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Effect on Tensile and Bending Capabilities for Low Carbon Steel Plate in Marine Environment

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Abstract

Nowadays corrosion in in real life is serious case and it affected the strength of a structure. Corrosion is caused by many factors and in the scope of the marine structure; most of the structure failure are caused by salt water corrosion. This study focused on corrosion of Low Carbon Steel material which is widely used in construction and structure. The marine environment was simulated by using artificial salt water. The content of the salt in the water is varied from 20%, 40% and 60%. This study will determine the corrosion rate of Low Carbon Steel when it is controlled under different percentage of salt content and different period of immersion. This research will be accomplished when the tensile and flexural test were done to the material in order to determine the strength after the process of immersion. From the data collected, the analysis will be done to determine the relationship of salt content to the rate of corrosion and strength of the material.

Keywords; *corrosion, salinity, tensile, bending.*

I. INTRODUCTION

There are many sources that can contribute to the factor of structural failure such as corrosion. Marine structures including ships, offshore platform, shipyard, steel parts and tools which are exposed to seawater directly and indirectly are highly risk for corrosion, particularly after many years in service which is around 15 to 20 years. From an incidents such as Erika in 1999 (Center of Documentation, Research and Experimentation on Accidental Water Pollution (CEDRE), "Erika", 2009) have highlighted the issues of the corrosion onboard the ship.

Nowadays, due to highly concern about safety of life at sea, many agencies are involved in design, operation and maintenance of marine structures. Besides that, classification society which act as a third party, establish classification rules and carry out a survey to ensure that the vessels are well maintained. In addition, the International Maritime Organization (IMO) aim to improve the efficiency safety improvement at an international level. The programmed develop by (IMO) is a guidelines, particularly for bulk carriers and oil tankers inspection.

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Understanding on the corrosion process is important for naval architectures, structural engineers, supplier and users to identify the causes of marine corrosion and the prevention methods. Preventive method can be consider as materials that can be used to reduce or eliminate sea water corrosion problems. There were many types of disintegrating that can be occurred to marine structures and other working industries which directly contact to seawater. The term 'aqueous corrosion' describes the majority of the most troublesome problems encountered in contact with sea water, but atmospheric corrosion of metals exposed on or near coastlines, and hot salt corrosion in engines operating at sea or taking in salt-laden air are equally problematical and like aqueous corrosion require a systematic approach to eliminate or manage it.

Many researches regarding the strength analysis of the material has been founded. However, a research that related to the strength analysis of Low Carbon Steel immersed in artificial sea water has not yet been carried out in marine engineering field. This encouraged the researcher to perform this analysis. In this study, the researchers are going to identify the strength of the Low Carbon Steel plate immersed in artificial saltwater at certain period. The scope of this study will includes temperature, percentage of salt and time period of immersion. In order to get the results, the Low Carbon Steel plate will be immersed within two weeks, three weeks and four weeks. For the percentage of salt in the saltwater, 20%, 40% and 60% of salt contain in salt water will be used. After the period of immersion, then the specimens will be ready to be tested by using experimental methods such as destructive test and nondestructive test

II. LITERATURE REVIEW

A. Introduction

More than 70% of the earth's surface is covered by the sea water. Ship vessel and boat for example are moving on the sea water. If the structure of this vehicle is made of metal or alloys, this material are tendency become corrode because it is attacked by the seawater. Table 1 showed the typical classifications of marine environment. The composition of seawater is a complex because, it is not just containing the salt but it also has a suspended silt or dissolved gases. Therefore, it is easier to make the metal corrode.

Table 1 : Typical Classification of Marine Environment [1]

No	Marine Zone	Description of Environment	Charactertstic Corrosion Behaviour of Steel
1	Atmosphere (above splash)	The corrossion can be occured to the surface above the water since the particles of salt are carried by the wind. The particles of salt which condesed, and dissolve by the rain water maybe can distribute the corrosion onto more area of the structure material.	Sheltered surface can be exposed to corrosion. Coal dust combined with salt make more corrosive to steel
2	Splash Zone	Wet, surface which exposed to the air	Most agressive zone for steels. The coating is difficult to maintain
3	Tide Zone	Marine fouling	Steel in this zone may act cathodically
4	Shallow water	Seawater is concentrated with oxygen.	Corrosion can be occurred
5	Deep Ocean	Oxygen content is varies and the pH is also lowaer than at water surface.	The corrosion is lesser
6	Mud	The bacteria is present	Mus also can cause the corrosion

B. Pitting Corrosion

Pitting corrosion is a localized form of corrosion by which cavities or "holes" are produced in the material. Pitting is considered to be more dangerous than uniform corrosion damage because it is more difficult to detect, predict and design against. Corrosion products often cover the pits. A small, narrow pit with minimal overall metal loss can lead to the failure of an entire engineering system.

