UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Crack Analysis in Weld Joints of Pipes in the Oil and Gas Industry

Thesis submitted in accordance with the partial requirements of the Universiti Teknikal Malaysia Melaka for the Degree of Bachelor of Engineering (Honours) Manufacturing (Engineering Material)

By

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APPROVAL

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ABSTRACT

The idea and objective of this study is to analyze cracks that initiates in weld joints of pipes due to quenching phenomenon. The crack is analyzed using two Quality Control methods which are Mechanical Testing (MT) and Nondestructive Testing (NDT). The pipe material is as per API 5L Grade B and joined using Shielded Metal Arc Welding (SMAW) which is common for Process Piping in the oil and gas industrial application. The materials are prepared as per ASME IX Welding Codes and Standards. In order to initiate the crack formation, the quenching phenomenon is simulated using tap water at post weld treatment. After the simulation process, NDT is conducted using Visual Inspection (VI), Ultrasonic Testing (UT), Magnetic Particle Inspection (MPI) and Dye Penetrant Testing (DPT) along with MT which is Hardness Test (HT), Charpy Impact Test (CIT) and Bending Test (BT). The VI conducted has determined the post weld temperature of the weld joint and the weld metal is the area with the highest temperature followed by the Heat Affected Zone (HAZ) and the base metal. The quality control testing conducted results no visible defects on the external surface of the pipes (face weld) through VI, MPI and DPT but the root weld has four main defects which are Incomplete Root Penetration, Concave Root, Root Undercut and Root Crack determined using UT. The MT conducted indicated that the properties of the welded pipe material are affected. The weld metal and the face weld area have higher hardness value than the base metal, HAZ and root weld. The CIT conducted results the base metal has higher toughness than the weld metal and HAZ. The face weld also has higher ductility than the root weld when root and face BT is conducted. There are no visible cracks at the face weld area because quenching process is only simulated at the internal surface of the weld joint and has only affected the root weld. The properties of the pipe material are affected due to the heat treatment that occurred from high temperature of SMAW process and quenching simulation.

ABSTRAK

Gagasan kajian ini ialah untuk menganalisis pembentukan keretakan yang dalam sendi kimpalan paip yang disebabkan oleh fenomena perbezaan celupan. Retak dianalisis menggunakan dua kaedah kawalan mutu iaitu Ujian Mekanikal (UM) dan Ujian Tanpa Musnah (UTM). Bahan paip adalah seperti mengikut API 5L Gred B dan disambung menggunakan Kimpalan Arka Logam Terlindung (KALT) yang biasa digunakan untuk Sistem Paip Pemprosesan dalam aplikasi perindustrian minyak dan gas. Bahan paip disediakan seperti mengikut ASME IX Piawaian dan Kod Kimpalan. Bagi membentuk keretakan, fenomena perbezaan celupan disimulasi menggunakan air paip selepas proses kimpalan. Selepas proses simulasi, UTM dijalankan menggunakan Pemeriksaan Visual (PV), Ujian Ultrasonik (UU), Pemeriksaan Zarah Magnet (PZM) dan Ujian Penembusan Pencelup (UPP) berserta UM yang mengandungi Ujian Kekerasan (UK), Ujian Hentaman Charpy (UHC) dan Ujian Lentur (UL). PV yang dijalankan telah mengenalpasti suhu sendi kimpalan dan logam kimpal adalah kawasan dengan suhu tertinggi diikuti Zon Kesan Haba (ZKH) serta logam asas. Hasil ujian kawalan mutu yang dijalankan menunjukkan tiada kecacatan dapat dilihat di permukaan luar paip (muka kimpalan) melalui PV, PZM dan UPP tetapi akar kimpalan mempunyai empat kecacatan utama iaitu penembusan akar tidak lengkap, akar cekung, potongan muka akar dan keretakan akar yang ditentukan menggunakan UU. UM yang dijalankan menunjukkan bahawa ciri-ciri kimpalan bahan paip terjejas. Logam kimpal dan muka kimpalan mempunyai nilai kekerasan yang lebih tinggi berbanding logam asas, ZKH dan akar kimpalan. Hasil UHC yang dijalankan menunjukkan logam asas mempunyai keliatan lebih tinggi daripada logam kimpal dan ZKH. Muka kimpalan juga mempunyai kemuluran lebih tinggi daripada akar kimpalan apabila UL muka dan akar dijalankan. Tiada keretakan dapat dilihat di muka kimpalan kerana proses perbezaan celupan hanya dilakukan di permukaan dalam sendi kimpalan dan hanya memberi kesan pada akar kimpalan. Ciri-ciri bahan paip terjejas disebabkan oleh rawatan haba oleh suhu tinggi KALT dan simulasi perbezaan celupan yang dijalankan.

