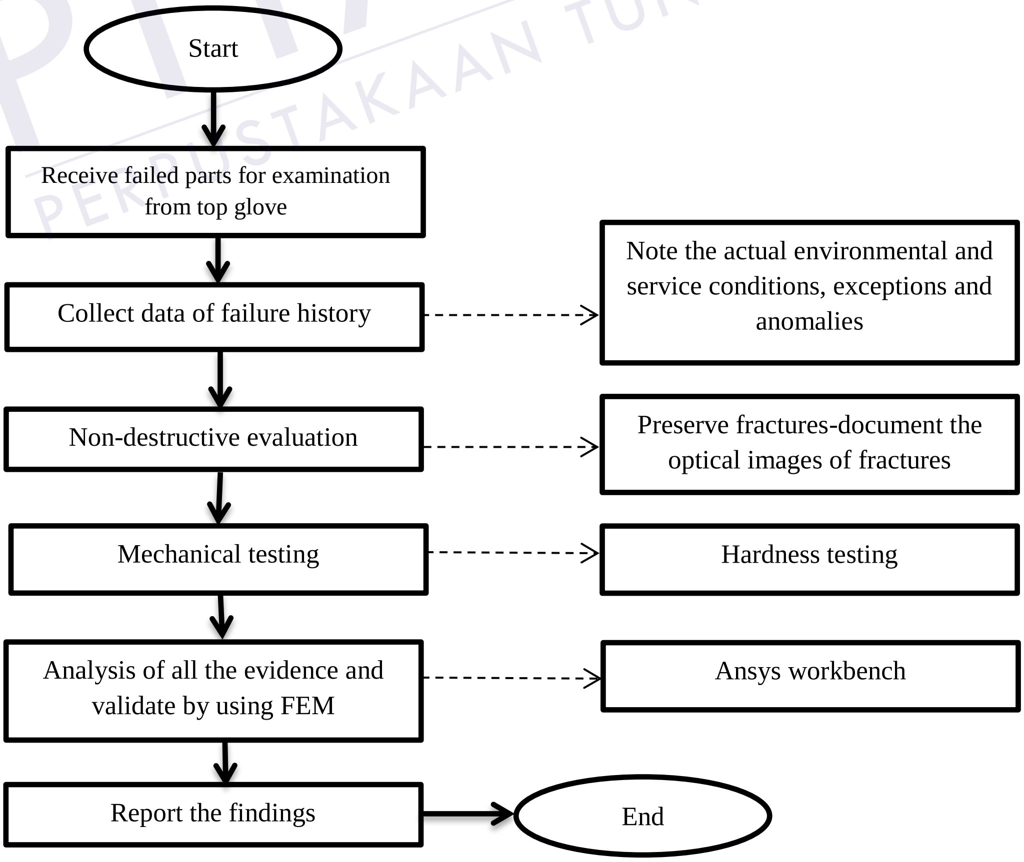
There are several factors that contribute to the failures that can be categorized into four; manufacturing-in defects, designing-in defects, operating-in defects and environment-in defects. These types of defects can be inherited defects of generated defects that have been discussed in Chapter 2 before.

CHAPTER 4

METHODOLOGY

This chapter describes the methodology used to achieve the project objectives. First, the failure analysis methodology illustrated in flow chart. The steps to perform failure analysis have been discussed in this chapter starting with visual examination, non-destructive testing, metallographic analysis and hardness testing.

4.1 Failure analysis methodology flow chart



4.2 Introduction of failure event

Failure analysis is the process of collecting and analyzing data to determine the cause of a failure. Commonly, there are 14 steps in basic approach to perform failure analysis procedure (AMC, 2012). The primary tools that will be used in this case study are:

i. Visual Examination
ii. Mechanical Properties
iii. Scanning Electron Microscope Analysis
iv. Chemical Analysis
v. Metallographic Analysis

4.2.1 Visual examination

First phase will perform preliminary examination by visual after receive the failed samples from Top Glove Corporation. Visual means that we do inspection at failed samples using human senses such as vision. At this preliminary investigation we will record part numbers, serial numbers and supplier of manufacturing markings. Then photo of the part with special attention paid to anomalies (scratches, fractures and unusual marks) aided by using Canon D90 DSLR.