Pitting corrosion can be observed on the impeller and housing of a two-stage steam turbine after a very short service [1]. The impeller was made of martensitic grade stainless steel, while the casing was made of plain carbon steel. The turbine was run by super saturated steam. Special quality boiler feed water was converted to steam and fed to the impeller of the steam turbine. Then, the heat of the low

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pressure steam was abstracted from it by cooling in seawater in the condenser and water was recirculate. It was observed that the chloride content of the fresh water was more than the specified limits, suggesting that the chloride induced pitting were due to ingress of seawater through the condenser leakage.

C. Bimetallic Corrosion

Bimetallic corrosion is the phenomena by which preferential corrosion will appear between two joined metals of different galvanic status with the corrosion attacking the anodic metal.

D. The Highest Salt Content for Water

One of the most popular and highest salt content water are named Don Juan Pond. It is a lake that is very small and hypersaline lake which located at Antarctica. A hypersaline lake is a landlocked body of water that contains significant concentrations of sodium chloride or other salts, with saline levels surpassing that of ocean water (3.5%, i.e. 35 grams per litre or 0.29 pounds per US gallon). Specific microbial and crustacean species thrive in these high-salinity environments [2]. It is a lake that has salinity of 44% which means (440g/L). Other than that, Lake Vanda in Antarctica are specified to have salinity almost 35%. Other saline bodies of water include the Dead Sea, shared between Israel, Jordan and Palestine; Great Salt Lake, Mono Lake, and Salton Sea in the US, and Europe's Baltic Sea [3]. Table 3 below will show the salt content of the water due to different location.

Table 3 : Salinity Percentage in the Water Based on Location

Rank	% of Salinity	Name	Type	Region or countries
1	44%	Don Juan Pond	Salt lake	Antarctica
2	40%	Lake Retba	Salt lake	Senegal
3	35%	Lake Vanda	Salt lake	Antarctica
4	35%	Garabogazköl	Lagoon	Turkmenistan
5	34.80%	Lake Assal	Salt lake	Djibouti
6	33.70%	Dead Sea	Salt lake	Israel, Jordan, Palestine
7	18%	Little Manitou Lake	Salt lake	Canada
8	8.5–28%	Lake Urmia	Salt lake	Iran
9	5–28%	Laguna Cejar	Salt lake	Chile
10	5–27%	Great Salt Lake	Salt lake	United States
11	5–9.9%	Mono Lake	Salt lake	United States
12	4.40%	Salton Sea	Salt lake	United States
13	3.6-4.1%	Red Sea	Mediterranean sea	Saudi Arabia, Yemen, Egypt, Sudan, Eritrea, Djibouti, Israel, Jordan
14	3.50%	Pacific Ocean	Ocean	
15	3.50%	Atlantic Ocean	Ocean	
16	3–4%	Lake Natron	Salt lake	Tanzania
17	2.40%	Lake Van	Salt lake	Turkey

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18	1.3–2.3%	Black Sea	Mediterranean sea	Bulgaria, Romania, Ukraine Russia, Georgia, Turkey
19	1.25%	Caspian Sea	Lake	Azerbaijan, Iran, Kazakhstan Russia, Turkmenistan
20	1.00%	Baltic Sea	Mediterranean sea	Europe
21	013–3.173	Chilika Lake	Lagoon	India

E. Previous Study

[4] - stated that the influence of corrosion damage on the ultimate strength for the steel plate in marine platforms. The corrosion can be predicted by using two methods which from corrosion database and the data was collected from the ship surveys (bulk carrier, oil tankers) and the other one was empirical corrosion modeling by using the calculation. The factors that contributed to corrosion on ship hull were coating system, cathodic protection, maintenance of the corrosion protective system, percentage of time in ballast, the moisture content in empty tanks, frequency of tank washing, cargo temperature and fuel in adjacent tanks, speed, salinity and water velocity.

[5] - stated that the study on mechanical properties of AISI 304 stainless steel due to seawater (salt water). The study also founded the effects of different type of corrosion that occurs after immersion in salt water. The variables used were percentage of salt in salt water, temperature and time period of immersion influences the corrosion rate. It was stated that, the higher the percentage of salt content in salt water will make the higher the corrosion rate.

