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The Effect of Heating Temperature in Static Thermal Tensioning (STT) Welding on Mechanical Properties and Fatigue Crack Propagation Rate of FCAW in Steel A 36

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Abstract. The trend in mechanical design and manufacturing process is marked by the use of thin structures to reduce product weight and fuel savings. It is known that the main problem related to the welding of thin plates is distortion and residual stress which influence fatigue performance of welded structures. The aim of this study is to minimize distortion, improve the mechanical properties and to increase fatigue crack growth resistance of flux-cored arc A 36 steel welded joints using static thermal tensioning (STT) process. In this research, FCAW welding was conducted with and without STT process. The voltage, current, and heat input were 40 Volt, 210 Ampere and 2.184 kJ/mm, respectively. The position of both heaters was 80 mm, and weld with the cooling system was heated near weld center line. During the experiment, the weld metal cycles were measured using data acquisition. After completing the welding process, a sequence of the experiment was conducted including chemical analysis, measurement of distortion, tensile strength and hardness measurement and fatigue tests. Results of this research show that the STT-treat weld joints process performed at temperature of 200 °C produces the highest quality of weld, marked by lowest distortion, high tensile strength, low hardness in weld metal and improvement of fatigue performance

INTRODUCTION

A welding process is increasingly used technique for joining metals in industries that produce machines and structures such as shipbuilding industry, aircraft, automotive, piping, offshore buildings, and other engineering constructions. It is an important method in the manufacturing process because it produces lower production costs, it optimizes operation, it is easy to maintenance and cheap for inspection costs. It has led to the development of welding technology and given a challenge to scientists and experts[1].

The problems of welding plates for ship construction are distortion and buckling in the steel of structure joints. The introduction of the heat of arc welding can cause buckling, distortion, and residual stresses, leading to the quality and high cost for every ship productions. The common methods for reducing buckling distortion and residual stress of thin plate in welding are the post weld treatment and in-process welding. In-process welding includes: preheating and thermal tensioning which consist of transient thermal tensioning (TTT) and static thermal tensioning (STT) [2][3]. Transient thermal tensioning is a technique for controlling the residual stress and distortion by introducing heat at both sides of the weld in front, beside and behind the weld and move together with weld torch. The use of TTT in welding can reduce the rate of fatigue crack propagation [4]. Recent investigation has shown that STT can reduce distortion, residual stress and rate of fatigue crack propagation [5]

However, there has been limited data on the use of STT for reducing distortion and residual stress in FCAW steel welded structures. Therefore it is the subject of the present research.

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MATERIALS AND METHODS

The material used in this study was A36 steel plate with a thickness of 5 mm. The material has a maximum yield strength of 248 MPa and maximum tensile strength of 400 MPa while elongation of 20 %. Electrode used in this research was K-71T (AWS A5.20/ASME SFA-5.20 E71T-1C) with 1.2 mm in diameter and 15 kg/roll weight.

In this experiment, FCAW technique was used, and the welding parameters are voltage, current and heat input. The voltage, current, and heat input are 40 Volt, 210 Ampere and 2.184 kJ/mm, respectively.

FCAW welding was conducted by using forward welding speed of 3.846 mm/s. On the first run, it was not used preheat treatment. In the next welding, the heating temperature of 200 °C, the thermal cycles were measured with thermocouples at the distance of 10 mm, 35 mm, 55 mm and 80 mm from weld centerline.

After welding, distortion measurement was conducted with a dial indicator in longitudinal and transversal directions. Test on fatigue propagation rate was conducted with Servopulser machine type EHF-EB 20 with of 20 Ton. The specimen used was center crack tension (CCT) according to ASTM E 647-00 standard model. The frequency (f) and stress ratio (R) is 11 Hz and 0.1.

