UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Faculty of Manufacturing Engineering

EFFECT OF HEAT TREATMENT ON LOW CARBON STEEL CORROSION BEHAVIOR

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Master of Manufacturing Engineering

(Manufacturing System Engineering)

2013

EFFECT OF HEAT TREATMENT ON LOW CARBON STEEL CORROSION BEHAVIOR

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A thesis submitted in fulfillment of the requirement for the degree of Master of Manufacturing Engineering (Manufacturing System Engineering)

Faculty of Manufacturing Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2013

DECLARATION

I declare that this thesis entitle "**EFFECT OF HEAT TREATMENT ON LOW CARBON STEEL CORROSION BEHAVIOR**" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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APPROVAL

This report submitted to the Faculty of Manufacturing Engineering of UTeM as apartial fulfillment of the requirement for master of manufacturing engineering (manufacturing system engineering). The member of supervisory committee is as follow:

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ABSTRACT

This work was to investigating the corrosion behavior of low carbon steel in a salt solution of 3.5wt% NaCl after undergoing two different types of heat treatment at 960 ºC in a furnace. The material of low carbon steel was cut into nine small pieces under three groups A, B and C, without heated annealing and hardening heat treatment respectively. The heat treatment was at temperature 960ºC. The hardness of the sample as received will be 203 kg/mm^2 while after hardening the hardness was increased. The sample was mounted using hot and cold mounting. The microstructure and surface morphology was observed by using Scanning Electron Microscope (SEM) and Optical Microscope (OM) after grinding, polishing and etching on the sample. In group A cementite can be observed clearly on pearlite on the surface before corrosion test. After four days soaking in 3.5 wt% NaCl solution was observed all cementite and pearlite will be transformed to austenite with the remnants of cementite make the surface unstable hence increases the initial corrosion. After four days soaking when the cementite is oxidized and a thick film of corrosion product covers the material surface. The formation of Martensite due to quenching and rapid cooling in group C sample increases the corrosion rate from 0.072 mpy to 0.302 due to decreased of corrosion potential from -572 mV to -639 mV after four days soaking. The corrosion rate of each sample was measured by using electrochemical polarization measurement and Tafel extrapolation technique. From previous result, it was observed that samples which had undergone annealing mode of heat treatment turned out to be the ones with the best corrosion resistance.

ABSTRAK

Projek ini adalah untuk mengkaji kelakuan terhadap kakisan keluli karbon yang rendah dalam larutan garam 3.5wt% NaCl selepas menjalani dua jenis rawatan haba iaitu pada 960 ° C dalam relau. Bahan keluli karbon rendah telah dipotong sembilan keping kecil di bawah tiga kumpulan A, B dan C, masing-masing tanpa rawat dan dipenyepuhlindapan dan dirawat haba pengerasan. Rawatan haba adalah pada suhu 960 ° C. Kekerasan sampel yang diterima terjadi 203 kg/mm^2 dan diperhatikan ia akan menjadi bacaan tertinggi selepas rawatan pengerusm keras. Sampel telah dipasang menggunakan pelekap panas dan sejuk. Mikrostruktur diperhatikan dengan menggunakan Mikroskop Imbasan Elektron (SEM) dan Mikroskop optik (OM) selepas pembersihan sampel. Ini kerana, kumpulan simentit boleh menjadi jelas dalam pearlit di permukaan sebelum kakisan, (selepas empat hari direndam di dalam 3.5 wt% larutan NaCl). Kadar hakisan sampel telah ditentukan dengan menggunakan kaedan elektrokimia polarisasi dan ekstrapolasi Tafel teknik. Permukaan morfologi diperhatikan dengan menggunakan Mikroskop imbusan Elektron (SEM) dan didapati pertumbuhan karat pada pearlit, di masa sama juga ada meningkatkan hakisan dengan peningkatan masa rendaman. Sebaliknya dikumpulan B penyepuhlindapan rawatan haba menukarkan semua simentit dan pearlit lcepada austenit dengan sisa simentit yang menjadikan punca permukaan tidak stabil dan meninglcatken kader kalaisan kadar kaksin akan meningiear selama empat hair redam dan selepas sepuluh hair rendaman benkatan berikatan pening kecton kaksisan.Sample Kumpulan C menerusi proses haba pengerasan dan dimana mengubah

