The effect of ship replating welding process on floating conditions against strength value

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Abstract. Ship replating is one of the important things in the process of ship maintenance. Ship replating can be done during docking and floating. The cooling rate of the welding process gave different effects on the mechanical properties of the material when the welding process is in a floating position and docking position. This research uses four variations in the distance between the weld groove lines and the water lines which were 30 mm, 60 mm, 100 mm, and 130 mm. This research also uses four variations in water temperature were 25°C, 28°C, 30°C and 32°C. The strength value of the variations will be compared to the strength value of dock welding. The results of tensile testing showed that there was a decrease in strength value at each increment of the water line spacing with weld groove lines and water temperature variations. Based on this research, welding in a floating condition with a minimum distance waterline and weld groove line of 30 mm, and the temperature of water between 25°C - 32°C can be applied in the field, because the strength value for all variations on this research satisfies by BKI (Biro Klasifikasi Indonesia) standards.

Keywords: ship replating, floating, cooling rate, tensile strength

1. Introduction
In shipping world, ship replating term is often heard. Ship replating is a change process and renewal of the steel plates to replace the old plates that have suffered damage [1]. Repairing can be done on top of the dock, and floating on the water [1]. Repairing which is done in water are limited to the part that is not submerged to water, the example is ship replating on the side plate [1]. These reparations generally have low levels of difficulty as well as a relatively short working time [1]. Ship replating that is done in floating condition should consider some aspects, such as one of them how the distance between the water line with Weld groove line. This is due to the process of cooling the welding rate at floating conditions faster than when docking [1].

The water temperature also affects the cooling rate of the ship replating process under floating conditions. Water temperature in Indonesia is very varied, which is influenced by climate or weather as well as wind [2]. Indonesian water temperature data is obtained from the Marine Research Center (Pusriskel) – Ministry of Maritime Affairs and Fisheries from 2004 to 2018 [2]. The data shows the water temperature in Indonesia ranges from 24°C – 32.5°C [2]. The coldest water temperature is in eastern Indonesia, while the warmest water temperature is in the western part of Indonesia [2].
The research on cooling rate of low carbon steel has been done by Sun [3]. After the heat treatment, the material was cooled with several methods [3]. The mechanical properties and microstructures of low carbon steel were tested after cooling [3]. The results of the microstructure indicate on the slow cooling phase that occurred was the ferrite phase, while on fast cooling phase that occurred was a finer ferrite grain [3]. The results of mechanical properties showed that in slow cooling, hardness value and strength value decreased, while its ductility increases [3]. Conversely, at fast cooling the value of hardness and strength increases, while its ductility decreases [3].

The cooling rate will affect the mechanical properties and microstructure on the material. Turichin et al. [4] investigated the influence of heat input against cooling rate, and mechanical properties on the low carbon steel material [4]. In this research used automatic welding system, so that all welding parameters can be kept in a constant condition [4]. It was found that increasing the heat input making the cooling rate increasingly slow [4]. This leads to the value of strength and hardness was decreasing, but the impact testing value was increasing [4].

In addition, before doing this research, first did a simple experiment that aims to determine the water temperature propagation in the low carbon steel material. This simple experiment was done by immersing the low carbon steel material into the water as deep as 100 mm, and then measuring the material temperature on the water line and every 10 mm above the water line. From the results Simple experiments were carried out, obtained variations between the water line and the weld groove line by 30 mm, 60 mm, 100 mm, and 130 mm. The variation in the distance is taken because at these points there is a change in temperature due to water temperature propagation to the material.

The material used in this research is a BKI (Biro Klasifikasi Indonesia) grade A steel plate. The welding process uses SMAW with 2G welding position, and uses single bevel butt with 30° angle. In this study used fresh water and assumed to be in calm waters, so wave influence was not taken into account. This research aims to determine the accepted criteria of floating welding based on BKI regulations [5]. As well as knowing the characteristics of the strength value on each given variation.

2. Experimental procedure

2.1 Materials and equipment

The material used in this research is a BKI grade A steel plate with a thickness of 12 mm, according to the material used in the hull of the vessel. BKI Grade A steel plate is a low carbon steel, widely used for general construction. Table 1 shown the chemical composition of BKI Grade A steel plate. Equipment needed in this research are electrode type E 7016 with 3.2 mm diameter, welding machine with 27 Volt and 180 Ampere, and polarity of DCEP, tensile test machine, and water tub used during the process of welding on floating conditions. Water tub is equipped with a faucet at the bottom to circulate the water during the welding process. Figure 1 shown the water tub that used in this research.

