INVESTIGATION OF MIG WELDING TO THE CORROSION BEHAVIOUR OF HEAT TREATED CARBON STEEL

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ABSTRACT

The corrosion behaviour of metal inert gas (MIG) welded heat treated carbon steel was investigated. Filler material of ER308L and ER70S were used to complete the butt joint welding on non-heat treated and heat treated low carbon steel (AISI 1010). The welding heat input was manipulated by varying the welding voltage for MIG welding process. The microstructures for welded specimens were analysed with the optical microscope. During the electrochemical test, the corrosion rate on the carbon steel was determined. Microstructural analysis for specimen without cleaning and after cleaning was analysed by using SEM. Results showed that the increase in welding heat input was highly significant to the corrosion rate of carbon steel. The welding heat input was able to change the ferrite content on the microstructure of specimen which affected the corrosion rate on the carbon steel.

ABSTRAK

Kajian tentang karat terhadap keluli karbon yang diproses dengan rawatan haba dan dikimpal dengan mesin MIG (metal inert gas) telah dijalankan. Rod kimpal yang digunakan semasa proses pengimpalan termasuk ER70S dan ER308L untuk mengabungkan keluli karbon (AISI 1010). Voltan pengimpalan semasa proses pengimpalan dimanipulasikan. Imej mikrostruktur terhadap keluli karbon yang dikimpal telah dianalisiskan dan dibincang. Kadar pengaratan keluli dikaji dengan menggunakan ujian kakisan. Kajian mikrostruktur terhadap keluli sebelum dan selepas dibersihkankan telah dianalisis denagan menggunakan SEM. Keputusan menunjukkan bahawa voltan pengimpalan mempengaruhi kadar pengaratan keluli disebabkan mikrostruktur yang telah diubah setelah proses pengimpalan.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

A	Exposed area
Ar	Argon
C	Carbon
Cr	Chromium
Cu	Copper
d	Density
E_{corr}	Corrosion potential
Fe	Iron
$Fe_2O_3{\cdot}nH_2O$	Iron (III) oxides
FeO(OH)	Iron (III) oxide-hydroxide
$Fe(OH)_3$	Iron (III) oxide-hydroxide
HCL	Acid hydrochloric
I	Welding voltage
I_{corr}	Corrosion current
K	Constant value
Mn	Manganese
Mo	Molybdenum
NaCl	Sodium chloride
P	Phosphorus
Q	Heat input
S	Welding speed
S	Sulphur
Si	Silicon
V	Vanadium

Wt%	Weight percentage
V	Welding voltage
%	Percentage

LIST OF ABBREVIATIONS

AISI	American Iron and Steel Institute
ASTM	American Society for Testing and Materials
CR	Corrosion rate
EW	Equivalent weight
GMAW	Gas Metal Arc Welding
HAZ	Heat affected zone
MIG	Metal inert gas
SAE	Society of Automotive Engineers
SEM	Scanning electron microscopy
SCC	Stress corrosion cracking
UMP	University Malaysia Pahang

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Eventually, millions of dollars are lost every year in industrials because of the existence of corrosion. Maintenances and replacements are spent to prevent losses and improve the productivity of output. Much of the losses are due to the corrosion of iron and steel, as well as the other metals. Corrosion of bridges is a major problem as they age and require replacement, which may cost billions at least. In chemical industry, corrosion maintenance always the priority in its acid plants even though the corrosion conditions are not considered to be particularly severe. Bunch of costing are needed on painting steel to prevent rusting by a marine atmosphere. The petroleum industry spends a million dollars per day to protect underground pipelines. In prediction, costs of corrosion will increase substantially because of shortages of construction materials, higher energy cost, and aggressive corrosion environments in coal conversion process.

Welding is an efficient metal joining process which is commonly used in the industry. This type of welding will need to use a welding gas to shield the welding puddle and arc during the welding process. MIG welding is considered as the most common welding process in the light or even the heavy industries nowadays. However, during the welding process, due to the different quantity of heat input as well as the quality of the weldments, many problems arise from the process especially in corrosion. Thus, joint is always considered as the weakest part in the components.