Visual examination then will be aided by using light microscope and image analyser to see more clearly than naked eye the fractures surfaces and surface defects. This step is to examine fracture surfaces and to identify what type of fractures it is either ductile or brittle as shown in Figure 4.1. Chevron marks always appear at fracture surface as a result of a fracture process. Chevron marks very helpful because it can point to the crack origin such as an example at Figure 4.2.

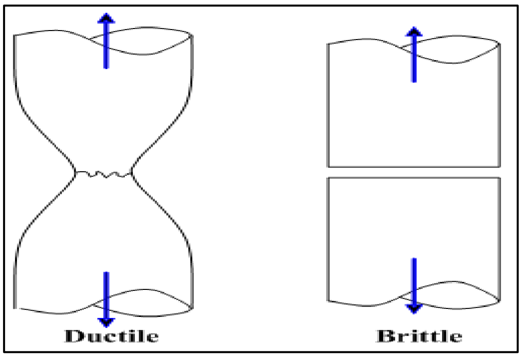


Figure 4.1: Ductile and Brittle Fractures (Kopeliovich, 2012)

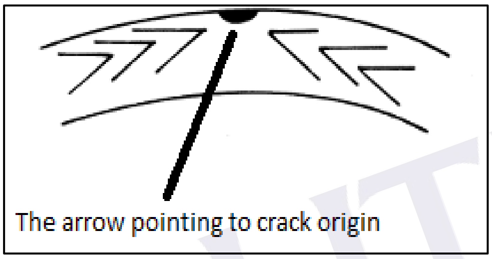


Figure 4.2: Chevrons pointing to the crack origin

Furthermore, at this preliminary stage, other important information such as engineering drawings, part specifications, product literature, life history of part including servicing and maintenance also will be collected. So, all observations should be recorded, photographed and information must be gathered before the part is cut for destructive testing.

4.2.2 Perform non-destructive testing

4.2.2.1 Scanning electron fractography

Usually, investigator of failure will perform non-destructive testing or commonly known as NDT after Visual Examination and low magnification stereomicroscope. NDT is a wide group of analysis techniques used in science and industry to evaluate the properties of a material, component or system without causing damage (Cartz, 1995).

So, one of the most important instruments used to carry out failure analysis is Scanning Electron Microscope or commonly known as SEM. SEM is a a type of electron microscope that images the sample surface by scanning it with a high-energy beam of electrons in a raster scan pattern and belongs to the non-destructive test.

The electrons interact with the atoms that make up the sample producing signals that contain information about the sample's surface topography, composition and other properties (Shamsudin, 2011). SEM magnification can be control over a range up of to 6 orders from 19x to 300,000x. SEM also can achieve resolution better than 1 nanometre. And the important of SEM in failure analysis is due to its ability to provide three-dimensional image for the purpose of fractographic study where the depth of field is needed on an irregular fracture surface (De Carvalho, 2003). In this investigation, scanning electron microscopy (SEM with EDX: TM3000 Hitachi) as shown in Figure 4.3 will be used to reveal the fracture surface topography at high magnification.

Figure 4.3: SEM with EDX: TM3000 Hitachi at *UniMAP*

4.2.2.2 Chemical analysis

The chemical composition of the material in the region of the fracture surface shall be inspected (Hutchings & Unterweiser, 1981). So, this chemical analysis will be carried out by using Scanning Electron Microscope (SEM) equipped with Energy Dispersive Spectrometry (EDS/EDX). EDS is used for the elemental analysis or chemical characterization of a sample. All elements from atomic number 4 (Be) to 92 (U) can be detected using EDS.

