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THE ROLE OF RESIDUAL STRESS TO HARDENING AND CRACKING ON QUENCHED AND TEMPERED ARMOR STEEL WELDED JOINTS

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The welded joint always leaves residual stress when welding is complete; this stress produces distortion and reduces the distance between of microstructures in the joint. The purpose of this study was to observe the pattern of residual stress before and after welding of Q_{900}&T_{125} Steel and Q_{900}&T_{175} Steel. The material used in this study is Hot Rolled Plate Steel 10 mm thick. The material cut into two parts. Both are heated at 900 °C, held for 30 minutes, and cooled in water. The first and second specimens tempered at 125 °C and 175°C, respectively, and produces Q_{900}&T_{125} Steel and Q_{900}&T_{175} Steel. Measure d and do, and the axial, normal and transverse residual stresses using neutron ray diffraction. The method used is to measure free stress and stress, and the axial, normal, and transverse residual stresses using neutron diffraction. The shrinkage always leads to the weld center which causes the weld joint curved by the solidifying weld metal surface. The pattern and direction of the three residual stresses concentrated at the weld center.

Keyword: armor steel, welded joints, heat treatment, residual stress, hardening

INTRODUCTION

The need for high strength and hardness steel needs in the commercial and military manufacture. One type of steel is armor quenched and tempered steel (AQ&T Steel). This steel cannot be separated from the welding process when specific shapes desired.

Welding arcs cause metals to melt, expand, and freeze (in the atmosphere). The freezing end leaves permanent stress that triggers a crack and is called residual stress. It has been shown that effective stress relaxation without cracking can be achieved by fast heating to the post weld heat treatment (PWHT) temperature beyond the precipitate solvus temperature, thus avoiding any precipitation [1]. Initial stress which is generated during the manufacturing steel structure occurs due to a temperature difference on the surface and inner side of steel while it goes through the heating and cooling process during manufacturing [2]. The thermal cycle causes non-uniform heating and cooling of the metal and creates heterogeneous plastic deformation and residual stress on the weld [3]. While the maximum residual stress occurs in the centreline of the weld, it is the compression residual stress [4]. Weld residual stresses and weld residual stresses relaxation have notable influences on fatigue crack propagation in welded joints, and therefore affect the fatigue life of welded joints [5]. Weld residual stress increased the growth rate of fatigue crack perpendicular to the weld line, reducing the fatigue life [6]. Cavities formed at grain boundaries and residual stresses from the welding process will affect crack growth [7].

Significant tensile stress develops not along the center of the weld metal but the heat-affected zone (HAZ) [8]. Hochhauser and Rauch found that the width of soft layer ranged from 0,33 to 0,6 times of the specimen thickness, and the reduction of tensile strength of butt joint was 3% to 8% of its original strength [9].

The residual stress of welding influences the performance of the welded structures, fracture resistance, resistance to fatigue crack propagation, fatigue strength, and fatigue period [10]. Therefore residual stress produced during welding must be considered at the design stage [11]. The effects of complex microstructure transformation during welding change the local thermo-mechanical properties and development of residual stresses [12]. Residual stress can predict fatigue crack propagation in rigid panel welding [13] – more significant tensile stress at the upper surface of the weld [14]. Because the influence of the arc heat causes the hardness profile to change, the heat-affected zone hardness results in the ability of welding assessed [15]. HAZ often has a lower hardness than base and weld metal [16]. Likewise, the selected filler metal will affect the stress and strain distribution at the welded joint [17]. Because CGHAZ is close to the fusion line, this area reaches the maximum temperature that allows carbide melting, considering base metals and grain growth [18].

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Residual strain (ε_z) obtained by measuring the distance between the standard grid d_o (considered stress free) and the stressed d_n and calculated with following formula,

$$\varepsilon_z = \frac{(d_n - d_o)}{d_o} \tag{1}$$

The basis for calculating the residual stress is Bragg Law [19]

$$n\lambda = 2 \times d \times sin\theta \tag{2}$$

Residual stress on three-axis σ written by [20]

$$\sigma_x = A \times \{(1-v)\times\varepsilon_x + v \times (\varepsilon_y + \varepsilon_z)\}$$
$$\sigma_y = A \times \{(1-v)\times\varepsilon_y + v \times (\varepsilon_x + \varepsilon_z)\} \tag{3}$$
$$\sigma_z = A \times \{(1-v)\times\varepsilon_z + v \times (\varepsilon_x + \varepsilon_y)\}$$
$$A = \frac{E}{\{1 + v\times(1-2v)\}}$$

Where: $\varepsilon_{x,y,z}$ is strain in axial, transverse and normal direction respectively. n = constants. λ = wavelength. v = Poisson ratio. θ = angles of incidence. E = Modulus elasticity.

The purpose of this study was to observe residual stresses before and after welding of Q_{900} & T_{125} Steel and Q_{900} & T_{175} Steel. Achieve the research objectives, the following steps taken:

1 Make a visual observation of the welded joint deformation before and after welding.
2 Observe the pattern and value of residual stress of the welded joint.
3 Evaluate residual stress patterns that contribute to the effect of hardening on the weld metal. The benefit of this research is to ensure that residual stress has an impact on cracks.

