# Mechanical Behavior of Medium Carbon Steel welded with SMAW and Corroded with Sea Water

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**Abstract.** The problem of metal corrosion is a very serious to be observed, especially the corrosion of medium carbon steel because it can reduce the economic value of the metal. Corrosion of carbon steel is influenced by the environmental conditions. This paper discusses the effect of the corrosion rate of medium carbon steel with SMAW welding and corrodes it with sea water during several hour. Electrodes of AWS A5.1E7016 type were used in the welding. The test results show that the medium carbon steel which was corroded with sea water has small weight loss. It seem that the weight loss has small influence on the mechanical behavior of the metal. For the welded medium carbon steel, the ultimate strength and surface hardness are smaller than the un-welded one. The microstructure of welded medium carbon steel has unsimilar structure with un-welded steel because it has about the same amount of ferlite, ferrite and martensite.

Keywords: Medium carbon steel, SMAW processes, corrosion, tensile test, hardness test, microstructure

#### 1. Introduction

In industrial world, it is widely used materials such as ferrous and non-ferrous metals, in the process of processing a variety of ways, such as welding process for connecting a construction, for example the manufacture of bridges, buildings, vehicles and other means, it was chosen because it has economic value and efficiency which is quite high. Grafting material is steel welding, as a result of welding can reduce the value of the power, it is no change in the microstructure resulting from the welding heat.

In the process of welding, welded parts that receive local heat which resulted in the development of thermal, while the cold does not change it can result in a lack of uniformity of strain, this can result in changes in the form and cause residual stress, residual voltage is the voltage that works in the absence of material external forces acting on the material [8].

It can be known that the strength of welded joints of steel materials are widely used as elements of a building or construction is welding Shield Metal Arc Welding SMAW), therefore the standard steel material made specifically to regulate or assume as tensile strength, compressive strength, strong at, as well as resistance to crack propagation.

A variety of medium strength on steel material and welded joints make the basis of a wide range of testing, when the metal has been welded will corrode in time sooner or later depending on the environment. In a medium carbon steel is widely used in the construction of high pressure, with the

load is high enough to break a weld joint due to corrosion.

From the above discussion that the welded joints of medium carbon steel corrosion is not easily affected by way of re- welding electrodes and welding with the selection of the appropriate chemical constituents, so as to minimize the cost of treatment because by comparing the use of different electrodes, can reduce the corrosion rate of the most minimum. Therefore, it is necessary to experiment on the characteristics of the tensile testing, hardness testing, microstructure testing, and the rate of corrosion in the weld area in order to slow down the corrosion.

The purposes of this study are to determine the effect of mechanical behavior and corrosion rate in the welding surface area to know the microstructure in the welding surface area. Corrosion of metal due to a decrease in the electrochemical reaction with its environment. In general, corrosion on the metal covering the loss of certain parts, corrosion occurs in a variety of forms, ranging from corrosion evenly on the entire surface of the metal to corrosion concentrated on certain parts.

Corrosion rate is determined by the amount of area that is losing, the corrosion rate of the large value of the welding Flux Cored Arc Welding (FCAW) is better than other welding processes, welding area that occurred in most major corrosion in the Heat Affected Zone [5].

Corrosion rate is influenced by the tensile strength in welded steel, based on the photo SEM (Scanning Electron Microscope), the surface morphology of welding metal corrosion rate with the highest value of surface look more rugged. However, the rate of corrosion of welds with electrodes - electrodes are still at the level permitted [7].

Corrosion which is at an elevated temperature environment will fail faster and decreases the value of its strength and strain tends to increase (increased ductile) metals are compared with room temperature environment [2].

The corrosion and mechanical properties of welded joints that the liberation of residual stresses in submerged arc weld results by post weld heat treatment using oxy aseteline heat can lower current densities up to 43.88  $\mu$ A/cm2 at sipesimen head T 3000 that affect the rate of corrosion that occurs in water concentration of 3.3% NaCl. Lowest corrosion rate occurred in specimens with treatment head T 3000 namely 0.311 mm/year compared with sipesimen without treatment (TT) which has a value of corrosion rate 0.377 mm/year [8].

Corrosion of metals is due to the flow of electric current in one part to the other parts of the metal surface, The current flow will cause the loss of metal on which the stream is released to the environment (Oxidation or reaction Anode).

There are four key elements that must be met in order for corrosion to occur if one of them is missing, then corrosion will not occur. The four main elements are:

- 1. Anode, where beewis oxidation reactions.
- 2. Cathode, where the reduction reaction.
- 3. Electrolyte, cathode and anode neighborhood occurred.
- Metal connection, cathode and anode must be connected with the use of metal connections so that an electric current can flow.