Table 1.1: Cost related to corrosion

Region / Industry	Cost of Corrosion	Reference
Aircraft (lost revenue when grounded for corrosion maintenance/repairs)	$100,000 per day	IAR Flyer, Spring 2000 Edition, NRC Institute for Aerospace Research (Canada).
Bridge (Old Severn Bridge) in England	£20 million to mitigate corrosion (projected), with £3 million previously spent on corrosion assessment of suspension cables	BBC news (on-line edition), March 7, 2007.
Coast Guard, United States, Aircraft	$20 million per year	Lee Ann Tegtmeier: "U.S. Coast Guard Treads in Deep Water", Overhaul & Maintenance Magazine (May 1, 2002).
Gas Pipeline Industry (North America)	$80 million per year purchased in coatings to coat new pipelines and recoat existing pipelines (1993 reference)	Cavassi and Cornago: "The Cost of Corrosion in the Oil and Gas Industry", JPCL, May 1999, pp30-40.

1.2 PROBLEM STATEMENT

The modernization of this era expands the demands and applications of carbon steel especially in construction industry and the naval structure builder. A lot of mega steel structure platforms have been designed and constructed to fulfill the exploitation of civilization. Most of these structures are fabricated by technique of welding. However, these weldments usually are more vulnerable to steel corrosion crack than the corresponding base plates, the welded zones represent potential weak links which may limit or impair performance. Moreover, the corrosivity 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. Thus, improvements in weldment properties are critical to increase the reliability of high-performance structures utilizing welded carbon materials.

1.3 OBJECTIVE

The objective of this study is to investigate the corrosion behavior of metal inert gas (MIG) welded heat treated low carbon steel.

1.4 SCOPE OF WORK

The scope of works involve in this study:

i. Material used was low carbon steel (AISI 1010).
ii. Full annealing heat treatment process on low carbon steel (AISI 1010).
iii. The two metal inert gas welding fillers used were ER70S and ER308L at welding voltage of 19 V, 20 V and 21 V.
iv. Microstructures analysis on welded specimen by using optical microscope.
v. Electrochemical test with solution of 3.5 wt % NaCl by using potentiostat.
vi. Scanning Electron Microscope (SEM) was used to identify the corrosion product.

CHAPTER 2

LITERATURE REVIEW

2.1 HEAT TREATMENT

Heat treatment is the metal working process that controls the heating and the cooling of metals to modify the physical and the chemical properties of the metals without changing the product shape. Heat treatment is sometimes done unwittingly due to the manufacturing processes involved such as welding or forming processes. Heat treatment process usually associated with increasing and altering certain manufacturability of metals such as to improve the machining quality and restore the ductility of the target materials. There are four basics types of heat treatment processes nowadays which including the annealing, normalizing, hardening, and tempering.

2.1.1 Annealing

In general, annealing process relieves the stresses set up in the metal, soften the metal and make the metal become more ductile by refining the grain structures. As annealing process, the metal is heated to specific temperature and holds it at that temperature for a set length of time. The cooling temperature for the annealing process will be at the room temperature. Somehow, the cooling method usually depends on the metal and the properties required. Some metals are cooled in furnace, by means that the metal will has the slow cooling rate as some to the furnace. Others cooling method found to bury the metal in ashes, lime or other insulating materials.

To enhance the maximum softness in steel, the metal is heated to proper temperature and cooled in a very slow cooling rate. The cooling can be done by burying the hot part in an insulating material or by shutting off the furnace and allowing the furnace and the part to cool together. The soaking period is depending on both the mass of the part and the type of metal.

The nonferrous metal such as copper is hard and brittle when undergoes the mechanical work. However, it can be soften by this annealing process. The annealing temperature for copper is between 700 ℉ to 900 ℉. Copper maybe cooled rapidly or slowly since the cooling rate has no effect on the heat treatment. The one drawback experienced in annealing copper is the phenomenon called “hot shortness.” At about 900 ℉, copper loses its tensile strength, and if not properly supported, it could fracture.

For aluminum, the similar reaction as the copper when undergo heat treating. There is a number of aluminum alloys exist and each of these alloys are requiring special heat treatment to gain the best mechanical properties (Sanjib, 2008).

2.1.2 Normalizing

Normalizing heat treatment process is only applicable to the ferrous metal only. It is differing from the annealing process in that the metal is heated to a higher temperature and will be removed from the furnace for air cooling purpose.