| Table 1. Chemical composition of BKI Grade A steel plate |
|-----------------|---------|
| Carbon (C)      | 0.13 %  |
| Silicon (Si)    | 0.17 %  |
| Manganese (Mn)  | 0.76 %  |
| Phosphorus (P)  | 0.007 % |
| Sulfur (S)      | 0.005 % |
| Cuprum (Cu)     | 0.01 %  |
2.2 Experimental Preparation
Variation of the welding distance with the water surface is done by dipping material into the water, after that welding in the condition of the material is immersed in water. The weld groove line spacing with the water surface distance used are 30 mm, 60 mm, 100 mm, and 130 mm, as shown in Figure 2.a. The water temperature will be used in this research, which are 25°C, 28°C, 30°C and 32°C. To keep the water temperature at the time of welding to remain stable according to the expected temperature, the steps are circulating water by supplying new water into the water tub and give outlet holes in the water tub. Then the outlet hole in the water tub is installed faucet to be adjusted the amount of water discharge that comes out. It is intended to keep the water temperature from being exposed to heat propagation so that the water temperature stays awake at the expected temperature and the water line height variation can still be maintained. This process is done as an approach with real conditions that occur in field. Moreover, the step is Inserting ice cube in the water used to soak the material during the welding process. Ice cube is given according to the needs of temperature that want to be kept on water. During welding process, monitors at the water temperature periodically using thermal gun, as shown in Figure 2.b.

2.3 Cooling rate
Base on American Welding Society [6], cooling rate experienced in the weldment is a function of the rate of energy dissipation. Cooling rates vary with temperature. However, for purposes of comparison, cooling rate calculations should be made at a given temperature (Tc). The cooling rate for single pass welding applications can be calculated using thin plate equations. However, it is not
very obvious whether the plates used belong to the category thick or thin. For this reason, it is preferable to determine whether the plates used are in the thick or thin plate category, can be known by using a relative plate thickness ($\tau$) formula such as the following equation (1). Where $\tau$ is the relative plate thickness, $h$ is the thickness of the workpiece (cm), $\rho$ is the density of the base metal (g cm$^{-3}$), $C$ is the specific heat of base metal (cal g$^{-1}$˚C$^{-1}$), $T_C$ is the temperature at which the cooling rate is calculated (˚C), $T_0$ is the initial plate temperature (˚C), and $H_{net}$ is the net heat input per unit length (cal cm$^{-1}$).

$$\tau = h \sqrt{(\rho C(T_C - T_0)) H_{net}^{-1}}$$ (1)

The thick plate equation applies when $\tau$ is greater than 0.9, whereas the thin plate equation applies when $\tau$ is less than 0.6. When $\tau$ falls between 0.6 and 0.9, the upper bound of the cooling rate is given by the thick plate equation. The lower bound is given by the thin plate equation. The following is an equation used to calculate the cooling rate on a thin plate (2), and a thick plate (3). Where $R_C$ is the cooling rate at weld center line (˚C s$^{-1}$), $\pi = 3.1416$, $k$ is the thermal conductivity of metal (cal cm$^{-1}$ s$^{-1}$˚C$^{-1}$), and $h$ is thickness of the base metal (cm).

$$R_C = -2\pi k \rho C (h H_{net}^{-1})^2 (T_C - T_0)^3$$ (2)

$$R_C = -(2\pi k (T_C - T_0) H_{net}^{-1})$$ (3)

2.4 Welding process

The welding process is done using SMAW welding, with 2G welding position, using single bevel butt, according to the condition of ship replating hull of the vessel in field. After the material to be welded is finished in the settings according to the height of the water line is varied, next is to adjust the discharge of water in and out of the water tub. The discharge of this incoming and outgoing water must be the same to keep the water height constant according to the variation in water height. After that the water temperature before welding is measured according to the variation of water temperature used in this research. If all steps are completed, then the welding stage can be done. During the welding process, the altitude of water and also the temperature of water is still maintained according to each variation.

2.5 Specimen test

Dimensions of specimen test used in accordance with BKI 2019 standards [5], as shown in Figure 3. Figure 4 shown the specimen that used based on BKI 2019 standards [5]. In each variation, there are three tensile test specimens. The objective of provided three specimens test is the data obtained is more valid. The three test specimens are seen in their value consistency, and then take the average value of them.

![Figure 3. Dimensions of specimen test based on BKI 2019 standards [5]](image-url)
2.6 Tensile test
The testing process was conducted at the Strength and Construction Laboratory, the Faculty of Marine Technology, Institut Teknologi Sepuluh November Surabaya. Tensile testing was performed using all weld specimens. The tensile test specimen was given a pull test loading until the specimen test rupturing. Tensile testing result in the form of force (F) and length increase (∆l), which can be analysed further. A universal testing machine (MFL/UFD-20, 200 kN) was used to perform testing at room temperature.

3. Result and discussion

3.1 Cooling rate analysis
The result of the relative plate thickness (t) calculation on the entire experiment done is less than 0.6, then to calculate the cooling rate using the equation (2) for the category of thin plates. Table 2 explains the result of cooling rate calculation (RC), and Figure 5 shows the graphic of the cooling rate. The cooling rate calculation result of all variations showing the highest cooling rate value is at 25°C, it is in accordance with the literature [4] that the temperature of 25°C has the highest cooling rate compared to other temperatures. Based on the calculation of the cooling rate, the welding has been done in the whole variation can be used and compared to the strength value between one and another.