4.2.2.3 Sample selection and preparation for scanning electron microscope (SEM)

i. Specimen will be chosen exactly to the fracture surface which will identify the chemical compositions at the failure parts of chain links. The ideal size should not exceed 10 mm. The thickness should be as small as can be handled easily without damaging the sample or region of interest on the sample.

ii. Before doing any SEM characterization, the sample must be clean and completely dry (meaning that it will not outgas). Surface oils or dirt must be removed with solvents such as methanol or acetone then can be blown dry using a compressed gas. After cleaned by water, samples should be dried completely using oven or hot plate. Surface dusts are removed using above processes, and they can also be removed by blowing a compressed gas.

iii. Samples then, have to be mounted on a circular metallic sample holder that available. The samples have to be fixed onto the sample holder rigidly enough so that they do not fall off easily while handling.

iv. Samples must be arranged in a circular pattern and will be locating in SEM chamber which is always under vacuum.

v. Since an electron beam is incident on the samples for SEM analysis it is essential that the samples are electrically conducting. If not, this can be achieved by coating the samples with 20-50 nm thick gold or silver.

References

Aliya, D. (2003). *The failure analysis process. An overview.* Materials Park: ASM International.

Allen, S. (Jan, 2010). *Henry Ford - Founder of Ford Motor Company and Assembly Line Innovator* . Retrieved 10 Jan, 2013, from About.com Guide: http://entrepreneurs.about.com/od/famousentrepreneurs/p/henryford.htm

AMC. (25 Jan, 2012). *General Failure Analysis Procedure*. Retrieved 1 Oct, 2012, from American Metallurgical Consultants: http://www.materialsengineer.com/CA-Failure-Analysis-Procedure.htm

ASTM. (2010). *ASTM E18 - 11 Standard Test Methods for Rockwell Hardness of Metallic Materials.* American Society for Testing and Materials .

Ban, C. W. (2000). *Failure Analysis Of Conveyor Chain.*

Barton, C. J. (7 Oct, 2010). *Conveyor Systems Overview - The Different Types.* Retrieved 12 Nov, 2012, from Ezine Articles: http://ezinearticles.com/?Conveyor-Systems-Overview---The-Different-Types&id=6557682

Bošnjak, S. M., Arsic, M. A., N. .., Odanovic, Z. D., & Dordevic, M. D. (2011). Failure Analysis of the Stacker Crawler Chain Link . *Engineering Procedia*, 10: 2244–2249.

Bosnjak, S., Arsic, M., Zrnic, N., Rakin, M., & Pantelic, M. (2011). Bucket wheel excavator: Integrity assessment of the bucket wheel boom tie-rod welded joint. *Engineering Failure Analysis*, 18:212–22.

Bramfitt, B. L., & Benscoter, A. O. (2002). *Metallographer's Guide:Practice and Procedures for Irons and Steels.* ASM International.

Cartz, L. (1995). *Nondestructive Testing.* Materials Park: ASM International.

DAIFUKU. (2008). *DAIFUKU WEBB*. Retrieved 12 Dec, 2012, from Daifuku America Corporation: http://www.daifukuamerica.com/products/1/4/Automotive/Chain-Conveyor-System

De Carvalho, M. C. (2003). Fracture analysis of a flow control device used in the petrochemical industry. *Engineering Failure Analysis*, 423-429 .

DEMATIC. (2012). *Conveyor Systems*. Retrieved 2013 Jan, 1, from DEMATIC: http://www.dematic.com/conveyor-systems

Diamond. (1999). *British Standard Chain Product Guide.* Retrieved 10 Oct, 2012, from Diamond Chain Company Inc.: www.diamondchain.co.uk

EN-10293, D. (2005). *Steel castings for general engineering uses (English version).*

ESAB. (2013). Retrieved 7 May, 2013, from Welding & Cutting United States: http://www.esabna.com/euweb/mig_handbook/592mig10_7.htm

Gagg, C. (2005). Failures of components and product by 'engineered in defects'. *Engineering Failure Analysis*, 212–222.