DEDICATION

I would like to dedicate this thesis of my research titled Crack Analysis in Weld Joint of Pipes in the Oil and Gas Industry to the hardworking lecturers and professors of Universiti Teknikal Malaysia Melaka who never gave up on their students and apprentices. I would also like to dedicate it to the hardworking team of college staffs, Faculty of Manufacturing Engineering and the lab technicians.

This thesis also goes to my fellow classmates at 4BMFB1, course mates of BMFB and friends from other courses and faculties. This thesis is also dedicated to the freshmen at college for their future reference and the Library of Universiti Teknikal Malaysia Melaka.

Finally to my beloved friends from out of this college and my family. I'm trying my best to make you guys proud.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS, SYMBOLS, SPECIALIZED NOMENCLATURE

API	American Petroleum Institute
ASME	American Society of Mechanical Engineers
ASTM	American Standard for Testing and Materials
BT	Bend Test
CIP	Charpy Impact Test
DPT	Dye Penetrant Testing
HAZ	Heat Affected Zone
HT	Hardness Test
MPI	Magnetic Particle Inpection
MT	Mechanical Testing
NDT	Non Destructive Testing
SMAW	Shielded Metal Arc Welding
UT	Ultrasonic Testing
VI	Visual Inspection

CHAPTER 1

INTRODUCTION

1.1 Background of the Research

Crack is also defined as fracture or fatigue which is common among materials. Fatigue of welds is even more complex. Welding strongly affects the material by the process of heating and subsequent cooling as well as by the fusion process with additional filler material, resulting in inhomogeneous and different materials. [1]

The common weld joints are meant to be a strong form of structure in the industry. Furthermore, a weld is usually far from being perfect, containing inclusions, pores, cavities, undercuts etc. The shape of the weld profile and non-welded root gaps create high stress concentrations with widely varying geometry parameters. Last but not least residual stresses and distortions due to the welding process affect the fatigue behavior.

As a consequence, fatigue failures appear in welded structures mostly at the welds rather than in the base metal, even if the latter contains notches such as openings or re-entrant corners. For this reason, fatigue analyses are of high practical interest for all cyclic loaded welded structures, such as ships, offshore structures, cranes, bridges, vehicles, railcars etc. In view of the complexity of the subject and the wide area of application it is not surprising that several approaches for fatigue analysis of welded joints exist. However, it is almost impossible to follow up the great amount of related literature dealing with fatigue testing and the development or application of approaches to consider all the different influence parameters. [1]

1.2 Problem Statement

The Oil and Gas Industry has a lot of discipline involved in the construction and fabrication activity to conform the growth and development of the industry regarding the production of crude oil and natural gas. There are a lot of projects done to develop the industry such as refinery plants, processing plants, gas terminals, compressor stations and offshore oil rigs.

All of the plants and stations mentioned above operate internally through a pipe network and it is connected through a series of pipeline. The pipeline and pipes may be connected through aboveground, underground, in-plant or even sub-sea. The pipes distribute crude oil and natural gas from the oil rigs, to the onshore terminals and throughout the plants and stations.

This exposes the pipes to corrosion risk since that the materials used as pipes have high tendency to corrode and it carries hydrocarbon based medium. Even though the pipes are protected with various corrosion prevention applications, the internal surface of the pipes still has the tendency to corrode. This phenomenon is supported by the existence of tensile stress of pipes from the pressure it withheld. The corroded layer makes the pipes thickness to decrease and with the stress applied to the pipe, a slight crack may agitate before it burst through a larger crack. The leakage of the pipes distribute the medium which is highly flammable into thin air and has the possibility to explode if it happens to be near a heat source and this may cause a major catastrophe to the industry.

As the problem stated above, a study is conducted to simulate the quenching scenario using the sample obtained from actual plants and stations, corrode the internal surface and applying internal stress to the pipe in order to study the crack by analyzing it using Non-Destructive Testing (NDT) and Mechanical Testing (MT).