The main objective of normalizing is to remove the internal stresses induced by heat treating, welding, machining, forming and other machinability works. Stress is very important where if there’s no proper control, it may leads to metal failure. Hence, before any hardening process, the materials should undergo normalizing process first to ensure the maximum desired results. Normally, low carbon steel does not need this pre normalizing process. However, there is no harmful reason if this steel is normalized. Normalized steels are harder and stronger than annealed steels. In the normalized condition, steel is much tougher than in any other structural condition. Parts subjected to impact and those that require maximum toughness with resistance to external stress are usually normalized (Dosset and Boyer, 2002).

2.1.3 Hardening

The hardening treatment for most steels is that the metals are heating to a set temperature and cooled rapidly by quenching into water, oil or brine. Most of the steels need this rapid cooling for hardening but few can be air cooled to have the same result.

By undergoing the hardening process, the hardness and the strength of the steel are increasing but less ductile. Generally, the harder the steel, the more brittle it becomes. To remove the brittleness, metal should be tempered after the hardening process. Many nonferrous metals can be hardened and their strength increased by controlled heating and rapid cooling. In this case, the process is called heat treatment, rather than hardening.

Case hardening always produce hard, wear resistant surface over a strong and tough core. The principal forms of case hardening are carburizing, cyaniding and nitriding. However, only ferrous metals are case hardened. Case hardening is ideal for the parts that require wear resistant on the surface with tough enough to withstand the heavy loading during work. In case hardening, the surface of the metal is changed chemically by introducing a high carbide or nitride content. However, the core remains chemically unaffected. When heat treated, the high carbon surface responds to hardening and the core toughness.

Flame hardening is another procedure that is used to harden the surface of metal parts. With the existence of oxyacetylene flame, thin layer at the surface of the part is rapidly heated to its critical temperature and then immediately quenched by a combination of a water spray and the cold base metal. This process produces a thin, hardened surface. At the same time, the internal parts retain their original properties because the heating process only affects the surface of the product. Whether the process is manual or mechanical, a close watch must be maintained, since the torches heat the metal rapidly and the temperatures are usually determined visually (Rajan and Sharma, 1992).

2.1.4 Tempering

After applying the hardening treatment, steel is often harder than desired. This situation creates difficulty for most practical uses because it is too brittle. Besides, severe of the internal stresses are set up during the fast cooling rate from the high temperature during the hardening process. Hence, tempering process is carried out to relieve the internal stresses and reduce the brittleness. Tempering consists of heating the steel to a specific temperature (below its hardening temperature) and hold the steel at the high temperature for certain of period before cooling it at still air condition. The resultant of mechanical properties of the steel is based on the working temperature during the tempering process.

Tempering is always conducted at temperatures be-low the low-critical point of the steel. In this respect, tempering differs from annealing, normalizing, and hardening in which the temperatures are above the upper critical point. Normally, the rate of cooling from the tempering temperature has no effect on the steel. Steel parts are usually cooled in still air after being removed from the tempering furnace; however, there are a few types of steel that must be quenched from the tempering temperature to prevent brittleness (Pierre et al., 2006).

Seawater is one of the most corroded and most abundant naturally occurring electrolytes. The corrosivity 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 (Saleh Fozan and Anees Malik, 2005).

The corrosion behavior of metals and alloys differ from one zone to another. In splash zone the stainless steels have usually satisfactory performance while, the carbon and low alloy steels do not. Anderson and Ross had found that the austenitic grades performed much better than martensitic and ferritic grades (Anderson and Ross, 1976). The Ni, Cu and P alloyed steels were found to be much more resistant than carbon steel in splash zone (Larrablee, 1958). Also, it was found that Mn, P and Al had measurable influence on corrosion rates of low carbon steels under tidal exposure. After 5 years exposure test it was found that the rate of attack in splash zone was much higher than the atmosphere and deep submerged zones (Humbles, 1949).

Welded pipelines are widely used and for these the most severe pitting corrosion has been observed to occur primarily at and near the welds. Such pitting tends to occur at very different rates in the parent metal, the heat affected zone (HAZ) and in the weld metal (Vetters, 1978; Hunkler, 1987). The HAZ is present on either side of a weld seam as a result of the thermal gradient set up between the weld metal and the parent metal (Traverso and Ventura, 1974). This region of parent metal has been heated briefly to temperatures approaching the melting temperature of the steel and then cooled rapidly (Vetters, 1978). In contrast, general corrosion loss, important for strength considerations, tends to occur at a more moderate rate (Bai, 2005).