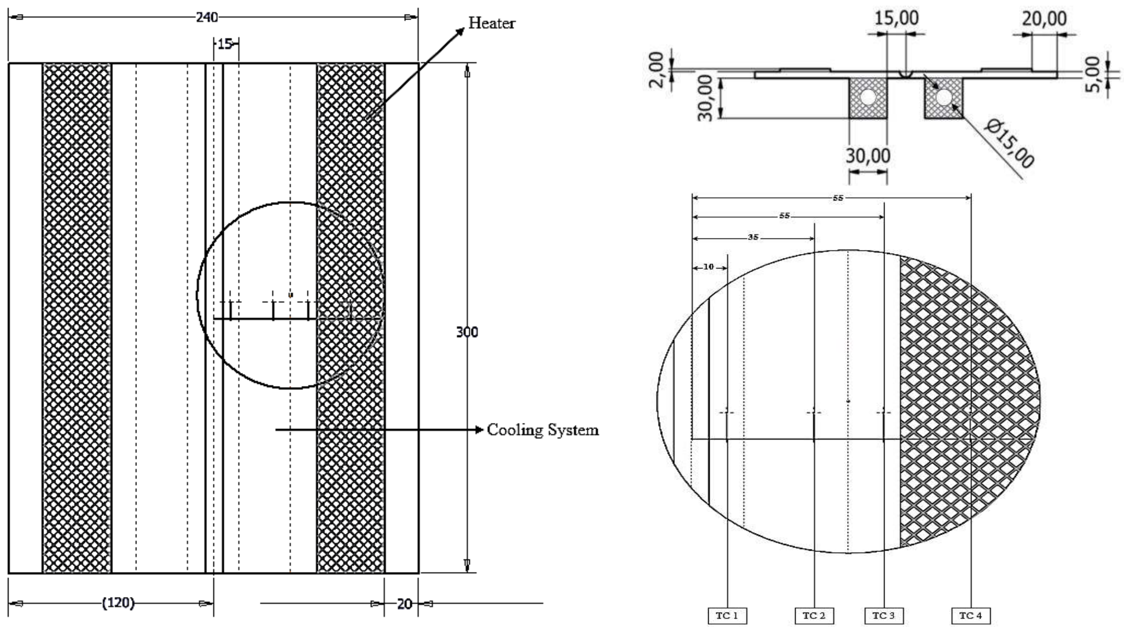


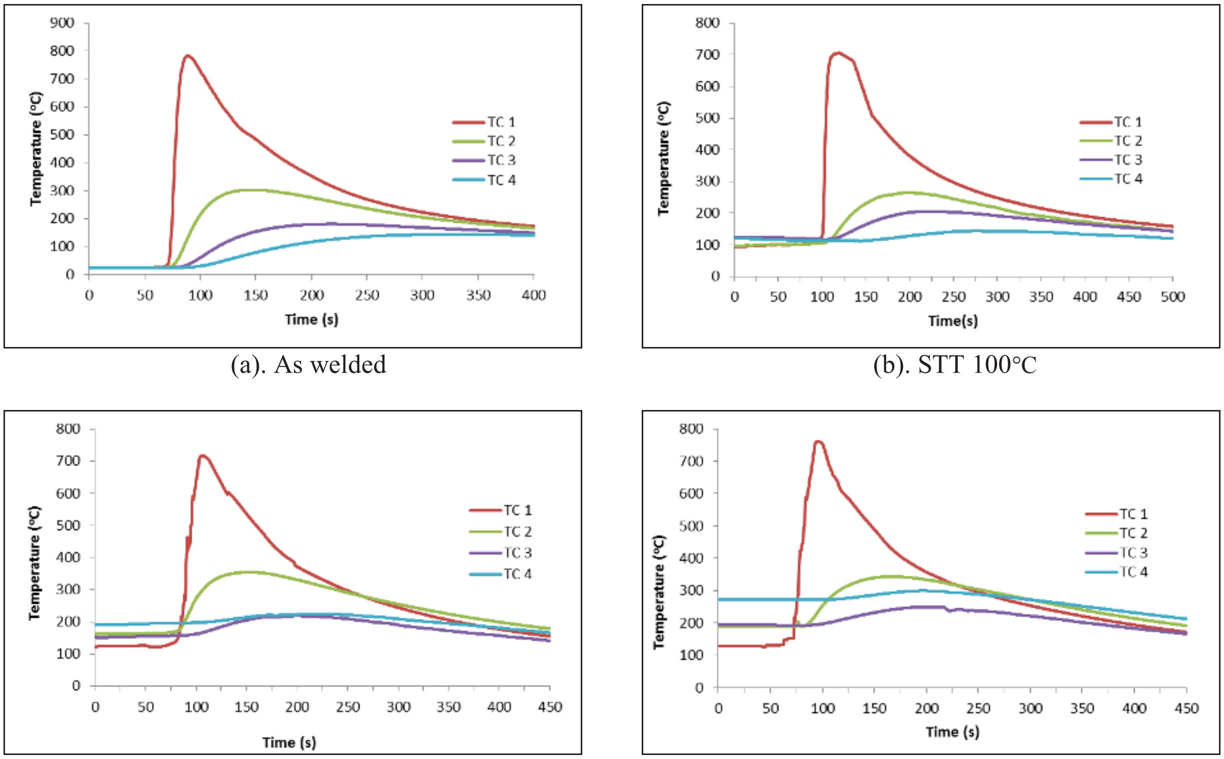
FIGURE 1. Experimental setup with STT treatment weld facilities for a FCAW welding process