One part of the surface may be the surface of the anode and the other becomes the cathode, it can happen because of the possibility of metal composed of a different phase, because the metal surface is coated with different coating conditions or because of the metal surface has more than one kind of electrolyte.

Corrosion current fluctuation occurs some time after the addition of chloride ions and increases sharply when the corrosion pits started to happen, The current fluctuation decreases when re-passive start of the process, with analysis of the corrosion current fluctuations can be expected if the corrosion pits occur in certain circumstances [4].

Metals can be immersed in an electrolyte or metal surface can be flooded by the electrolyte form a thin layer. The rate of corrosion depends on the electrical conductivity of the electrolyte; pure water has poor electrical conductivity, so that the rate of corrosion that occurs will be lower when compared to acid or salt solution (seawater) which has a high electrical conductivity.

One example is the corrosion that occurs between zinc and HCl acid. The following is an overview of electrochemical Reaction happened.

$$Zn + 2HCL \rightarrow ZnCL_2 + H_2$$
 (1)

reacts with an acid solution to form zinc chloride and release hydrogen gas into the air, ionic reaction that occurs is as follows.

$$Zn + 2H^+ + 2CL \xrightarrow{\longrightarrow} Zn^2 + 2CL - H_2 \tag{2}$$

The reaction above can be divided into anode and cathode reaction.

$$Zn \rightarrow Zn^2 + 2e$$
 anode reaction (3)

$$2H^+ + 2e \rightarrow H_2$$
 cathode reaction (4)

Electrochemical reaction can only occur at certain values if available electron, then the potential at the surface will become more negative, the excess electron will result in negative currents collected on the metal or in the subsequent reaction solution waiting to happen. The reaction will not be enough to accommodate all the electrons are available; the potential negative current is called the cathodic polarization. Shortage of electrons in the metal due to the release of electrons that occurs in the solution will result in a positive change in current is called the anode polarization. If the electron deficiency (polarization) getting larger, the tendency will be getting anode termination great. Anode polarization that occurs will encourage the occurrence of corrosion at the anode reaction. Polymethyl methacrylate (PMMA) is a polymer material that is able to inhibit the corrosion events, the greater the concentration of dispersant the fewer number of heavy iron loss due to erosion of the sea water, the longer the event of immersion in sea water corrosion event is rapid due to oxidation on an ongoing basis

In an electrolyte solution, the surface potential will be achieved equilibrium value of whose value depends on the ability and the rate of electron exchange on cathode and anode reaction, when the potential increased value of the anode reaction rate or the rate of corrosion in general will increase. Effect of tempering temperature on mechanical properties and corrosion resistance, the alloy microstructure shows that although the Fe - 1, 26 Al - 1.05 C as cast and has ferrite pearlite structure, trends ferrite structure formation occurs at the higher tempering temperature. The maximum tensile strength occurs after hardening is equal to 47.25 after the highest temperature of 4500C. The hardenees occurred at 287.1 VHN after hardening, the corrosion test results showed that the corrosion rate of 1.26 alloy Al - 1,05 as cast will decrease with getting high- temperature tempering [11].

Martensitic stainless steel AISI 410 which has been implemented in the titanium nitride ions to increase the corrosion resistance of 34.5% or about 2.34mm/year with a median of 0.9% NaCl compared with those not at implantation [6].

Based on the shape and place of the occurrence of corrosion, it is divided into several types of corrosion, namely Uniform corrosion, pitting corrosion, inter-grain corrosion and erosion corrosion and there are still many other types of

corrosion. Evenly corrosion is the most common form of corrosion that occurs, visible corrosion appeared evenly on the entire surface of the metal with the same intensity, one example is the effect of atmospheric corrosion on metal surfaces. Evenly corrosion occurs when all of the metal parts have the same composition; corrosion of this type can usually be overcome by coating how to metal surfaces.

Pitting corrosion is corrosion that appears and concentrated in certain areas, this form of corrosion is usually caused by chloride, the formation mechanism of pitting corrosion at the crevice corrosion, pitting corrosion is only just smaller than the size, because it was adjacent to each other, will lead to pitting corrosion metal surface becomes rough. Pitting corrosion occurs due to the composition of the material is not homogeneous, the destruction of the protective layer, the deposition on the surface of the material and the presence of defective parts on material.