Naval structures are especially vulnerable because they are constantly exposed to a particularly aggressive environment which provides conditions favorable to corrosion cracking damage. Many of these structures are fabricated by welding, and because weldments frequently are more vulnerable to corrosion crack than the corresponding base plates, the welded zones represent potential weak links which may limit or impair performance (Gooch, 1974). Thus, improvements in weldment properties are critical for increasing the reliability of high-performance structures utilizing welded high-strength materials.

2.2 WELDING

Welding always refer as the fabrication process that joins materials causing by coalescence. These joining materials usually include metals or thermoplastics. This joining process is often done by the melting between the two base materials with the adding of a filler material to form a pool of molten material which also known as weld pool. As the weld pool is cold, the joint between the two base materials become strong, with pressure sometimes used in conjunction with heat to produce the weld. The welding process can be contrasted as the soldering and the brazing in which these processes involve the melting on a lower melting point material between the workpieces to form a bond between them.

There are several energy sources can be used for welding including a gas flame, an electric arc, a laser, an electron beam and etc. In industrial process, welding can be performed in different environments such as open air, under water and in outer space. While performing the process of welding, hazardous undertaking and precautions must be taking care to avoid burns, electric shock, vision damages and inhalation of poisonous gases and fumes (Gooch, 1974).

To a large extent, the welding process determines the metallurgical and microstructural characteristics of deposited weld metals. The thermal cycles associated with multi-pass welding techniques invariably produce a spectrum of tempered material and residual stresses which impact on the mechanical and SCC behavior of weldments. Additionally, based on the results of several studies on the embrittlement of high-strength steels, the effect of impurities may also be a very significant factor which influences the mechanical and stress corrosion crack properties of steel weldments (Kenichiro and McMahon, 1974; Briant and Banerji, 1979; Robert, 1977; Viswanathan and Hudak, 1977).

2.2.1 MIG welding

The MIG, metal inert gas welding process is actually also known as Gas Metal Arc Welding (GMAW). This type of welding will need to use a welding gas to shield the welding puddle and arc during the welding process. MIG welding is considered as the most common welding process in the light or even the heavy industries nowadays. MIG welding is so popular due to the easy handling during the welding process. It is faster and quicker to perform the joining process for the common metals in industries. MIG welding usually used with the robots and automation purposes. The main reason why MIG welding is popular because it is able to weld joins variety of metals at different thickness. For MIG welding, it uses a consumable wire electrode that is fed from a spool.

The most common weld joins include the lap joint, butt joint, T-joint and the edge joint. MIG is used to weld many materials with different gases to form the arc which is depending on the materials to be welded together. Argon CO_2 blend is usually used to join the mild steel, aluminum, titanium and alloy metals as well. Helium is sometimes used to weld the carbon steel and titanium in high speed process. However, carbon dioxide is the most often used to weld the carbon steel and low alloy steel for the MIG process.

The very advantage of MIG is the fact that it is able to weld at different positions. Welder can weld overhead, horizontal, vertical up and down with the one welding machine. Welder does not need to stop all the time to change the electrode compare to the stick welder. There are fewer spatters if using the solid MIG welding wire as comparing to the gasless welding wire where spatter is around about the same as that of manual metal arc welding. By performing the MIG welding, the heat affected zone (HAZ) will be smaller because of the fast travel rates that are attainable with this welding process. The fast travel rates have the less heat input and energy going into the same weld joint.

However, the use of inert gas causes this MIG welding less portable than the arc welding where the arc welding requires no external source of shielding gas. The other disadvantage of MIG welding is that it is able to produce sloppier and less controlled weld as compared to the tungsten inert gas welding (Gooch, 1974).

The thermal diffusity of the base metal is important where if the diffusivity is higher, the material cooling rate is high and hence the heat affected zone is relatively small. The amount of heat inputted at the welding process is also important where high heat input will increase the size of the HAZ. Inversely, limited amount of heat at the welding process will resulting in a small heat affected zone. The formula of the welding heat input is the significant and showed as followed:

$$Q = \frac{V \ x \ I \ x \ 60}{S \ x \ 1000} \tag{2.1}$$

Where Q = heat input, kJ/min, V = voltage, V, I = base current, A and S = welding speed, mm/min

From the research of Dursun O zyurek, the increase in heat input related with current will caused the coarsening of the microstructure of weld nugget and also of heat affected zone, HAZ. From the experiment conducted, the tensile shear load bearing capacity of welded materials increases with the increasing of heat input related with weld current due to the enlargement of nugget size which shown in Figure 2.1 (Dursun, 2007).