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THE USE OF MAGNETIC FLUX TO THE WELDING OF HOT ROLL QUENCH TEMPERED STEEL

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ABSTRACT

Hot Roll Quench Tempered Steel (QTS) is term of hot roll steel which produced by PT. Krakatau Steel with carbon content 0.29 %C that given by martempering treatment. Martempering treatment meant to increase the steel hardness for about 500 BHN, thus it cannot be penetrated by bullet. QTS designed as alternative material for industrial supporting of military tactical vehicles. Martempering treatment has been changed metal microstructure from tough ferrite-pearlite to the hard martensite. The weakness of martensite structure in welding field is low weldability and prone to the delay cracking for post welding. Delay cracking also resulted in defect or initial crack which occur by the rapid cooling in the post welding and the dissolved of inclusion and gas in the welding area during solidification in weld metal. In many researches, high circulation rate of weld pool could improve weld metal structure and HAZ, decrease welding defect and improve the other properties. Circulation rate of weld pool can be increased by enlarging electromagnetic force or Lorenz force (F_L). Electromagnetic force can be enlarged by increasing welding current density (J) or increasing magnetic flux (B) as with the equation $F_L = J \times B$. In this research, it was conducted by QTS plate welding used MIG welding with gas protector CO_2. Welding electric current 140 A was flowed to the electrode wire AWS ER 70-S6 with the average welding speed 15 cm/minute. Magnetic flux was added from outside during the welding by flowing DC current to the solenoid 100 x 100 x 10 mm. The DC current that flowed to solenoid was 0, 3, 6, 9, 12 and 15 Ampere. Those current variations resulted in magnetic flux for 0 mT, 2,4 mT; 3,4 mT; 4,43 mT; 6,43 mT and 9,03 mT. Thermocouple of K type was carbon welded in the distance of 10 mm from welding core to measure HAZ temperature. The result was peak temperature in the distance of 10 mm from welding core getting lower because of outside magnetic flux addition from 0 mT to the 9.03 mT. By taking temperature range of post welding comparison from 400°C to 200°C, it was known that without magnetic flux addition which results the highest post welding cooling rate and getting lower to the magnetic flux addition of 9.03 mT. From the radiography test, it was known that magnetic flux addition could decrease welding defect percentage. The bigger magnetic flux addition resulted in smaller welding defect percentage. The bigger magnetic flux addition also resulted in bigger impact strength of welding area with more ductile fracture.

Keywords: magnetic flux, welding, cooling rate, welding defect, impact strength, QTS.

INTRODUCTION

Before the welding process, Hot roll quench tempered steel (QTS) has been treated with martempering process so the structures are changed from ferrite-pearlite to rapid martensite, it lower the weld-ability of the specimen. The indication are there will be a crack distibuting as the welding effect. To increase or to fix the weld quality we need to prepare for the welding process.

High cooling rate will cause early form of welding defects appearing as a cause cracks that propagate during loading. Cracked weld stems from gases and oxides are dissolved and the difference in expansion and contraction of the metal during melting and solidification. Micro weld cracking would be the beginning of a crack that propagates post-welding (delay cracking).

Several studies have been done to improve the quality of the weld. Investigated that the higher the preheating temperature of the room temperature, 100 ° C to 200 ° C causes the amount of heat are getting down and rising again to raise the preheating temperature to 300 °C [1]. Decreased proportion of the grain boundary of ferrite microstructure (GF) in the weld metal caused the hydrogen to diffuse and cold cracking reduced. To reduce the proportion of GF and ferrite with second phase structure (FS), flux core containing 1.5% Ni are used [2]. Pulse shaping the laser beam welding also affect the crack solidification. Al 6061-T6 solidification cracking decreased with the decrease of ramp-down gradient of 137 kW/s, 52 kW/s, 32 kW/s [3]. Some of these studies have positive results but only applied to the welding of the base metals that has not undergone structural changes as a result of pre-welding heat treatment.

Welding thermal cycle is the process of heating and cooling in the weld metal and HAZ. During welding the weld metal and HAZ temperature rises until it reaches a peak temperature then drops back to its start temperature. Because of this process, the metal around the weld experiencing rapid thermal cycling which leads to complex metallurgical changes, deformation and thermal stress. It is very closely related to toughness, welding defects and cracks which can reduce the quality of the welds [4].