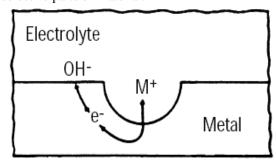


Figure 1. The mechanism of pitting corrosion. [10]

# 1.1 Inter-grain Corrosion.

Corrosion between grains (interglanular corrosion) is the corrosion that occurs at the boundary grained a metal or alloy. This type of corrosion is usually caused by the presence of an impurity or impurities at the grain boundaries and occurs locally along the boundaries in metal alloys.



Figure 2. inter-grain Corrosion [10]

The image above shows a stainless steel corroded metal in the heat affected where the distance is not far from the weld. This is typical of corrosion between grains on austenic stainless steel.

#### 1.2 Erosion corrosion.

Erosion corrosion damage is a combination of electrochemical and high fluid velocity at the surface

of the metal. Erosion corrosion can also occur due to the presence of very high fluid flow past the stationary or static objects, or it can occur because of a fast moving object in a fluid is stationary.

# 1.3 Mechanical Properties of Carbon Steel.

Carbon steel is steel that consists only of the elements iron (Fe) and carbon (C), and there are three kinds of carbon steel are:

- 1. Low Steel Carbon. Carbon content of the steel is between 0.1% to 0.2% due to very low carbon content of the steel is soft and of course cannot be hardened, can be advanced, pourable and easy to weld [16].
- 2. Medium Carbon Steel Carbon content in the steel is between 0.2% to 0.5%, this type of steel can be hardened, can be easily welded, and well done on the machine [16].
- 3. High Carbon Steel Carbon content in the steel is 0.5% to 1.7%, due to the high carbon content of the steel is easier hardened, has good hardness and is very difficult to weld [16].

Mechanical properties of carbon steel with regard to strength, hardness, ductility and stiffness. These properties are needed for an object to obtain three loads: tensile, compressive load, shear load. For each major mechanical property owned by medium carbon steel can be done with a variety of mechanical tests are: Tensile Test, Hardness Test, Test microstructure.

#### 1.4 Tensile Test.

To determine the mechanical properties of the material are tensile testing. Of the materials tested made a rod with a standardized size, mounted on a tensile machine and loaded tensile force is increased slowly until dropping out. During the experiment measured continuously load and strain rod and the second magnitude is shown in a picture (diagram) stress and strain. The scale shows the voltage stress in N/mm2 sticking to the original stem cross-section, while the horizontal scale expressed strain (extension) in the percentage of initial length. Tensile stress ratio (stress) and strain (strain) is constant:

Stress:  $\sigma = F / A$ F: pull force

A : cross sectional area

Strain :  $\varepsilon = \Delta L / L$  $\Delta L$  : thelength

L : length of the initial

The relationship between stress and strain is formulated:

$$E = \sigma / \varepsilon$$

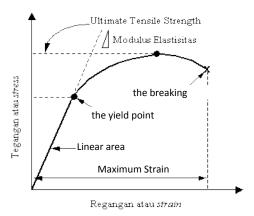


Figure 3. Stress and Strain Diagram

#### 1.5 Hardness Test

Hardness is a measure of material resistance to deformation Plastic or permanent deformation, there are several methods of hardness testing, among others: Methods of Brinell, Vickers and methods Rockwell method. Hardness testing is generally used small spherical indenter is pressed or pyramid surface material by controlling large loads and loading rate. In this study the method used Vickers.

#### 1.6 Vickers method

Aiming to determine the hardness of a material to the diamond/diamond-shaped pyramid that is superimposed on the surface of the test specimen. Vickers hardness number (VHN) is the quotient of F test load in kg and press the scar surface area of the diamond pyramid A in mm<sup>2</sup>.



Figure 4. Free diagonal of Viker's test

The load of identor range of 1-1000 gram. Test results in the form of indentations examined with a microscope with VHN = Vickers Hardnees Nabers.

#### 1.7 Testing microstructure

The test aims to see the microstructure grain size of the material, because it affects the mechanical properties of the material. The quality of grain is very by temperature changes resulting from the welding process is a process of grafting materials. There are two kinds of observation metallographic macro and micro. Macro observation can be seen with the naked eye, while observations with optical microscopy, micro should be to analyze the microstructure.

# 1.8 Corrosion Testing

Corrosion testing aims to determine the level of corrosion rate at the weld area as it affects the strength of welded joints in steel material, to determine the corrosion rate should be held experimental. In this test medium carbon steel material should be the same size, 10 cm and 30 cm long by 5 pieces (for each variation) and then welded to each other, in order to avoid errors of observation, the material must be completely clean. Media solution used is seawater.