GlobalSpec. (2013). *Conveyor Chain Information*. Retrieved 10 Jan, 2013, from Global Spec: http://www.globalspec.com/learnmore/mechanical_components/chains_sprockets/conveyor_chain

Glove, T. (2008). *Top Glove Sdn. Bhd.* Retrieved 13 1, 2013, from The World's Largest Rubber Glove Manufacturer: http://www.topglove.com.my/

HERA. (2013). *Heavy Engineering Research Association.* Retrieved 1 6, 2013, from Defects/Imperfections in Welds Type of Porosity: http://www.hera.org.nz/Category?Action=View&Category_id=511

Hitachi. (2011). *HITACHI Conveyors Chain.* Hitachi Metals Techno, Ltd.

Hutchings, F. R., & Unterweiser, P. M. (1981). Failure analysis: The British Engine technical reports. *American Society for Metals*.

Jeffrey, R. (2013). *Conveyor Chain.* Renold.

Keng Lek Engineering. (2012). *Keng Lek Engineering Sdn Bhd*. Retrieved 3 April, 2013, from Keng Lek Engineering Sdn Bhd: http://www.kenglek.com/

Kerremans, V., Rolly, T., Baets, P. D., Pauw, J. D., Sukumaran, J., & Delgado, Y. P. (2011). Wear of conveyor chains with polymer rollers. *Sustainable Construction and Design 2011* .

Kopeliovich, D. (31 May, 2012). *Fracture Toughness*. Retrieved 10 Dec, 2012, from SubsTech: http://www.substech.com/dokuwiki/doku.php?id=fracture_toughness

Lewis, A. (15 Dec, 2011). *Morocco's fish fight: High stakes over Western Sahara*. Retrieved 1 Nov, 2012, from BBC News Africa: http://www.bbc.co.uk/news/world-africa-16101666

M. Sujata, M. V. (2006). Failure analysis of conveyor chain links. *Engineering Failure Analysis* , 914–924.

MHEDA. (Jan, 2001). *Transport Of Bulk Materials By Conveyor Dates Back To 1795*. Retrieved 10 Dec, 2012, from The MHEDA Journal: http://www.themhedajournal.org/index.php/2004/07/transport-of-bulk-materials-by-conveyor-dates-back-to-1795/

MHET. (30 Sept, 1999). *Material Handling Equiptment Taxonomy*. Retrieved 12 Dec, 2012, from CIC/MHE: http://www.ise.ncsu.edu/kay/mhetax/TransEq/Conv/index.htm#Chain%20conveyor

Momčilović, D., Hut, N., Milović, L., & Atanasovska, I. (2011). FAILURE ANALYSIS OF CHAIN BRACKET. *New Trends in Fatigue and Fracture*, 123-126.

Otoshi, K. (1997). *The complete guide to chain.* Retrieved 12 Nov, 2012, from U.S. Tsubaki: http://chain-guide.com/

Reddy, A. V. (2004). *Aeronautical and engineering component failure.* United States of America: CRC Press.

RENESAS. (2006). *Renesas Corp.* Retrieved 1 Jan, 2013, from Renesas Corp.: http://am.renesas.com/

Ross, R. B. (1995). *Investigating Mechanical Failures-The Metallurgist's Approach.* Chapman & Hall.

Sahu, G. (2005). Iron Carbon Diagram. In *Handbook of Piping Design* (pp. 87-96). New Delhi: New Age International (P) Limited.

Schroeder, C. J. (2013). Metallurgical Failure Analysis: Case Study of a Fractured Hitch. *Technical Articles from Element experts*.

Shamsudin, S. R. (22 March, 2011). *Scanning electron microscope (SEM) & how it works*. Retrieved 12 Dec, 2012, from Scanning Electron Microscopy@UNIMAP: http://emicroscope.blogspot.com/2011/03/scanning-electron-microscope-sem-how-it.html

Singh, M., & Singh, M. (4 Oct, 2012). *Chain Conveyors have and can improve the efficiency of many industrial processes.* Retrieved 10 Dec, 2012, from NEO Conveyors: http://www.neoconveyors.com/blog/chain-conveyors-have-and-can-improve-the-efficiency-of-many-industrial-processes/

Zipperian, D. C. (2001). Metallographic Specimen Preparation Basics. *Pace Technologies*.