TABLE 1. Chemical composition of A 36 Steel plates and K-71T filler metals (wt %)

Element	C	Si	S	P	Mn	Al	Cr	Cu
A 36	0.1246	0.2485	0.0105	0.0149	0.4711	0.0583	0.0195	0.0123
K-71T	0.18	0.90	0.03	0.03	1.75		0.02	0.35

RESULTS AND DISCUSSION

The weld thermal cycles were measured by using thermocouple located on several points, namely TC1, TC2, TC3 and TC4 as shown Fig. 1. Figure 2 shows weld thermal cycles of the welded plates with and without STT treatment. As shown in Fig. 2(a), the plate temperature of untreated are 782°C, 302°C, 180.174°C and 143, 410°C at TC 1, TC 2, TC 3 and TC 4, respectively. The temperature distribution at any point can affect the cooling rate and will determine the mechanical properties as improve tensile strength [6].



(a). As welded

(b). STT 100°C

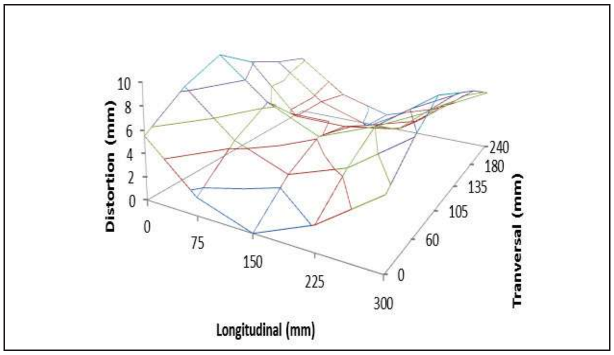
(c). STT 200°C

(d). STT 300°C

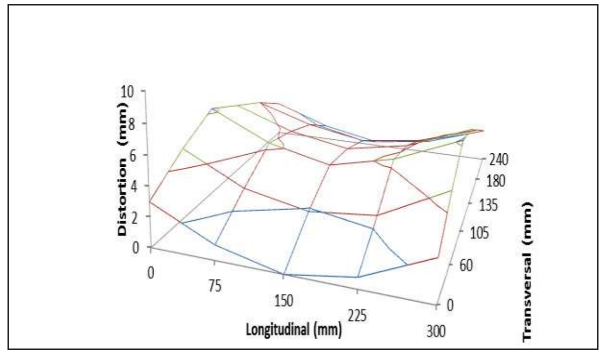
FIGURE 2. Result of temperature in (a) as welded, (b), (c), (d) STT-treated condition with 100°C, 200°C, 300°C heating temperature.

As shown in Fig. 2, in all weld the highest temperature was recorded at point TC 1. The effect of various temperatures in STT weld treatment could be seen in Fig. 2(b), (c), and (d). As shown in these figure the highest temperature at TC 1 increase with increasing secondary temperature. The temperature decreases greatly around the edge where the welding over a range of 600-650°C [7], it lower at this result, increasing heating temperature also decrease cooling rate, as shown in this figure. The cooling rate can control distortion, tensile strength, and residual stress[8].

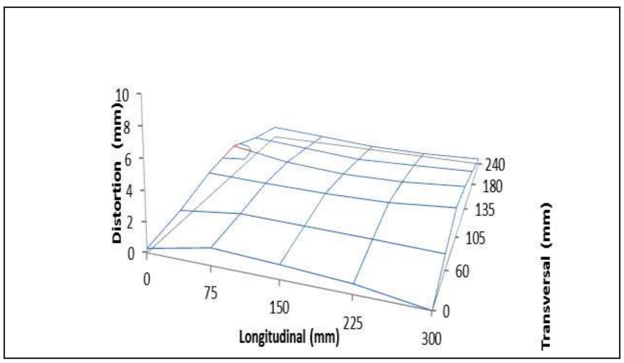
The result of 3D and 2D dimension curve in the welded plates prepared using the conventional welding process and the STT method can be seen in Fig. 3. As shown in Fig. 3(a) to (d) the distortions for all welded plate specimens were measured along the longitudinal and transversal direction. The highest distortion in longitudinal and transverse direction are 10.56 mm and 5.8 mm respectively observed in as-welded condition as seen in Fig. 3(a). STT weld treatment could decrease distortion curve as shown in figure 3 (a), It case also observed that distortion could be reduced by thermal tensioning [9]. In this research, the optimum STT weld treatment occurs at temperature 200°C as shown in Fig. 3(e). The results of measurements of distortion along the longitudinal direction in as welded sharp that large maximum distortion -6.46 mm and 4.02 mm at the middle part of the welded plate length. These investigated indicate that the cooling process after welding greatly influences the formation of distortion. It can be seen that a low or almost no distortion is observed when the heating temperature of STT achieves 200°C. These results seem to suggest that distortion could be mitigated with quenching and heating [5].