#### 2. Methods of Research

Specimen material is Medium Carbon Steel with a diameter of 10mm length of 12m. Before the welded test specimens or objects, first cut the speed size of 30 cm by 40 pieces and cleaned in order to be free of so that no initial corrosion in accordance with ASTM G1-90, "Standard Practice for Preparing Cleaning and Evaluating Corrosion Test Specimens".

In this experiment welded test specimens that have been shared role in tree boxes, arranged with different time. In this study the materials and equipment needed include: Carbon Steel Welded medium that uses electrodes AWS A5.1 E7016, after welding, the specimens were then immersed into the sea water during the hour 24, and 192, 360 hours, then observed how much loss weight as a result of corrosion for 360 hours, to test the microstructure, the specimens were given first etching can be seen that the grain is formed, then the specimens were tested using the Vickers hardness by as much as five points each specimen was then calculated an average, after the test micro-structure and hardness and tensile specimens were tested to determine how far the tensile strength of specimens without treatment and corroded. Data results of tensile testing, hardness testing, micro- structure and the corrosion rate is made in the form of tables and graphs. Corrosion rate with units of mm/year or mmp is given as follows:

$$Cpr = \frac{k.a.i}{n.D} [mmp]$$
 (5)

a = weight of corroded metal atoms (g/mol)

i = Cor=current density (mA/cm<sup>2</sup>)

k = constant(0.129 mpy and 0.00327 for the unit to unit mmpy)

n = number of electrons that are released on acorroded metal

D = density of corroded metal (g/cm<sup>3</sup>)

# 3. Results And Discussion

The Test results of testing tensile test are presented in stress strain curve. The stress is expressed by:

$$\sigma = \frac{F}{A}$$
 or  $\sigma = \varepsilon E$ 

Where:

 $\sigma$ : tensile strength

 $\varepsilon$ : Strain

E: Modulus of Elasticity

The test aims to determine the tensile stress and tensile strain based on true technical. Mechanical Specimen used was Universal Testing Machining RAT-30P type cap 30 Tf.

Tensile stress :  $\sigma = P/A \text{ (mpa)}$ 

Tensile ductility :  $\sigma u = (P \text{ max}) / A \text{ (mpa)}$ 

Yield limit :  $\sigma y = ky/(A_0)$ Tenacity :  $\sigma f = Pfpatah/(A_0)$ 

 $e\% = \Delta L$ 

 $\Delta L = (1-1_{10}) / (1_0) \times 100\%$ 

Table 1. Data observations tensile carbon steel welded medium without corroded.

No	$\emptyset(mm)$	L <sub>0</sub> (mm)	L <sub>1</sub> (mm)	Py(kgf)	Pu (kgf)	Pf (kgf)
1	10(9,5)	76	99	2480	3610	2850
2	10(9,5)	76	97	2500	3620	2850
3	10(9,5)	76	99	2550	3710	2890
4	10(9,5)	76	99	2590	3750	2900
5	10(9,5)	76	99	2450	3450	2800

Table 2. Data from tensile test calculations of medium carbon steel with no welded corroded.

No	Ø(mm)	A <sub>0</sub> mm <sup>2</sup>	Σy kgf/ mm²	Σukgf /mm²	Σfkgf /mm²	e%
1	10 (9,5)	70,84	35,29	51,10,	40,29	27,26
2	10 (9,5)	70,84	35,29	51,10	40,23	27,63
3	10 (9,5)	70,84	35,99	53,37	40,79	30,26
4	10 (9,5)	70,84	36,56	52,93	40,93	30,26
5	10 (9,5)	70,84	34,58	48,70	39,52	30,26
Mean			35,49	51,41	40,34	29,73

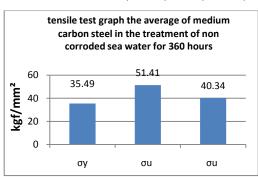


Figure 5. Graph of medium carbon steel with no welded and corroded.