[6] - stated that the corrosively of seawater is because of its salt (primarily NaCl) content. The salinity is the total solid matter (grams) in one kilogram of seawater. The properties of the seawater can vary considerably by geographical location, seasons and water depth. The 'average' salinity of open ocean water (i.e., well away from land) is in the range B32–36 ppt, and the corresponding average chlorinity in the B18–20 ppt range. In terms of salt content, the 'average' seawater composition corresponds to B3.5% NaCl solution. Thus, many researchers who do not have easy access to natural seawater often use this composition as a synthetic substitute. Others researchers use the artificial seawater solutions that attempt to more closely mimic real seawater or at least in terms of dissolved salts. For the material selection, normally used carbon steels in application at sea water. It is due to the carbon steels are widely used in seawater applications because of their ready availability, extensive range of mechanical properties, ease of fabrication and usually lowest initial cost. However, the carbon steels are susceptible to corrosion in marine environment.

III. MATERIAL SELECTION

The material selected in this experiment is Low Carbon Steel types ASTM A36 and table below showed the mechanical properties of ASTM A36 Steel [7].

Table 4: Mechanical Properties of ASTM A36 Steel

Mechanical Properties	Metric
Density	7.85 g/cm^3
Tensile Strength, Ultimate	400 - 550 MPa
Tensile Strength, Yield	250 MPa
Elongation at Break (in 200 mm)	20.00%
Elongation at Break (in 50 mm)	23.00%
Modulus of Elasticity	200 GPa
Bulk Modulus (typical for steel)	140 GPa
Poissons Ratio	0.26
Shear Modulus	79.3 GPa

From the Low Carbon Steel plate acquired, the process of preparation or cutting the plate will be done according to the test that will be conducted. The specimen then will undergo finishing process before immersed in artificial salt water. The bars

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shall be free of detrimental surface imperfections. The table following indicate the specimen scope for the research.

Table 5: Total Sspecimens for Each 2, 3 and 4 Weeks Immersion Period

Test	Percentage of Salt Content		
	20%	40%	60%
Tensile	3	3	3
Bending	3	3	3
Total	6	6	6

IV. RESULT AND DISCUSSION

The specimen has been immersed for maximum 4 weeks (28 Days) following each set in order to measure the formation of corrosion. Researcher has set the parameters of the location of immersion which is located at open place so that the corrosion are speed up and also form naturally. After all of the specimen has completed the immersion period, it will be taken out from the container and let dry for few hours to measure its weight reduction.

A. Weight Reduction Rate

The formula to calculate the percentage of weight reduction is:

$$\%\ of\ Corrosion = \frac{weight\ before\ immersion - weight\ after\ immersion}{weight\ before\ immersion} \times 100$$

$$Cumulative = \frac{total\ percentage\ of\ the\ specimen}{total\ specimen}$$

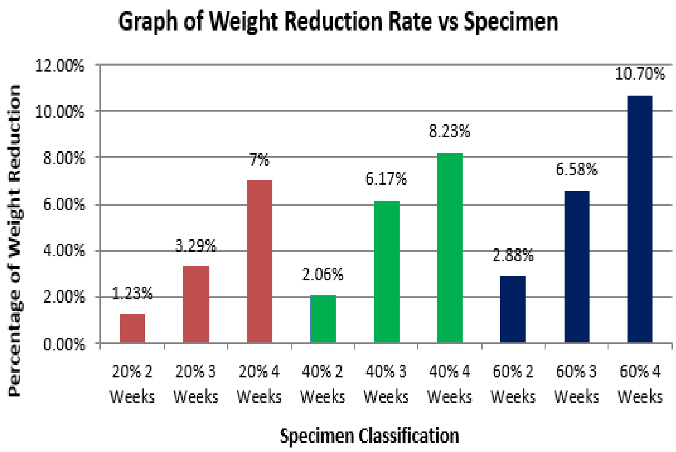

Figure 1: Graph of Weight Reduction Rate for all Specimen

Based on the data from the graph, supposedly the weight of the specimen before the immersion period should be equal to all specimens which all specimens are from the same material and the same dimension. Besides that, the percentages of weight reduction of the specimen are not uniformly decrease based on theoretical understanding due to some factors. First, the specimen was prepared manually by using milling machine and that could be a small misaligned from the original dimension and the finishing of the specimen is not perfect. Besides that, the salt solutions tend to become thicken at certain period and the salt penetrates on the specimen surface and it's affected the specimen weight.

However, the weight reduction also show some pattern where from 20% of salt content the percentage increase at 40% and 60% salt content. The period of immersion also affected the rate of weight reduction where the longer the immersion period time, the higher the weight reduction.