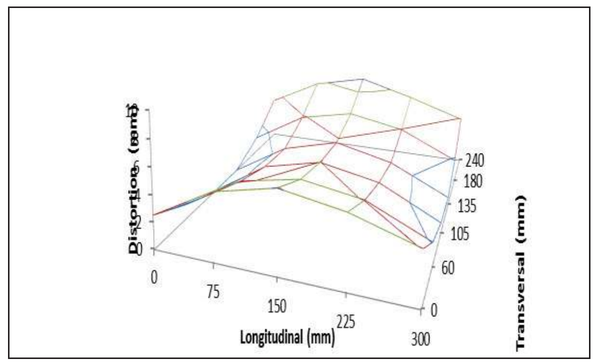
(a). As welded



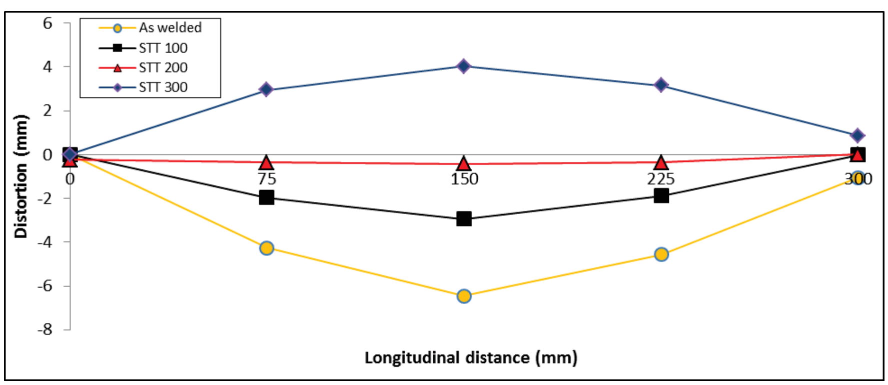
(b). STT 100°C



(c). STT 200°C



(d). STT 300°C



(e)

FIGURE 3. Result of distortion, (a),(b),(c),(d)**,** Three-dimension of distortion, (e) longitudinal direction of distortion

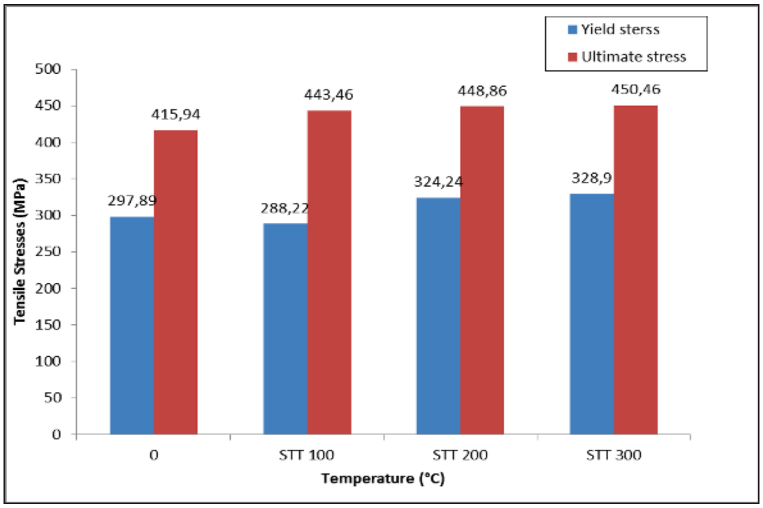


FIGURE 4. Result of tensile stress A36 steel with FCAW weld

The relationship of welded tensile stress and STT weld treatment temperature are shown in Fig. 4. As shown in the figure, increasing STT welt treatment temperature increase both yield and tensile strength. Reference [10] state that cooling rate plays a decisive role in determining weld yield and ultimate strength as confirmed in this research. Fatigue failure and crack propagation will be a delay when the strength is height. Comparing to [11], the result of this research on yield and tensile strength is better.