1.3 Research Objectives

There are two main objectives that have to be achieved in order to fulfill the requirements of this study. These objectives are identified from a series of discussion and references made regarding the problem statement.

a) To simulate and understand the quenching phenomenon by using actual sample of welded carbon steel pipe.

b) To conduct NDT and MT to the weld joint in order to identify the crack that agitates due to quenching.

1.4 Research Methodology

In order to achieve the objectives of my research, it is required to come up with a proper and suitable methodology. The quenching phenomenon is simulated and quality control testing and observations is applied to obtain results from my research

a) Two carbon steel pipes sample is chamfered fit up and welded using SMAW to form the single V butt joint.

b) Prior post weld, the material will undergo quenching process using tap water.

c) At the time of the crack agitates (identified through visual inspection), the pipe sample is tested using NDT and MT to determine the character of the crack.

CHAPTER 2

LITERATURE REVIEW

2.1 Crack Theory

Arising from the manufacturing process, interior and surface flaws are found in all metal structures. Not all such flaws are unstable under service conditions. Fracture mechanics is the analysis of flaws to discover those that are safe (that is, do not grow) and those that are liable to propagate as cracks and so cause failure of the flawed structure.

(a) (b)

Figure 2.1: Types of crack; (a) Intergranular Crack (b) Transgranular Crack

Fracture mechanics as a subject for critical study has barely been around for a century and thus is relatively new. There is a high demand for engineers with fracture mechanics expertise - particularly in this day and age where engineering failure is considered 'shocking' amongst the general public.

The following information is needed for a fracture mechanics prediction of failure:

a) Applied Load
b) Residual Stress
c) Size and Shape of the Part
d) Size, Shape, Location, and Orientation of the Crack

Usually not all of this information is available and conservative assumptions have to be made. Occasionally post-mortem fracture-mechanics analyses are carried out. In the absence of an extreme overload, the causes are either insufficient toughness or an excessively large crack that was not detected during routine inspection.

2.1.1 Griffith's Energy Relation

Fracture Mechanics was invented during World War I by English aeronautical engineer, A. A. Griffith, to explain the failure of brittle materials. Griffith was faced with the problem that theoretical calculations showed that the stress at the tip of a sharp crack approaches infinity. Accordingly, any structure containing a crack should fail, no matter how small the crack or how light the load. [2]

To solve this dilemma, Griffith developed a thermodynamic approach. He assumed that growth of a crack requires creation of surface energy, which is supplied by the loss of strain energy accompanying the relaxation of local stresses as the crack advances. Failure occurs when the loss of strain energy is sufficient to provide the increase in surface energy. [2]

2.1.2 Irwin's Modification of Griffith's Energy Relation

Griffith's work was ignored for over twenty years until a group under G.R. Irwin at the U.S. Naval Research Laboratory (NRL) took it up during World War II. Irwin and his colleagues developed a modified form of Griffith's approach; they reformulated it in terms of stress, rather than energy. Their work resulted in a new materials property, fracture toughness, and is now universally accepted as the defining property of fracture mechanics. [2]

But a problem arose for the NRL researchers because naval materials, e.g. ship-plate steel, are not perfectly elastic but undergo plastic deformation at the tip of a crack violating the underlying assumption of the theory. [2]

Linear-elastic fracture mechanics is of limited practical use for structural steels for two other reasons:

(a) Fracture toughness testing is very expensive and sufficient information for selection of steels can be obtained from the simpler and cheaper Charpy Impact Test.

(b) If a part's response to load is sufficiently close to linear-elastic that toughness can be measured, there is little plastic relaxation at the crack tip and the steel will be brittle. Structural steels, in particular, can be prone to brittle fracture, which has led to a number of catastrophic failures.

