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Effect of Heat Treatment on the Corrosion Rate of AISI 1045 Medium Carbon Steel in the Seawater

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***Abstract* - Steel is the most common material that used to building and construction fields. For example, AISI 1045 of medium carbon steel which has a low price with good quality. However, the metal will decrease quality. This is caused by the effect of corrosion. To slow down the corrosion phenomenon and give effect to the desired material properties, it can be treated by using heat treatment. The purpose of this researching was to determine the corrosion rate of the material without heat treatment and the material given heat treatment with variations of annealing, normalizing, quenching and tempering using AISI 1045 material with seawater electrolyte. The method used in testing the corrosion rate is electrochemical, according to the ASTM G59-97 (2009) standard. From the results of the study, the highest corrosion rate values in the test specimens without heat treatment were 0.068461, 0.069042 and 0.069597 (mmpy). While the lowest corrosion rate values in the annealing heat treatment specimen were 0.012147, 0.014623 and 0.017637 (mmpy). There are two things that affect the corrosion rate, the first is internal stress. If this stress is not removed, it causes stress corrosion cracking. The second, the pearlite phase. Pearlite has an arrangement of cementite and ferrite. When connected to an electrolyte, the two phases will experience microgalvanic corrosion. Because the microgalvanic effect causes the test specimen with more perlite phase to corrode faster.**

Keywords: AISI 1045, corrosion rate, electrochemical, heat treatment, microgalvanic corrosion.

I. INTRODUCTION

Regarding the problem of potential corrosion, it is necessary to pay attention to considering that most of the territory of the Indonesian state is divided into more than two-thirds as water areas located in the tropics so that it gets high rainfall and contains lots of chloride compounds [1]. Due to these geographical conditions, several metal-based construction buildings need serious attention from their managers. Several oil and gas piping construction buildings, harbor constructions on breakwaters and seawalls, steel pipe piles and bridges in our country are mostly in a corrosive environment and even some construction buildings are in direct contact with seawater, which has the potential to cause higher corroded material. As for one of the most commonly used steel materials to meet the material needs of the above buildings and constructions, AISI 1045 steel. AISI 1045 steel is a medium type carbon alloy steel [2]. With this carbon content, medium carbon steel has a large enough potential to be used as a raw material. Because of the many types with different characteristics, the steel used can be adapted to the needs [3]. However, with the longer use of a metal, it will experience a decrease in quality. One of the factors that can decrease the quality of a metal is the phenomenon of corrosion. So that the way that can be done to slow down the occurrence of corrosion phenomena and can have a direct influence on the properties and structure of the material as desired is to provide heat treatment. Heat treatment is a process of heating, holding and cooling the material at a certain temperature to obtain various mechanical properties [4]. Heat treatment or heat treatment can be carried out in a furnace or heating furnace by selecting a temperature that is in accordance with the conditions and specifications of the steel and then cooling it to the cooling medium [5]. Heat treatment is usually carried out in the following forms of normalizing, annealing, quenching and tempering. Corrosion is a phenomenon that shows a decrease in metal quality due to electrochemical reactions that occur between metals and their environment [6]. Corrosion can also be interpreted as a natural event that occurs in materials and is the process of returning the material to its original condition when the material was found and processed from nature [7]. The speed at which a material undergoes a corrosion process is called the corrosion rate [8]. The value of the corrosion rate of a metal in a neutral environment with a corrosion rate range of 1 mpy or 0.0254 mmpy. The factors that can affect the value of the corrosion rate of a material are the chemical composition of the material, temperature, electrolyte pH, and the effect of heat treatment [9]. The purpose of this study is to classify the corrosion resistance of specimens without heat treatment (non heat treatment) with other specimens given various heat treatments (heat treatment) on AISI 1045 steel material with seawater electrolyte, while the heat treatments used are annealing, normalizing, quenching and tempering.