During the welding process, the weld pool area experiencing circulation due to convection style. The convection style, among others, the force caused by the difference in specific gravity of the liquid metal due to

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differences in weld's temperature distribution called buoyancy force (F_b), the force due to the surface tension called Marangoni force (F_γ) and the force caused by the electromagnetic fields from power lines arc welding called electromagnetic force or Lorenz force (F_L). Of the three forces acts, the electromagnetic force gave the most dominant influence on the circulation weld pool [5]. The magnitude of the electromagnetic force is determined by the current density (J) and the vector magnetic flux (B) during welding and formulated F_L = A x B [4]. In some cases this convection force creates dual circulation loop that can affect the homogeneity of the structure, causing segregation and simultaneously effective in evaporating gasses from the weld pool. [6]. These statement was strengthen, that the convection flow in the weld pool can affect the homogenity of the structure, porosity and hydrogen inclusion in the weld pool [7]. From the results of two-dimensional modeling, it is known that convection currents due to electromagnetic force tends to produce penetration in weld pool which is steeper than the influence of convection currents due to a marangoni force [8]. Increased convection in the weld pool by adding an external magnetic field will increase the value of the effective thermal conductivity of weld metal (k_L), the heat transferring to the weld pool becomes more effective, and lower the weld pool temperature [4].

To increase the circulation rate of molten metal, it can be done by increasing all the three forces acting on the main weld pool electromagnetic force. Enlarge electromagnetic force by increasing the flow will increase heat input and thermal stresses in welding are certainly not the right solution. Enlarge electromagnetic force by adding the magnetic flux from the outside can be an alternative to raise the circulation rate of molten metal and improve the quality of the welds.

Adding magneto-fluid dynamics mechanism in laser beam welding can alter the condition of the liquid metal flow and improve circulation rate of molten metal in the weld pool [9]. Strong magnetic fields influence the effect of shielding gasses, causing the depth of penetration of the weld pool increased by 7%, while the width of the weld pool changes are not significant [10].

On electric welding (arc welding), the electromagnetic force can improve the mixing weld pool. With the convection currents, added metal filler can be mixed perfectly before experiencing solidification so that the composition of the weld metal becomes more homogeneous [4]. Porosity ere formed due to the interaction between hot molten metal with the parent metal surface on the pond so that the gasses dissolved in the molten metal will react with the parent metal and causing gas bubbles on a cold weld pool area. Gas bubbles that stay will form fine holes in solidification process. Convection occurs in the weld pool which theoretically can help release gas bubbles are formed into the atmosphere before slidificated [4].

EXPERIMENTAL METHODS

This study uses laboratory experimental methods. Specimens of QTS plate thickness 10 mm welded using MIG welding with protective gas CO_2. 140 A welding electrical current flowed in the wire electrode AWS ER 70-S6 with an average speed of welding 15 cm/min. Magnetic flux is added from outside during the welding process with DC current flowing to the solenoid coil of copper wire diameter of 0.7 mm and dimensions of 150 windings of solenoid 100 x 100 x 10 mm. The amount of DC current is supplied to the solenoid is 0, 3, 6, 9, 12 and 15 Amperes. The current variation produces a magnetic flux at 0 mT, 2.4 mT; 3.4 mT; 4.43 mT; 6.43 mT and 9.03 mT. K type thermocouple welded carbon at a distance of 10 mm from the weld center to measure the temperature of the HAZ.

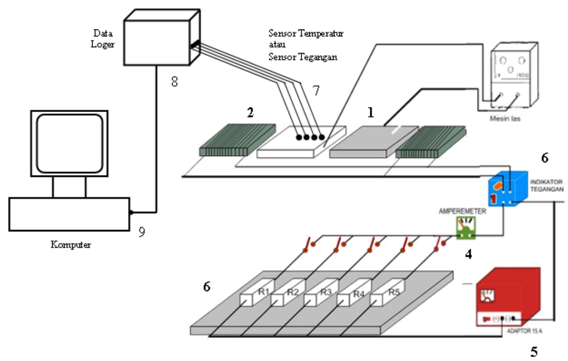

Figure-1. Sketch diagram of the experimental.

1. Base materials	2. Solenoid
3. MIG welding machine	4. Ampere meter
5. 15 Ampere Adapter	6. Voltage indicator
7. Temperature sensor	8. Data logger
9. Computer	

RESULTS AND DISCUSSIONS

From the results of temperature measurement range of 10 mm from the weld center is known that the addition of the magnetic flux from the outside causes the peak temperature of HAZ got down (Figure-2). Scalling back peak temperature is caused by the increasied electromagnetic force that fasten the circulation of molten metal during welding process [5] and increasing the effective value of the thermal conductivity of the weld metal (k_L) [4]. The circulation of the liquid metal causes the heat release from the molten metal and HAZ more effective. from the graph, welding without magnetic flux creates HAZ peak temperature of 658,3 °C and HAZ peak temperatures getting down to the addition of magnetic flux 9,03mT which produces HAZ peak temperature 406,7 °C.