Table 3. Data of medium tensile carbon steel welded and corroded

	and Co	moucu				
No	Ø	Lo	L <sub>1</sub>	Py	Pu	Pf
	(mm)	(mm)	(mm)	(kgf)	(kgf)	(kgf)
1	10 (9,5)	76	77	2550	2100	1450
2	10 (9,5)	76	83	2550	3400	3150
3	10 (9,5)	76	81	2490	2750	2450
4	10 (9,5)	76	78	2400	2530	2450
5	10 (9,5)	76	80	2470	2670	2350

Table 4. Data from the test calculations medium tensile carbon steel welded and corroded

No	Ø(mm)	A0 mm	σy (kgf/ mm2)	σu (kgf/ mm2)	Σf (kgf/ mm2)	e %
1	10(9,5)	70,84	35,99	29,64	20,48	1.31
2	10(9	70,84	35.99	47,99	44,46	9,21
3	10(9	70,84	35,14	38,81	34,58	6.57
4	10(9	70,84	33,87	35,71	34,58	2,63
5	10(9	70,84	34,86	37,69	33,17	5,25
Nilai rata-rata			34,71	37,96	26,53	4,99

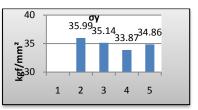


Figure 6. Graph of medium carbon steel welded and corroded

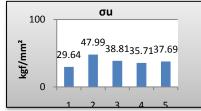


Figure 7. Graph of medium carbon steel welded and in corrode

Based on the graph above shows the tensile strength without welded and corroded 51.41 kgf/mm², while the medium is welded steel and corroded 47.99 kgf/mm showed that the medium carbon steel welded and corroded more brittle than the non-welded carbon steel.

Also seen from the graph there is a decrease in tensile strength carbon steel with no welded medium carbon steel welded and corroded medium, there are also different response eventhough the materials used the same at 51.41 kfg/mm, 37.96.

Observations etched microstructure after the observation of the microstructure of medium carbon steel without welded and corroded and medium carbon steel welded and corroded.



Figure 8. Microstructure of carbon steel welded and medium without corroded.

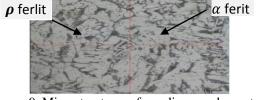


Figure 9. Microstructure of medium carbon steel with no welded and corroded.

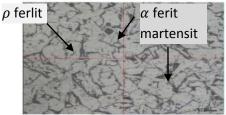


Figure 10. Microstructure of medium carbon steel with no welded and corroded

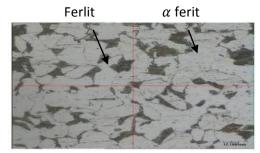


Figure 11. Microstructure of welded medium carbon steel and corroded

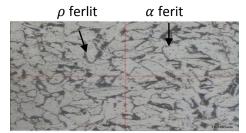


Figure 12. Microstructure of welded medium carbon steel and corroded

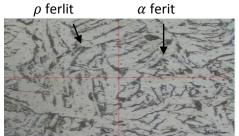


Figure 13. Microstructure of welded medium carbon steel and corroded

Based on the test results BKS non-treated microstructure of welded connection and corroded use seawater for 360 hours. Objective magnification 50x or 1000x, here seen clearly ferlite and ferite. LAS metal microstructure iof non-treatment Magnification 50x Objective or 1000x, the structure is still too perlite microstructure and ferit while its martensite is already clearly visible. BKS corroded welded using sea water for 360 hours Microstructure of base metal corroded seawater objective magnification of 50x or 1000x, here seen clearly perlite and the ferite. Microstructure of HAZ metal corroded seawater objective magnification of 50 x or 1000 x, the image boundary grain is also visible perlite and perite while the martensite seems too though.

Hardness test results obtained average price as follows, for non- treated steel VHN numbers averaged 144.04 VHN, which is the average number corroded 137.22 VHN hardness, here there is a decrease in both the specimen is 144.04 VHN - 137, 22 VHN = 6.82 VHN.

For carbon steel HAZ area being tested non violent treatment (vickers) obtained an average hardness numbers VHN 173.18 while medium carbon steel HAZ area after corroded with sea water during the 360 hour figure is 164.37 VHN hardness

decreases, the difference in the rate of decline of violence VHN of 173.18 - 164.37 VHN=8.81VHN. The test results show that a medium carbon steel immersed with sea water during the 192 -hour weight loss of 0.005 g of initial weight and then immersed for 360 hours turned out to lose weight by 0.17 g of initial weight of 174.74 g minus 174.574, then the longer soaked is getting larger corrosion rate. Corrosion occurred on any additional time or are in mm/year is 0.725mm/year.

#### 4. Conclusion

From the tensile test results that have been obtained decrease its strength, but having the character of a medium carbon steel brittle due to welding.

From the results of the test structure changes in the form martensite microstructure because the effect of welding.

From the results of Vickers hardness testing hardness impaired after tensile test.

From the observation of different corrosion test is not much good that is not welded and welded. The longer the time, the more rapidly corrosion rate.

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