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1.1 Method

This research was conducted by conducting three types of tests, namely microstructure, corrosion rate and macrostructure. The material used was AISI 1045 steel with dimensions of 25 mm in diameter and 10 mm in thickness as many as 20 specimens. The details are that 4 specimens were not given heat treatment and 16 other specimens were given heat treatment with as many as 4 specimens in each. AISI 1045 Carbon Steel is a medium carbon plain alloy steel type. There are several elements that make up the AISI 1045 steel alloy, for example Si, Mn and P.

Table 1: Chemical Composition of AISI 1045 Material

Kode	Chemical Composition Percentage (%)
C%	0,44
Si%	0,24
Mn%	0,74
P%	0,010
S%	0,007

II. PROCESS

The variation of the heat treatment process, namely normalizing, annealing, quenching and tempering. In the heat treatment process of annealing, normalizing, quenching and tempering variations, heating is carried out in a heating furnace (furnace) with a temperature reaching 860^{O}C and holding time for 15 minutes. Then the specimen is cooled in a controlled manner. In the annealing process, the specimen is cooled in a heating furnace until it reaches room temperature. In the normalizing process, the specimen is cooled in outside air until it reaches room temperature. In the quenching process, the specimen is rapidly cooled in water. In the tempering process, the specimen after the quench process was then reheated at a temperature of 500^{O}C with a holding time of 60 minutes then the specimen was cooled in air until it reached room temperature

Microstructure testing is intended to determine the microstructure of each specimen that has been subjected to variations in heat treatment, namely annealing, normalizing, quenching and tempering as well as non-heat treatment specimens. To be able to determine the microstructure produced from these specimens, it is necessary to test micro photos with a certain magnification. In the microstructure testing process, there are several stages, namely the grinding process using 120 to 2000 grid sandpaper and the polishing process using velvet cloth and autosol, then etching or etching process using 5% nital solution. After that, the microstructure of the specimen was photographed with a metallurgy microscope.

Then, to carry out electrochemical testing of five variations of AISI 1045 steel specimens, all specimens were first grinded using 120 to 1200 grid sandpaper. Then the materials that need to be prepared include seawater electrolyte and prepared specimens (soldered with cables and mounted). The surface area of the specimen is 19.6 cm^2 and the equivalent weight of Fe is 55.84 with an oxidation number of 2 and a density of 7.8 g/cm^3. Then for the tools prepared namely a 500 mL measuring cup and a CortTest type CS300 platform potentiometer. The schematic diagram for the test is shown in Figure 1.

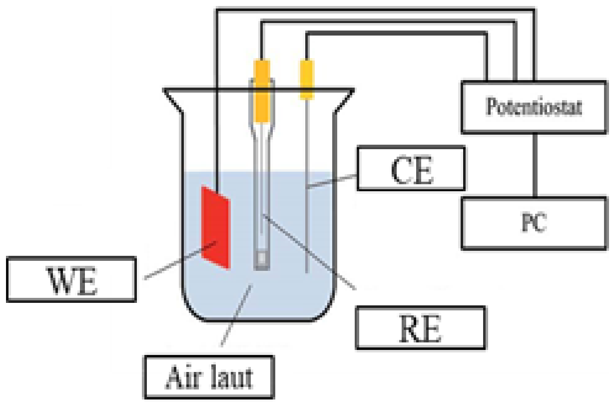

Figure 1: Schematic Diagram for Electrochemical Testing of the Cort Test Type CS300

The Cort Test Type CS300 potentiostat apparatus consists of three electrodes, namely a reference electrode (RE), a platinum counter electrode (CE), and the last working electrode (WE). The reference electrode (RE) used is Ag-AgCl. The working principle is that the working electrode pair and the reference electrode measure the cell potential, at the same time the working electrode and counter electrode measure the corrosion current [10]. So by knowing the value of the corrosion current, the value of the corrosion rate can be measured by the following equation:

$$\text{Corrosion Rate (mmpy)} = \frac{\text{icorr x 0,00327 (K) x 27,92 (EW)}}{\text{7,86 }(\rho)} [10]$$

Note: EW = Mass Equivalent AISI 1045
ρ = Density Material AISI 1045
K = Constant (0,00327 mmpy)

After that, macrostructure testing was carried out by using a metallurgy microscope with a magnification of 50x.