METHODOLOGY

The material used in this study is Hot Rolled Plate Steel (HRP) Steel 10 mm thick (made by PT. Krakatau Steel (Persero), Cilegon, Banten, Indonesia), both quenched at 900 °C (held in 30 minutes). The first and second specimens tempered at 125 °C and 175 °C, and Q_{900}&T_{125} Steel and Q_{900}&T_{175} Steel produced respectively.

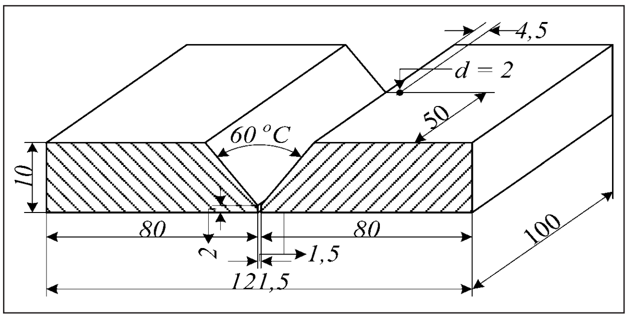


Figure 1 V butt joint

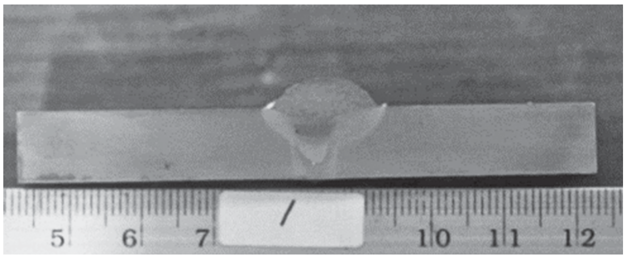
The materials prepared, as shown in Figure 1, and welded using gas-metal arc welding. To prevent distortion when welding uses a fixture.

Residual stress measurements using Neutron Ray Diffraction on the specimens before and after after welding complete.

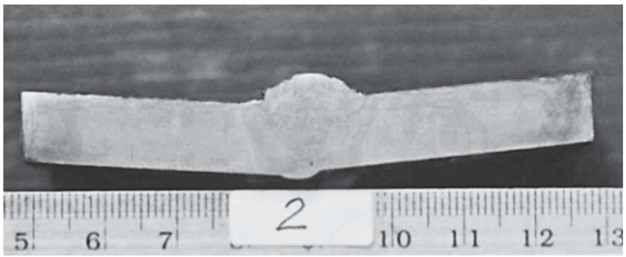
RESULTS AND DISCUSSION

The residual stress phenomenon in welded joint specimens shows in Figure 1 [21]. The joining surface pulled to the weld center by freezing after welding.

Figure 3 shows the residual stress produced when making Q_{900}&T_{125} Steel during quench (at 900 °C) and temper (at 125 °C). Both quench and temper heat treatments held for 30 minutes. It appears that the normal and transverse residual both are positive—positive residual stresses caused by rolling on the tensile side and compression on the compressive side. Quench at 900 °C producing transformation of austenite to martensite, and increase in hardness called metallurgical harden. When water quenching finished, the compression residual increased. Compression residual decrease due to tempering at 125 °C. Axial stress produced when materials compressed by a roller at the hot rolling process.



a) Fixture used



b) Without fixture

Figure 2 Gas Metal Arc Welded

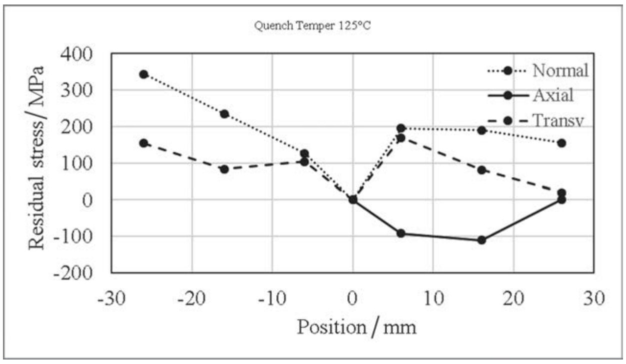


Figure 3 Q_{900}&T_{125} Steel Residual Stress before welding

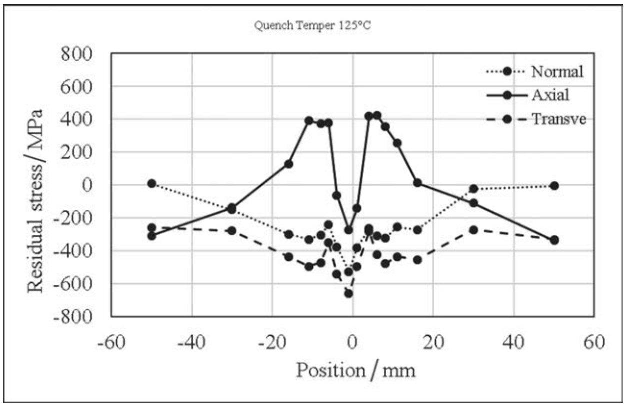


Figure 4 Q_{900}&T_{125} Steel Residual Stress after welding is complete

Figure 4 shows the residual stress pattern on Q_{900}&T_{125} Steels after the welding process. It seems that normal and transverse residual stresses are negative residual stresses (compressed residual pressure), both centered in the center of the weld. It seems that normal and transverse residual stresses are negative residual stresses (compressive residual), both centered in the weld center. The axial residual stress begins from the compression to tension residual stress, and this stress drops to the middle of the weld.