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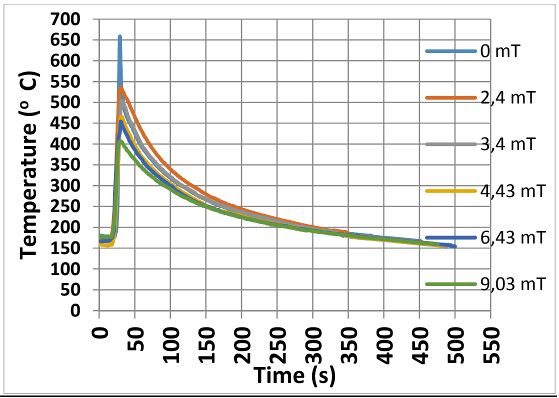

Figure-2. Graph of thermal cycles at distance of 10 mm from the weld's center or HAZ.

Furthermore, seen in the HAZ temperature that decreased from 400 °C to 200 °C, addition of the greater magnetic flux causes the cooling rate got lower (Figure-3). The graph indicates that the steeper the metal cools rapidly and vice versa. smaller peak temperature caused a temperature gradient which means that the smaller the cooling rate decreases. This is in accordance with equation (1) [11]:

$$R = 2\pi.k.\rho.Cs.\left(\frac{h}{Hnett}\right)^2 (Tc - To)^3 \qquad (1)$$

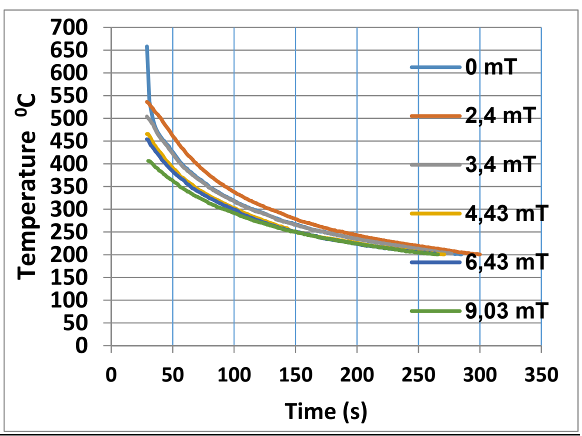

Figure-3. The cooling rate within 10 mm from the weld center or HAZ from 400 °C to 200 °C.

A slow cooling rate will give more time to the structure of the metal granule to expand during solidification thus forming large granules (Figure-4). While the rapid cooling of the specimen without the addition of magnetic flux formed small granules.

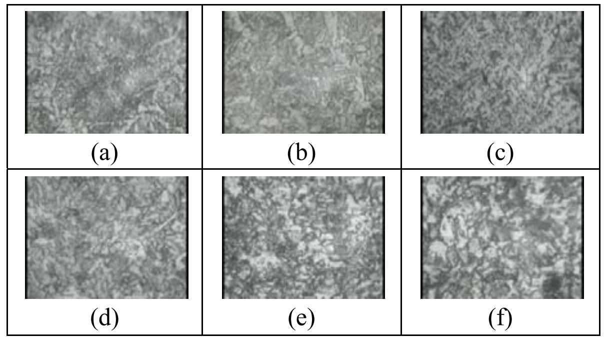

Figure-4. Structure of grain weld metals at 400x enlargement. (a) 0 mT;(b) 2.4 mT; (c)3.4 mT; (d) 4.43 mT;(e) 6.43 mT (f) 9.03 mT.

Welds performance was tested by investigate the welding defects with radiographic test. Furthermore, by using Autodesk Inventor Software 2012, obtained the data area of welding defects and weld joint area on the specimen as seen in Figure-5. The Percentage porosity is obtained from the comparison of the welding defects with the weld joint area.

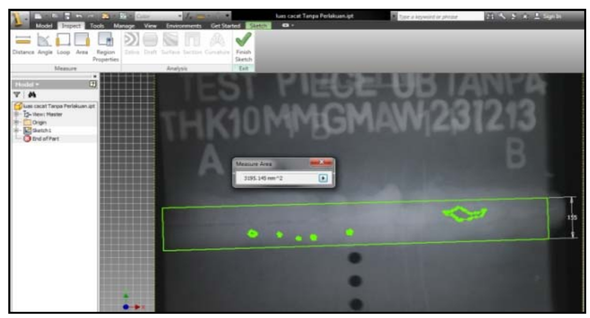

Figure-5. The processing of the weld defects area using Autodesk Inventor 2012.