Macrostructure testing was carried out to observe the corrosion products on the surface of the specimen before and after testing the corrosion rate.

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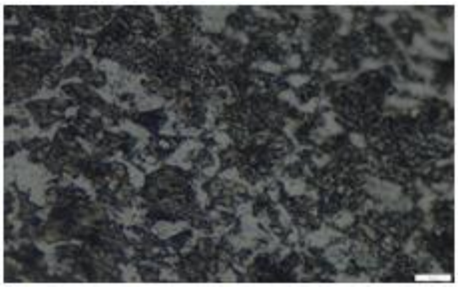
III. RESULTS AND DISCUSSIONS

(a)



(b)

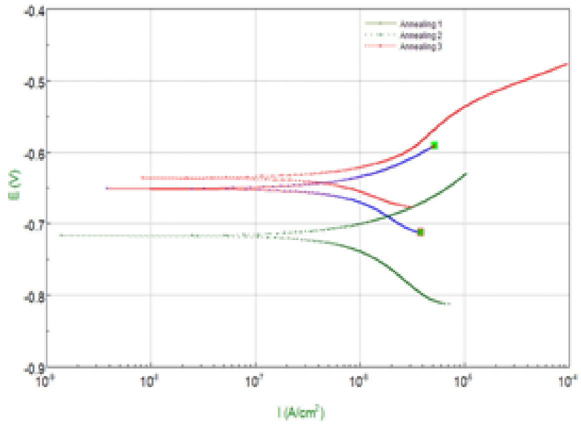
(c)

(d)

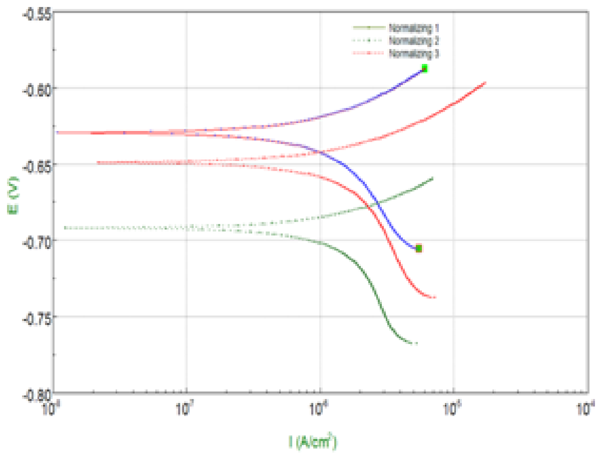
(e)

Figure 3: Test Results of AISI 1045 Steel Microstructure (a) Annealing, (b) Normalizing, (c) Quenching, (d) Tempering and, (e) Non Heat Treatment

It was observed that the annealing variation specimens produced ferrite and pearlite phases with a percentage of ferrite 60% and pearlite 40%. Then for normalizing variation specimens produce ferrite and pearlite phases with a percentage of ferrite 52% and pearlite 48%. The annealing and normalizing heat treatment process is a type of softening heat treatment which has the property of eliminating internal stresses on the specimen. Meanwhile, in the observations, it was found that the quenching variation specimens produced ferrite and martensite phases with a percentage of ferrite 23% and martensite 77%. Then for the tempering variation specimens produce ferrite phase and bainite phase with a percentage of 27% ferrite and 73% bainite phase. The heat treatment process of quenching and tempering is a type of hardening heat treatment that has the property of generating internal stress on the specimen. And for non-heat treatment specimens obtained ferrite phase and pearlite phase with a percentage of 29% ferrite and 71% pearlite phase. Where the initial condition of the AISI 1045 steel raw material used has excess residual stress, this is because the process of working the material from the start is cold working. Cold working on metal is a deformation process carried out below its recrystallization temperature.