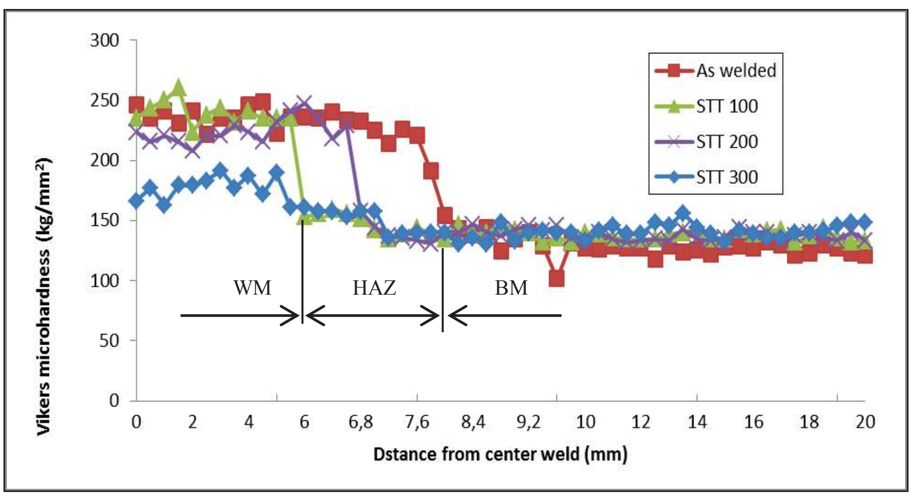
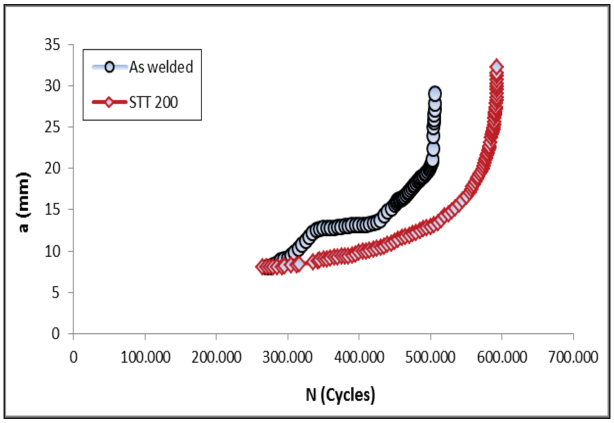
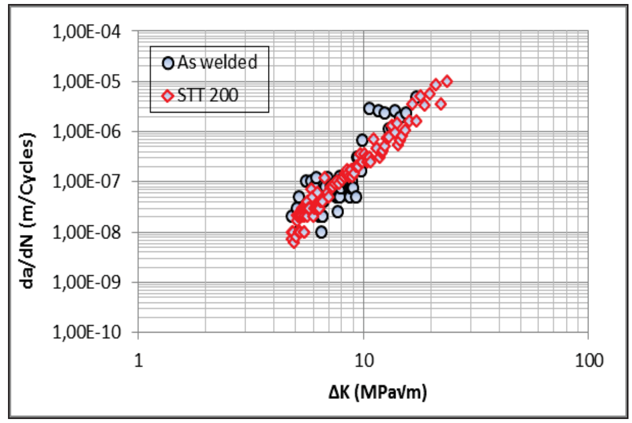


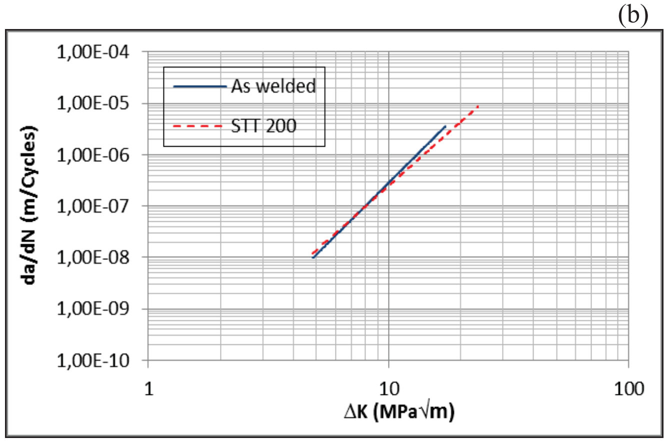
FIGURE 5. Result of hardness FCAW weld in A36 Steel with STT various treatment

Figure 5 shows the distribution of hardness all of welded over the region. Hardness test was conducted in weld metal coarse HAZ, fine HAZ, base metal. The highest test result shows that increasing STT weld treatment temperature decreases the number of hardness. In other hand increasing STT weld treatment slightly increase hardness number of base metal.