Percentage calculation results weld defects on average every treatment are shown in Figure-6. It appears that the greater the external magnetic flux added to the process, the smaller the weld defect percentage to appear.

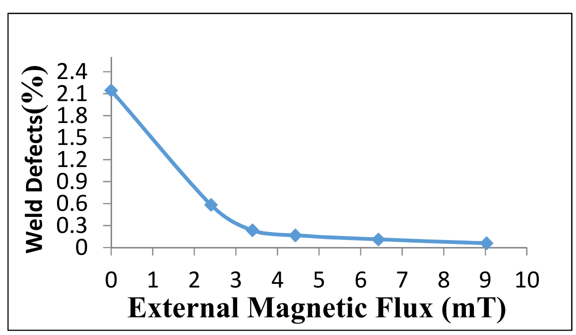

Figure-6. The graphic of relations between the external magnetic flux to weld defects.

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From Figure-7 it appears that the greater the magnetic flux that is added cause impact strength increases. Seen on specimens without the addition of magnetic flux has the smallest impact strength of 1,2 J/mm^2 and increased to 1.95 J/mm^2 on the addition of 9.03 mT magnetic flux.

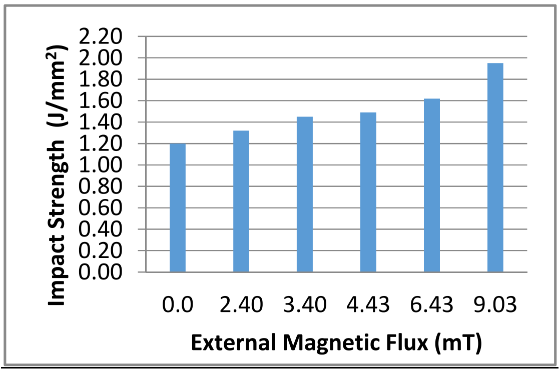
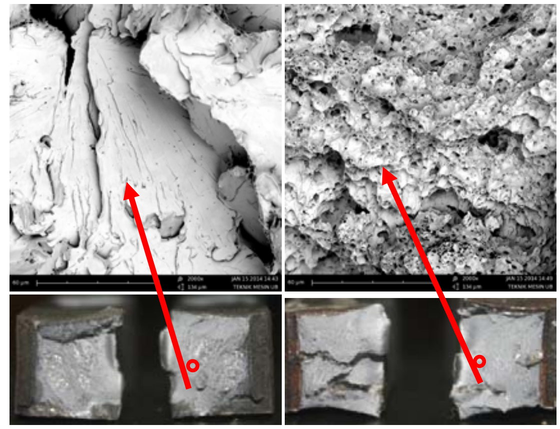


Figure-7. Result of impact strength in weld area.

Form of fracture surface from impact test results on specimens without treatment showed a mixture of brittle and ductile fractures, which is dominated by brittle fracture. While the speciment with the addition of 9.03 mT magnetic flux showing an ductile fracture. By using SEM (Scanning Electron Microscope) on the specimens without a treatment and specimens with addition of 9.03 mT magnetic flux there was an apparent differences in impact fracture. From Figure-8 (a) the fracture pattern was dominated with *cleavage* patterns. Cleavage fracture occurs in fracture resulting granular material/crystalline, which is generated by the mechanism of gap (cleavage) in the grains of metal material that has fragile characteristic (brittle). appeared by a flat fracture surface capable of providing high light reflectance (shiny). While in Figure-8 (b) shows the fracture pattern which is dominated by the dimple pattern. Fault caused by overload charge, resulting in the formation of unoccupied granules which are then joined to the structure of the alloy. This uncoccupy resulting granules that are joining discontinuity strain, when the strain increases causing this growing void grains that form a fracture surface that shows sunken growing basins creating the dimple pattern. Dimple fracture pattern often found in tough materials.



(b)

Figure-8. SEM results on surface fractures a) 0 mT, b) 9,03 mT (2000X enlargement).

CONCLUSIONS

The greater the external magnetic flux which is added, it will reduce peak temperature and cooling rate of the HAZ. A decrease in the cooling rate of HAZ and weld metal will form an larger metal grains so that the weld metal is more resilient and greater impact strength. The greater the magnetic flux that is added from outside also leads to smaller percentage of weld defects.

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