struktur mikroskopik komposisi kepads lapisan logam Martensit. Proses pelindapkejutan dan penyejukan yang pantas menyebabkan peningkatkan kadar hakisan dari 0.072 mpy kepada 0.302 mpy dan menurun potensi kakisan dari -572 mV kepada -639 mV. Dari hasil kajian sebelumnya, didapati bahawa sampel yang telah menjalani mod penyepuhlindapan rawatan haba ternyata mempunyai rintangan kakisan yang terbaik .

DEDICATION

I would like to present my work to those who did not stop their daily support since I was born, my dear mother, my kind father, my wife and my daughter “Shaghaf”. They never hesitate to provide me all the support to push me foreword as much as they can. This work is a simple and humble reply to their much goodness I have taken over during that time. I don't forget my brothers, sisters, and all my friends from Iraq and Malaysia.

Raed Abdulameer Mahmood

ACKNOWLEDGEMENT

قال تعالى في محكم كتابه الكريم

وَقُلِ اعْمَلُوا فَسَيَرَى اللّهُ عَمَلَكُمْ وَرَسُولُهُ وَالْمُؤْمِنُونَ

صدق الله العظيم

الاية ١٠٥سورة التوبة

First and foremost, praise is to Allah, for giving me this opportunity, the strength and the patience to complete my thesis finally, after all the challenges and difficulties. I would like to thank my supervisor, Assoc. Prof. Dr. Mohd Warikh Bin Abd Rashid for his high motivation and most significant contribution in this thesis, to the Dean of Faculty of manufacturing engineering Assoc. Prof. Dr. Mohd Rizal Bin Salleh

I would also like to thank the Ministry of Higher Education and Scientific Research of IRAQ, Furthermore, I want to thank my friends who have helped and motivated me throughout. May Allah reward them all abundantly, Sincere thanks to all

Raed Abdulameer Mahmood

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CHAPTER 1

INTRODUCTION

1.0 Background of Study

The mainly accepted definition for corrosion is the damage of material due to chemical reaction of the material with its environment. Generally, this destruction takes place on its surface in the form of material dissolution or redeposit ion in some other forms. Metallic systems are the predominant materials of construction, and as a class, are generally susceptible to corrosion. Therefore, the bulk of corrosion science focuses upon metals and alloys (Guthrie and Gretchen, 2002). Usually it's beginning at the surface of the material and occurs because of the natural tendency of the materials to return to their thermodynamic stable state or to one of the forms in which they were originally found. Metals are generally prone to corrosion because most of them occur naturally as ores, which is the most stable state of low energy and there is a net decrease in free energy, ΔG from metallic to oxidized state (Ogunleye et al., 2011). The corrosion is happening extensively in carbon steel because the resistance of its relatively limited, despite from this most widely used engineering material, accounts for approximately 85% of the annual steel production worldwide, carbon steel is used in large tonnages in marine applications, chemical processing, petroleum production and refining, construction and metal processing equipment (Fouda et al., 2011).

The corrosion of carbon steel in natural environments is of practical importance, therefore it is considered by many studies. It is widely recognized that the corrosion of carbon steel may be accounted for by the anodic reaction as in Equation 1.1 and cathodic reaction in the presence of oxygen Equation 1.2,

$$Fe_{(s)} \longleftrightarrow Fe^{+2} + 2e^{-} \quad \text{Material dissolution} \quad (1.1)$$

$$\frac{1}{2} O_2 + H_2O + 2e^{-} \rightarrow 2OH^{-} \quad \text{Oxygen dissolution} \quad (1.2)$$