(a)



(b)

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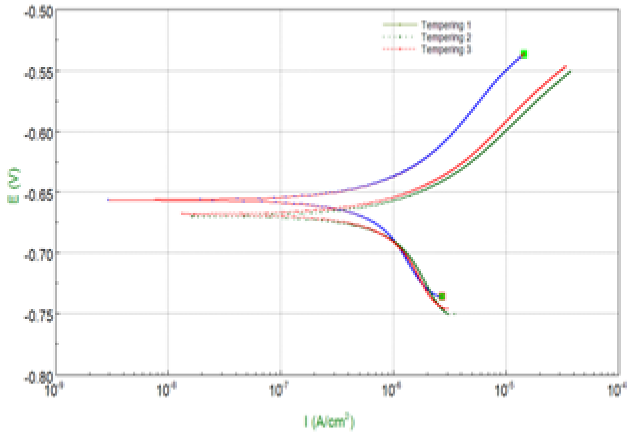
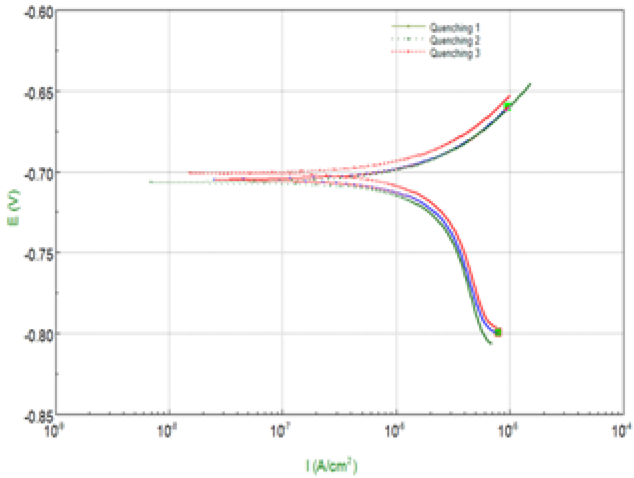
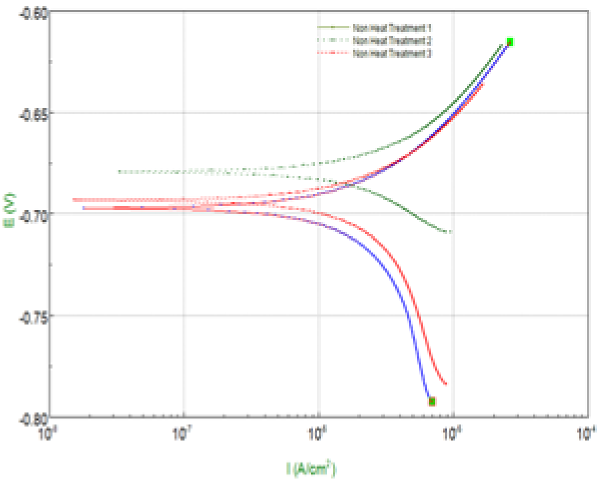


(c)



(d)



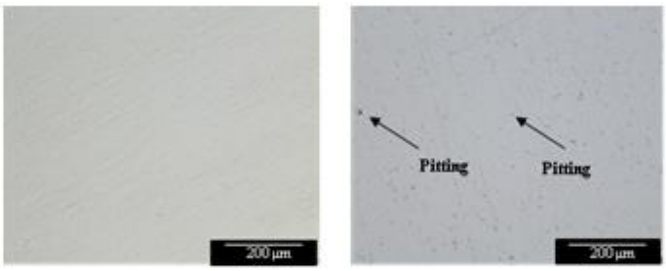
(e)

Figure 4: Plotting Tafel Diagram of AISI 1045 Steel (a) Annealing, (b) Normalizing, (c) Quenching, (d) Tempering and (E) Non Heat Treatment

Table 2: The Results of Testing the Corrosion Rate of AISI 1045 (a) Annealing, (b) Normalizing (c) Quenching (d) Tempering and (E) Non-Heat Treatment In Seawater Electrolyte