Figure 5 shows the residual stress produced when making Q_{900}&T_{175} Steel during quench (at 900 °C) and temper (at 175 °C). Both quench and temper heat treatments held for 30 minutes. The standard and transverse are tension stress caused by rolling on the tensile side, and axial on the compressive side—the residual stresses of compression decrease by the quench and temper treatment processes. Normal and transverse residual stresses change from compression to tensile stress. Axial residual stress is compressive stress due to the strength of the roller technique. The residual stress is almost the same as the Q_{900}&T_{175} Steel, the difference in stress patterns due to tempering at 175 °C.

Figure 6 shows that the end of welding then freezes to produce residual compression stress (exceptionally normal and transverse residual stresses). In contrast, the axial residual stress due to the roller pull is quite significant even though it is in quench and temper treatment.

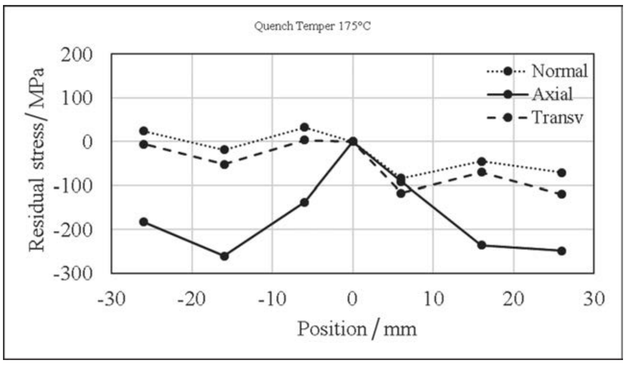


Figure 5 Q_{900}&T_{175} Residual stress before welding

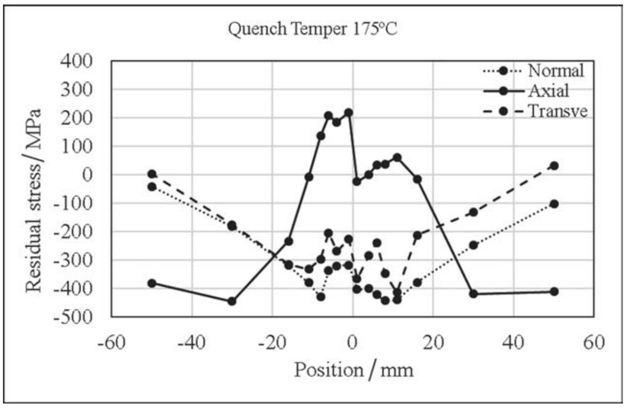


Figure 6 Q_{900}&T_{175} Residual stress after welding is complete

Before welding, the residual stress pattern is random, and the residual stress created during the hot rolled steel manufacturing process. It appears that the residual stresses created are positive (normal and transverse pressures), which are on the tensile and negative (axial stresses), which are in a compressed position. When experiencing quench and temper, the rest of the stress patterns change.

The residual stress pattern changes after welding are complete, and differences due to the welding process. When cooling is full, welding of the weld metal freezes and the residual stress pattern leads to the weld center (as shown in Figures 4 and 6). In the middle of the weld, most axial residual stresses are negative (partly positive because there is a movement speed of motion, and the freezing process is slower than the speed of action). In contrast, the freezing process produces the normal and transverse residual stresses.

During the welding process, the electrodes and base metals melted together and stirred by a magnetic field, and freezes to produce a welded joint. The frozen metal creates shrinkage and fuses in the middle of the weld. The contraction causes compaction between structures, which ultimately increases the hardness.

The structures of each other are irregular, and each microstructure has a flat plane that is in contact with different microstructures. The residual stress of compression also causes tension between the surface of the structure. If the surface tension exceeds the plastic limit, it creates a slip between structures and causes a crack.

From the residual stress patterns (axial, standard, and transverse direction), it seems that everything concentrates on the weld center. It means that all three stresses lead to the weld center and cause an increase in hardness.

From the residual stress patterns generated during the welding process to completion are axial, normal and transverse residual stresses, and stresses. Axial residual stress produces residual stress, which is a combination of compressive and tensile pressure. In contrast, the normal residual stress and transverse stress are compressed, which gives a higher hardening effect than the axial residual stress.

CONCLUSIONS

The results of the study are summarized as follows,

Visual observation (naked eye) the shrinkage always leads to the weld center, which causes the weld joint curved by the solidifying weld metal surface.

The results observe the pattern and direction of the three residual stresses using a neutron ray diffraction at the weld's center.

Residual stresses that contribute to the effect of hardening on the weld metal are normal and transverse residual stress.

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Note: The responsible for English language is the lector from Diponegoro University, Indonesia