In many corrosion problems, there is strong evidence that the rate of uniform corrosion is controlled by mass transfer rate. This is true whether the corrosion fluid remains static or in fast motion with respect to the metal surface. However, molecular diffusion is not the only factor which influences the rate of corrosion. In addition, in turbulent fluids, the rate of transport of eddy diffusion appears to participate in the control of the overall transfer rate (Brodkey and Hershey, 1989). Seawater is one of the most corroded and most plentiful naturally happening electrolytes. The corrosively of the seawater is reflected by the fact that most of the common structural metals and alloys are attacked by this liquid or its surrounding environments (Johnsirani et al., 2013)

The corrosion characteristic of low carbon steel in natural seawater is the formation and growth of compact and thick layers composed of oxides, insoluble salts and organic materials. The result of surrounding environmental conditions water oxygen supply; ionic species; bacteria and organic matter, these layers are formed. The exchange of various species (ions, molecules, gas) between seawater and the rust layers or the metal depends both on the kinetics of the Faradaic reactions of the entities with either the oxides or the metal, as well as on their transport properties through the different strata of the rust layers (Memet et al., 2002).

Salts dissolved in water have a marked influence on the corrosivity of water. At extremely low concentrations of dissolved salts, different anions and cations show various degrees of influence on the corrosivity of the water. So there are many investigations for corrosion of carbon steel in neutral aerated salt solutions, especially sodium chloride (NaCl) solution. Some investigation has been found for corrosion of carbon steel in Na_2SO_4 salt solution. For example corrosion of turbine caused by a thin film deposit of fused salt (sodium sulphate) on alloy surface (carbon steel) is an example of corrosion in sodium sulphate (Bornstein and Decrescente, 1971; Goebel et. al., 1973). During combustion in the gas turbine, sulfur from the fuel reacts with sodium chloride from the ingested air at elevated temperatures to form sodium sulphate. The sodium sulphate then deposits in the hot-section components, such as nozzle guide vanes and rotor blades, resulting in an accelerated oxidation attack. This is commonly referred to as "hot corrosion" (Stringer, 2007). Generally, the corrosivity of waters containing dissolved salts increases with increasing salt concentration until a maximum is reached, and then the corrosivity decreases. This may be attributed to increased electro-conductivity because of the increased salt content, until the salt concentration is great enough to cause an appreciable decrease in the oxygen solubility, resulting in a decreased rate of depolarization (Revie and Uhlig, 2008). It is accepted that the corrosion of mild steel in aerated water is controlled by the rate of cathodic reduction of oxygen and hence by the oxygen transport from the mainstream solution to the reacting surface, generally if a metal is corroding under cathodic control it is apparent that the velocity of the solution will be more significant when diffusion of the cathode reactant is rate controlling, although the temperature may still have an effect. On the other hand if the cathodic process requires high activation energy, temperature will have the most significant effect. The effects of concentration, velocity and temperature are complex and it will become evident that these factors can frequently outweigh the thermodynamic and kinetic considerations (Shreir et al., 2000).

Also the temperature representing one of the critical environmental parameters in corrosion studies because of its severe effects on physicochemical and electrochemical reaction rates.

Accordingly, passive film stability and solubility, pitting and crevice corrosion behavior is known to be closely related to temperature (Samuel et al., 2011).

1.1 Problem Statement

The use of carbon steel is indispensable to virtually all aspects of human endeavor. Our human civilization cannot exist without metals and yet corrosion is their Achilles heel. Failure of parts and components of engineering origin in different industries by corrosion is one of the major problems. Corrosion is responsible for so many mishaps that have occurred in the engineering history of man. The two particular reasons for the extraordinary versatility of steel are heat treatment and alloying.

The usage of steel is well pronounced in various aspects of human life such as in manufacturing, oil and gas, construction, medical, textile, transport and aviation industries to mention a few. Low carbon steel is a type of metal that has an alloying element made up of a relatively low amount of carbon. Typically, it has a carbon content that ranges between 0.05% and 0.30% and a manganese content that falls between 0.40 and 1.5%. Low carbon steel is one of the most common types of steel used for general purposes, in part because it is often less expensive than other types of steel. While the steel contains properties that work well in manufacturing a variety of goods, it is most frequently made into flat-rolled sheets or strips of steel.