2.2 Carbon Steel

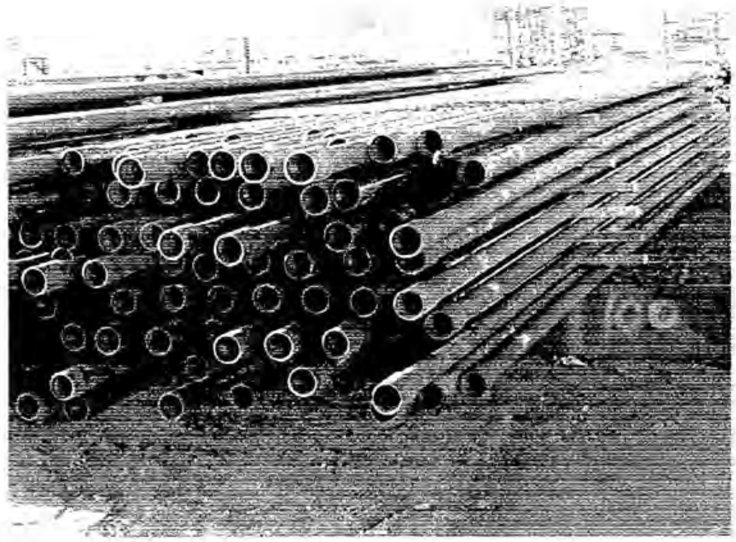

Figure 2.3: Carbon steel pipes.

Carbon steel, also called plain carbon steel, is a metal alloy, a combination of two elements, iron and carbon, where other elements are present in quantities too small to affect the properties. The only other alloying elements allowed in plain-carbon steel are manganese (1.65% max), silicon (0.60% max), and copper (0.60% max). [3]

Steel with low carbon content has the same properties as iron, soft but easily formed. As carbon content rises the metal becomes harder and stronger but less ductile and more difficult to weld. Higher carbon content lowers steel's melting point and its temperature resistance in general. Carbon content influences the yield strength of steel because they fit into the interstitial crystal lattice sites of the body-centered cubic arrangement of the iron molecules.

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 "break away". This is because the interstitial carbon atoms cause some of the iron BCC lattice cells to distort. [4]

2.2.1 Types of Carbon Steel

a) Mild (Low Carbon) Steel

Approximately 0.05–0.29% carbon content (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.

b) 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.

c) High Carbon Steel

Approximately 0.6–0.99% carbon content. Very strong, used for springs and high-strength wires.

d) Ultra-High Carbon Steel

Approximately 1.0–2.0% carbon content. Steels that 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.

Steel can be heat-treated which allows parts to be fabricated in an easily-formable soft state. If enough carbon is present, the alloy can be hardened to increase strength, wear, and impact resistance. Steels are often wrought by cold-working methods, which is the shaping of metal through deformation at a low equilibrium or metastable temperature. [4]

2.3 Metal Fabrication Process

Metal fabrication is a value added process that involves the construction of machines and structures from various raw materials. A fab shop will bid on a job, usually based on the engineering drawings, and if awarded the contract will build the product. Fabrication shops are employed by contractors, original equipment manufacturer and value added reseller. Typical projects include; loose parts, structural frames for buildings and heavy equipment, and hand railings and stairs for buildings. [5]

2.3.1 Fabrication Engineering

The fabricator may employ or contract out steel detailers to prepare shop drawings, if not provided by the customer, which the fabricating shop will use for manufacturing. Manufacturing engineers will program Computer Numeric Control machines as needed.[5]

2.4.2 Raw Materials for Fabrication

Standard raw materials used by metal fabricators are;

a) Plate Metal
b) Formed And Expanded Metal
c) Tube Stock
d) Square Stock
e) Sectional Metals
f) Welding Wire
g) Hardware
h) Castings
i) Fittings

2.3.3 Cutting and Burning Process

The raw material has to be cut to size. This is done with a variety of tools; Special band saws designed for cutting metal have hardened blades and a feed mechanism for even cutting. Abrasive cut-off saws, also known as chop saws, are similar to miter saws but with a steel cutting abrasive disk. Cutting torches can cut very large sections of steel with little effort. [6]

Burn tables are Computer Numeric Control cutting torches, usually natural gas powered. Plasma and Laser burn tables are also common. Plate steel is loaded on a table and the parts are cut out as programmed. The support table is made of a grid of bars that can be replaced. Some very expensive burn tables also include Computer Numeric Control punch capability, with a carousel of different punches and taps. [6]

2.3.4 Forming Process

Hydraulic brakes with v-dies are the most common method of forming metal. The cut plate is placed in the press and a v-shaped die is pressed a predetermined distance to bend the plate to the desired angle. Wing brakes and hand powered brakes are sometimes used. Tube bending machines have specially shaped dies and mandrels to bend tubular sections without kinking them. Rolling machines are used to form plate steel into a round section. English Wheel or Wheeling Machines are used to form complex double curvature shapes using sheet metal. [5]

2.3.5 Machining Process

Fab shops will generally have a limited machining capability including; metal lathes, mills, magnetic based drills along with other portable metal working tools.