B. Corrosion Formation Data

The method used is by visual inspection and plotting ratio. Before the immersion period, the specimen was ensured there is none of the formation of the corrosion on the specimen's surface. After all of the specimens has completed the immersion period, the specimen was taken out from the container and let dry for few hours. Then researcher has observed the formation of the corrosion on the specimen surface and the analysis are stated in the next section. The formula to calculate the rate of corrosion:

$$\%\ Rate\ of\ Corrosion\ Formation = \frac{area\ of\ corroded}{total\ specimen\ area}$$

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Figure 2: Formation of Corrosion After Period of Immersion (From Left: 20%, 40% & 60%)

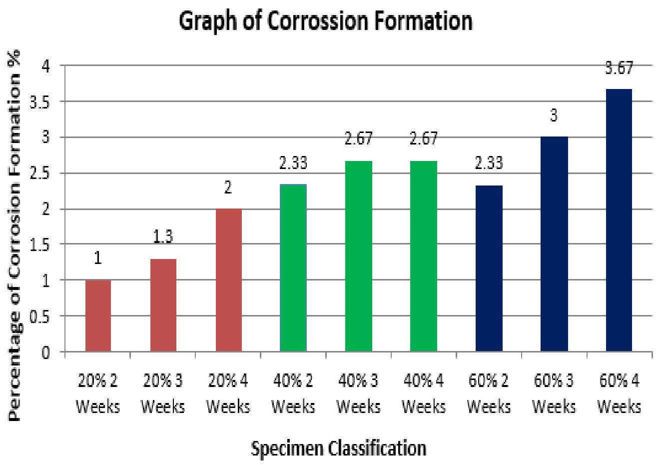

Figure 3: Graph of Corrosion Formulation for all Specimen

Based on the graph, it can be shown those corrosion formation patterns are increased accordingly to salt content and period of immersion. Due to suitable temperature and condition it can be the catalyst that supports percentage of salt in the solution which contributes to the development of corrosion. Specimen for 60% at 4 weeks immersion period show the highest percentage because the salt particle start to penetrate on the body of the specimen and create oxidation of the steel surface that corroded the surface of the specimen.

C. Corrosion Rate Data

The data from the previous analysis has been taken as a reference to calculate the corrosion rate for each specimen. To ensure that the data is valid, some of the units need to be change to follow the reference formula. Following are the formula to calculate the rate of corrosion as follow [8] and from the result the analysis on the acceptable corrosion rate.

$$ipy = \frac{12W}{TAR}$$

Where,
W = mass loss in time (T) (lb)
T= time (years)
A = Surface area (ft^2)
R = density of material (lb/ft^3)

Table 6: Acceptable Corrosion Rates

	Corrosion Rate (ipy)
Completely satisfied	< 0.01
Use with caution	< 0.03
Use only for short exposures	< 0.06
Completely unsatisfactory	> 0.06

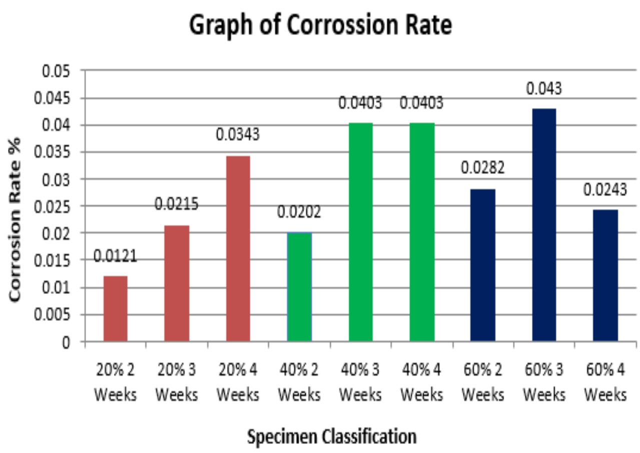

Figure 4: Graph of Corrosion Rate for all Specimen

It shows that at this condition the highest salt content are suitable at certain period to react with the water. At 4 weeks of immersion period, the salts start to become a solid particle that penetrates on the body of the specimen. Due to uneven surface of the specimen because of handmade machining

D. Tensile Test

The specimen has been tested by using universal testing machine with follow ASTM E8 standard and the speed was 15mm/min speed. The test also has

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been conducted for specimen which not immersed in salt water.