Items made from low carbon steel compete with products that can be manufactured using stainless steel and aluminum alloy metals. Low carbon steel can be used to manufacture a wide range of manufactured goods - from home appliances and ship sides to low carbon steel wire and tin plates. Since it has a low amount of carbon in it, the steel is typically more malleable than other kinds of steel. As a result, it can be rolled thin into products like car body panels. So the steel industry as profitable and important as one of the most engineering-solution defying problems known to man, is it Corrosion (Kruger, 1986).

The cost of corrosion has been estimated at $300 billion per year in the United States (Gerhardus et al., 2002). The corrosion-related cost to the transmission pipeline industry is approximately $5.4 to $8.6 billion annually (David and James 2008). This can be divided into the cost of failures, capital, and operations and maintenance (O&M) at 10, 38, and 52 percent, respectively (Gerhardus et al., 2002). Carbon steel and wide varieties of materials of diverse properties are used in Multi Stage Flash evaporation MSF plants. Especially in the Arabian Gulf Countries seawater that containing salts with different concentrations is the prime source of fresh water supply by desalination plants. where A seawater desalination plant offers numerous corrosion problems due to its process conditions, including factors such as temperature and pH, and operation in relatively aggressive environments consisting of deaerated seawater, seawater-air and salt-air aerosols, corrosive gases, slow moving or stagnant liquids or deposit forming liquids to control the scale formation, acid treatment and anti-scale additive are used in desalination plants. (Ismaeel and Turgoose, 1999).

High temperature corrosion is a widespread problem in various industries, including; establishing (oil pipelines), is an important element low carbon steel in especially at the edges of the pipes that are linked through by welding that high temperature is effect on microstructures of materials, so when are extended over long distances and sometimes within the sea or be displayed to normal environment condition shall be more prone to erosion.

Heat treatment is a heating and cooling operation applied to metals and alloys in solid state to impact desirable properties to the metal or alloy. Heat treatment of metals is an important operation in the final fabrication process of many engineering components.

Heat treatment is of various forms which include annealing, normalizing, tempering, hardening and isothermal operations. Heat treatment improves the microstructure of the metal, and this is what gives the metal desired properties for different service conditions. The purpose of heat treatment of low carbon steel is to improve the ductility, toughness, hardness tensile strength, and corrosion resistance.

Hardening and tempering process of metals offer enormous advantages to the manufacturing industry because the heat treatment results can reveal optimum combination of mechanical properties (Murugan, 2012). For example annealing process heated to austenitic temperature of 960 °C and held for one hour to ensure complete homogenization, without excessive grain growth and then cooled inside the furnace to room temperature an initial corrosion rate of 17.58×10^{-5} cm/hr was observed after 72 hours. This corrosion rate could be attributed to the larger portion of pearlite formed from cooling austenite. After 72 hours of soaking, corrosion rate reduction was observed, between the 144th hour and the 216th hour. The corrosion rate decreased due to the thicker corrosion products covering the surface of the sample, thus it formed a kind of protective film on the surface which retarded the corrosion rate. While the hardening process heated to austenitic temperature of 960 °C and held for one hour to ensure complete homogenization, without excessive grain growth and then quenched in cold water to room temperature If referring to heat treating, then the temperature in which the steel starts to turn to Austenite is 727 °C, and to be fully austenitic that will depend on the carbon content. Low carbon could be around 900 °C, medium around 850 °C and high carbon maybe below 800 °C. It can be observed the greatest weight loss trends of all the heat treatment modes the initial corrosion rate notice at 72nd hour was the highest after which it took a dive from the 72nd to the 216th hour. This initial rise in corrosion rate could be because of the residual stresses in the steel which may have arisen due to rapid cooling (Atanda et al., 2012).

In this research will study the effect of different heat treatment (annealing and hardening) on low carbon in saline solution soaking time to 96-240 hours the initiated, finally