No	Speciments	Potential (mV)	Current Density (μA/cm^2)	Corrotion Rate (mmpy)
1	*Annealing 1*	651,31	1,6191	0,017637
2	*Annealing 2*	717,25	1,3424	0,014623
3	*Annealing 3*	636,42	1,1151	0,012147
4	*Normalizing 1*	629,82	2,0383	0,022204
5	*Normalizing 2*	692,3	2,3185	0,025256
6	*Normalizing 3*	649,33	2,413	0,026286
7	*Tempering 1*	656,77	2,9513	0,032149
8	*Tempering 2*	670,24	3,1206	0,033993
9	*Tempering 3*	668,55	3,1857	0,034703
10	*Quenching 1*	705,16	4,3974	0,047902
11	*Quenching 2*	706,52	4,4327	0,048287
12	*Quenching 3*	700,87	4,6976	0,051172
13	*Non Heat Treatment 1*	697,38	6,2847	0,068461
14	*Non Heat Treatment 2*	679,49	6,338	0,069042
15	*Non Heat Treatment 3*	693,53	6,389	0,069597

After testing the corrosion rate, macrographic testing is carried out, this is used to observe the corrosion products produced on the surface of the specimen before and after testing the corrosion rate.



(a) **(b)**

Figure 4: The Results of the Macrostructure (a) Before and (b) After the Corrosion Rate Test was Carried Out

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IV. CONCLUSION

Based on the results of the research that has been done, some conclusions can be drawn as follows:

1) From the results of the microstructure photo on the test specimen without heat treatment (non heat treatment) it shows that the phase grains formed are ferrite and pearlite then the test specimen is given heat treatment with variations in annealing, normalizing, quenching and tempering cooling. In accordance with the purpose of heat treatment (heat treatment) obtained phase granules namely pearlite, ferrite, martensite, and bainite.
2) AISI 1045 steel material with seawater electrolyte on the test specimen without heat treatment (non heat treatment) has the highest corrosion rate value. The value of the corrosion rate on the test specimen without heat treatment is 0.068461; 0.069042; and 0.069597 (mmpy). While the test specimen with heat treatment (heat treatment) annealing variation has the lowest corrosion rate value. The value of the corrosion rate on the test specimen with heat treatment (heat treatment) annealing variation 0.012147; 0.014623; and 0.017637 (mmpy).
3) Test specimens with heat treatment (heat treatment) annealing variations have the best resistance to corrosion phenomena because they have a lower percentage of pearlite phase compared to ferrite phase. In heat treatment which produces more pearlite phase, it will cause decreased corrosion resistance. Pearlite itself has the composition of cementite (Fe_3C) and ferrite. Where when connected to an electrolyte or solution, the two phases will experience the phenomenon of micro-galvanic corrosion. Cementite will act as the cathode, and ferrite will act as the anode. Due to the micro-galvanic effect, the pearlite phase will cause the test specimen to experience the corrosion phenomenon more quickly. Test specimens with heat treatment (heat treatment) annealing variations have the category of relative corrosion resistance "outstanding" because the value is < 0.02 mmpy. In addition, the test specimen with a heat treatment process (heat treatment) with variations in annealing according to its purpose can eliminate internal stresses. If the internal stress is not removed, it will trigger stress corrosion cracking (SCC). So that the removal of the internal stress will inhibit the process of the corrosion phenomenon in the test specimen with heat treatment (heat treatment) with variations of annealing.
4) Prior to corrosion testing, it is ensured that no products with any type of corrosion are found on the test specimens without heat treatment (non-heat treatment) and with heat treatment (heat treatment). However, after corrosion testing was carried out, corrosion products began to appear, namely pitting corrosion and uniform corrosion products were found. The macrographic photo of the sample before the corrosion test still looks clean and shiny, but after the corrosion test, pitting or pitting corrosion products and uniform corrosion products are found. The heat-treated test specimens had more pitting and uniform corrosion products, and the heat-treated test specimens had fewer pitting and uniform corrosion products. This type of test specimen with annealing variation heat treatment has the least corrosion products when compared to others.

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