Figure 5: Based Specimen (Not Immersed in Salt Water) After Tensile Test

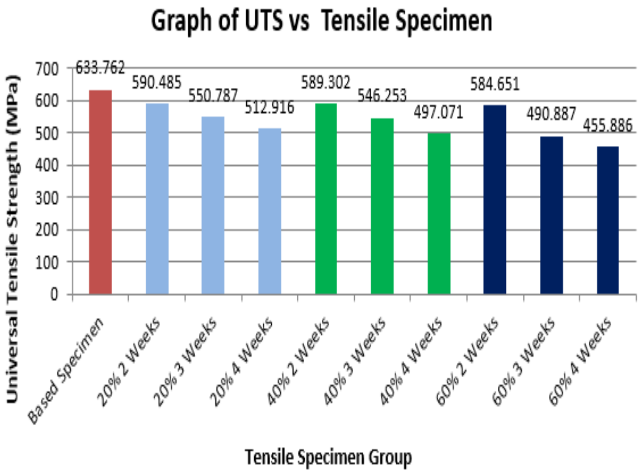

Figure 6: Graph of Result of Tensile Test

The highest reading is shown from the based material where the specimen is kept from exposed to any factor that can lead to corrosion formation. However, with the increase of salt content in the solution, the UTS reading has been affected and it shows the decrease of strength when the salt content increase. The period of immersion also show the result that corrosion may take place in a long time and it is not a strong factor that leads to corrosion formation.

E. Bending Test

The specimen has been tested by using universal testing machine with follow ASTM E8 standard and the speed was 15mm/min speed. To calculate the flexural stress is using this formula:

$$\sigma_f = \frac{3PL}{2bd^2}$$

σ_f = stress at midpoint (MPa)
P= load at a given point on the load deflection curve (N)
L= 180 mm, support span
b= 20 mm, width of test beam
d= 2 mm, depth of tested beam

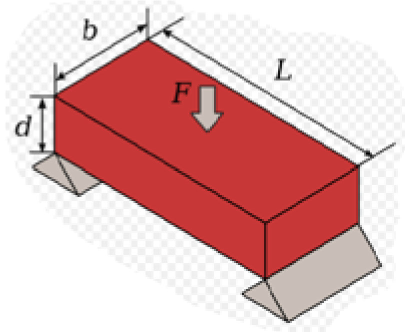

Figure 7: Dimension for Calculating the Flexural Strength

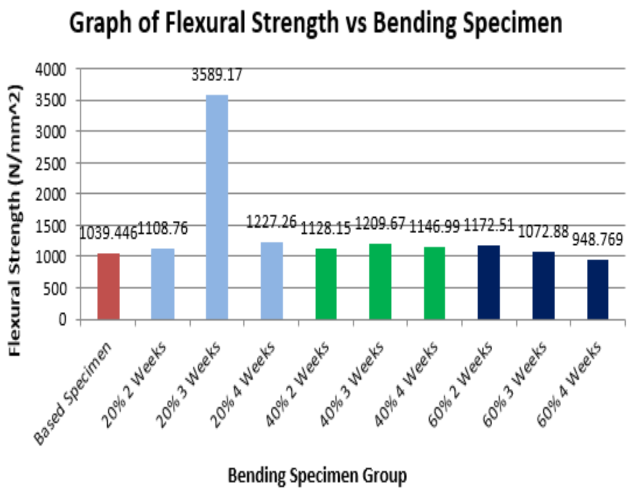

Figure 8: Graph of Result of Bending Test

From the above graph, the highest reading of flexural strength located at 20% salt content and 3 weeks immersion period due to the machine are suddenly malfunction and drag the reading until it become 3589.17. However, the patterns of the graph show the reduction of the flexural strength due to

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salt content and immersion period. The lowest strength are at 60% salt content and 4 weeks immersion period due to the penetration of corrosion that create pore inside the specimen and made the properties of low carbon steel change to brittle. The based specimens indicate lower strength from the tested specimen due to reduction of the thickness because of machining defect.

V. CONCLUSION

Conclusion that can be made from this project is the corrosion thus affects the material in every ways. It’s not only change the formation of the material surface, it also penetrate inside the material body and thus affected the strength of the material. With reference form the project outcome which is the corrosion rate for Low Carbon Steel plate immersed in artificial salt water in term of different period of immersion and percentage of salt content in artificial salt water solution can be identified and the ultimate strength of Low Carbon Steel plate immersed in artificial salt water in term of different period of immersion and percentage of salt content in artificial salt water solution can be determined. From all the results, it showed that the percentage of salt content in a solution thus affected the strength and it has become one of the strongest factor that lead to corrosion.

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