Table 2. Cooling rate at different temperatures

| Water Temperature (°C) | Rc (°C s⁻¹) |
|------------------------|------------|
| 25                     | 2.80       |
| 28                     | 2.73       |
| 30                     | 2.63       |
| 32                     | 2.54       |
| 35 (Dock welding)      | 2.44       |
Figure 5. Cooling rate at different temperatures

3.2 Tensile properties on dock welding
The result of tensile testing on dock material welding indicates the value of tensile strength meets the criteria of BKI regulations [5]. According BKI regulations, minimum tensile strength requirement on the welding of hull structure for Grade A materials is 400 N/mm² [5]. The value of tensile strength on dock material welding is 447.07 N/mm². The rupture position located at the base metal. That value can be used as comparative to the value of another floating welding.

3.3 Tensile properties on floating welding
Table 3 shown the tensile test results in floating welding. All tensile strength values on floating welding meet the minimum standard permitted by BKI [5]. According BKI regulations, minimum tensile strength requirement on the welding of hull structure for Grade A materials is 400 N/mm² [5]. The rupture position located at the base metal. So that the value can be used as comparative to other welding strength values.

Table 3. Tensile test on floating welding

| Distance variation (mm) | 25°C  | 28°C  | 30°C | 32°C | 35 (Dock welding) |
|-------------------------|-------|-------|------|------|-------------------|
| 30                      | 511.30| 510.32| 505.45| 500.03|                   |
| 60                      | 492.24| 490.73| 489.57| 481.11|                   |
| 100                     | 475.29| 473.97| 472.73| 464.10|                   |
| 130                     | 455.11| 454.18| 453.06| 450.06|                   |
Figure 6 shown the tensile test result against distance of waterline to weld groove line. From that chart can be seen that there is a decrease in the tensile strength value at each increment of the distance of waterline to weld groove line. This is due to the distance of waterline to weld groove line with a smaller is indicating the faster cooling rate. It is accordance with the literature’s Sun et al. [3]. The material that has undergone heat treatment and gets a fast cooling treatment will have a higher tensile strength value when compared to materials with slow cooling [3].

Figure 7 shown the tensile test result against water temperature. The chart also indicates that there is a decrease in the tensile strength value at every water temperature increase, although the value is not significant. This is due to the lower temperature of the water indicating the faster cooling rate.
It is accordance with the literature’s Sun et al. [3]. Based on Figure 7 it can be known that floating welding with low water temperature will produce stronger material when compared with the material that is welded in a floating condition with a higher water temperature (slow cooling) [3]. Floating welding techniques can be applied to conventional steel plate replating processes with a sandwich plate system in the form of steel-polyurethane elastomer [7], steel-unsaturated polyester resin [8,9,10] or steel-vinyl ester bio-resin [11]. Also, floating welding can also be applied to other floating structures such as the pontoon of the Vertical Axis Hydrokinetic Turbine [12]. For the next research, application of floating welding in low alloy steel of higher strength grade that used for pressure hull application, can also be used [13]. Jorge et al. [14] denote that heat treatments were not necessary to complement welding procedure of the high strength low alloy. It is similar to the research conducted by Zhang et al. [15] who said that the ultimate tensile strength values of the China Low Activation Martensitic with various heat input were all higher than 630 Mpa. A variety of heat input with a combination of water cooling on the welding process make the value of strength increasingly higher [16].

3.4 Tensile properties comparison

Table 4 shown percentage comparison of tensile strength value on floating welding with on dock welding. From Table 4 it can be noted that the percentage increase in the tensile strength value between floating welding and on dock welding is the greatest in the range of waterline to weld groove line of 30 mm with a water temperature of 25°C, with a percentage of 14.37%. While the percentage of the smallest tensile strength is the value in the range of waterline to weld groove line of 130 mm with a water temperature of 32°C, that is a percentage of 0.67%. From these results can be known that based on the value of its strength, the most optimal floating welding to be applied based on this research is on the distance variation of waterline to weld groove line of 130 mm with a water temperature of 32°C. Other studies need to be conducted to obtain a more comprehensive analysis of floating welding techniques, such as power supply current analysis [17] and bending strength of weld joints [18].

| Distance variation (mm) | 25°C | 28°C | 30°C | 32°C |
|------------------------|------|------|------|------|
| 30                     | 14.36% | 14.15% | 13.06% | 11.84% |
| 60                     | 10.10% | 9.76% | 9.51% | 7.61% |
| 100                    | 6.31% | 6.02% | 5.74% | 3.81% |
| 130                    | 1.80% | 1.59% | 1.34% | 0.67% |

4. Conclusions

There was a reduction in the value of tensile strength at each increment the distance of the waterline with weld groove lines, and at each increase in the water temperature variation. All tests on welding floating conditions were acceptable based on BKI regulations governing steel welding in the ship hull structure. The highest percentage increase in tensile strength value between floating welding and on dock welding was on the variation of the distance waterline to a weld groove line of 30 mm and the water temperature of 25 °C, which is 14.36%. In contrast, the lowest percentage was on the variation of the distance waterline to the weld groove line of 130 mm and the water temperature of 32 °C, which is at 0.67%. So based on this research, welding in floating condition with a minimum distance between waterline to weld groove line of 30 mm, and a water temperature of 25 °C - 32 °C, can be applied in the field.
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