(a) (b)



(c)

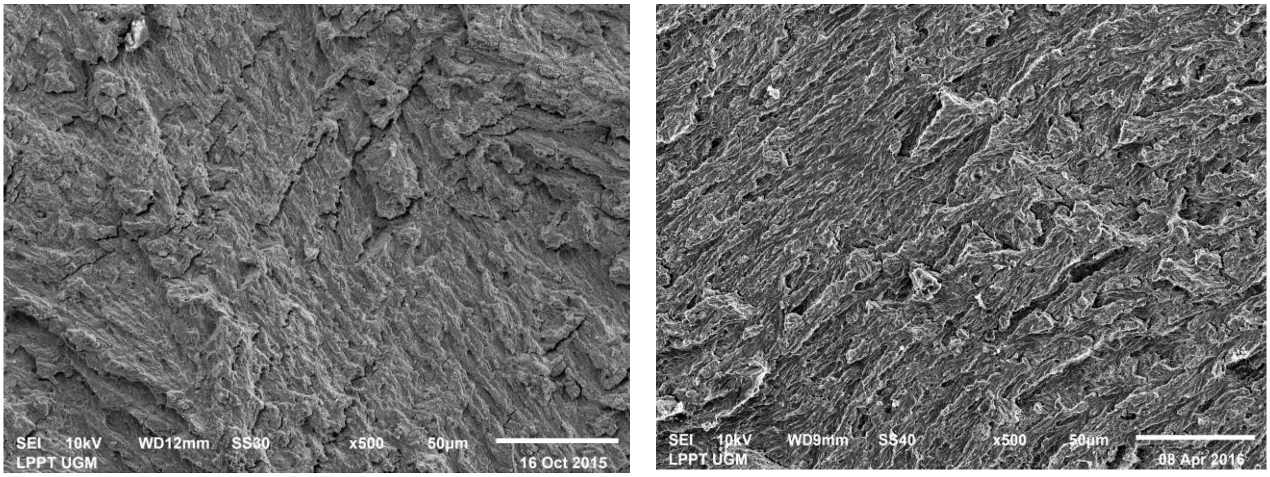
FIGURE 6. (a) Schematic diagram of a-N, (b) Plot of (da/dN)- ΔK, and (c) Curva trendline of (da/dN)- ΔK

Figure 6 shows the relation between propagation rate of fatigue crack (dα/dN) versus intensity of strength (ΔK) and their trend line. The fatigue crack propagation rate of is influenced by C and n values. The fatigue crack propagation of STT weld treatment 200°C is lower than the un-treatment specimen. From this result could be concluded that STT weld treatment can increase welding joint lifetime. It also confirmed that welds under treatments with heating temperature 200°C lowered fatigue growth rate [4].

TABLE 2. Paris constants on each specimen

Specimen	C	n
As welded	2.161 E-11	4.112
STT 200 °C	2.104 E-11	4.074

The constant value of Paris C and n can be seen in Table 2. For n value, STT 200°C of treatment weld is smaller than as welded. It meant that the propagation of fatigue crack by using STT 200°C of treatment weld is smaller than as welded.



(a) (b)

FIGURE 7. Fracture surface, a) welded without treatment, b) welded by STT treatment.

Fracture surface of as weld metal with and STT weld treatment could be seen in Fig. 7. As shown in this figure, fracture surface of as weld metal specimen shows cleavage fracture slightly. In another hand, the fracture surface of STT weld treatment shows a slightly ductile fracture. It also looked that fracture spacing was reducing by STT weld treatment. This result correlated with the value of Paris constant as shown in Table 2. This result of fatigue crack growth in this research similar with [12] that technical crack initiation occurred independent of the thin material, in high-stress intensities, the fracture mode changed to the intergranular mode or macroscopic sub-cracking along the elongated grain boundaries.

CONCLUSION

An innovation method to reduction and mitigation lifetime joint with STT weld treatment as summarized namely:

1. STT weld treatment could decrease the number of distortion.
2. 200°C weld treatment is the most optimum to reduce the number of distortion.
3. STT weld treatment could increase both mechanical properties and fatigue lifetime.

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