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THE EFFECT OF REPEATED WELDING CYCLES ON THE PROPERTIES OF 25Cr SUPER DUPLEX STAINLESS STEEL BY AUTOMATIC ORBITAL TIG WELDING

Danny Satya Mauliddin and Turnad Lenggo Ginta
Department of Mechanical Engineering, Universiti Teknologi Petronas, Bandar Seri Iskandar, Malaysia
E-Mail: dannysatyam@gmail.com

ABSTRACT

The main attention of this research is to evaluate welding properties of 25Cr Super Duplex Stainless Steel (SDSS) or also classified as UNS S32750 under repeated welding cycles with the main properties, i.e. hardness and tensile strength. The research is utilized tubing test specimen and weld by automatic orbital TIG. A small bore tubing with size diameter of 9.53 mm and thickness of 2.1mm are welded at the heat input of 0.248 kJ/mm. This process requires no filler metal and bevel end preparation since it will directly melt down two opposites edge of base metals. Welding was positioned at 2G horizontal, DCEN polarity and 99.99% Argon gas for the shield and purge. Test specimens are evaluated to simulate repeated weld cycles of original welding, R1, R2, and R3, respectively. The result shows an increase in number of repeated welding cycles will affect the ultimate tensile strength (UTS), yield strength and hardness properties. A correlation between each result and number of welding cycles is summarized into a line chart.

Keywords: UNS S32750, super duplex welding, automatic orbital TIG welding.

INTRODUCTION

Welding repair is important for oil and gas manufacturing industry but the technical reference on the maximum attempts of repeated welding on 25Cr SDSS is very seldom. Some information that can be obtained from industrial code and standard i.e. DNV-OS-F101 [1] Table C-7, Appendix C, is not permitting repeated repair on super duplex welding. NORSOK M-601 [2], Section 7, allows only one attempt of repair is acceptable in the same area for 25Cr duplex.

Majority of the researcher on 25Cr SDSS have studied the effect of cooling rates, thermal cycles, heat input, microstructural evolution [3-10] and some others had performed investigation on the effect of repeated welding on stainless steel 316L, 304, martensitic grade and carbon steel API 5L X52.

Chun *et al.* [11] investigated the effect of repeated weld repair on the microstructure, texture, impact and corrosion properties of AISI 304L stainless steel. The base material was welded originally by GTAW and subsequently repaired by SMAW. Based on the research it was concluded that the number of repeating welding or welding repair affected the microstructure and corrosion pitting, and impact fracture surface. The microstructure was observed using optical microscopy, XRD, SEM/TEM, and electron back scattering diffraction

Iman *et al.* [12] studied the effect of repeated welding on mechanical and corrosion properties of stainless steel 316L. The welding was performed by SMAW on a 316L plate of original weld, 1 time repair until 4 times consecutive repair and evaluating the microstructure, hardness, impact, tensile and corrosion properties. The summary of end conclusion was that 4 times consecutive repair will not deteriorate the mechanical properties but at a chloride environment the repair was suggested not more than 2 times.

Vega *et al.* [13] studied the effect of multiple repairs in girth welds of pipelines on the mechanical properties. The research was performed using API 5L X52 pipe and welded with SMAW to observe the tensile, impact, and microstructure properties. The conclusion showed the mechanical properties of the 4 times repair satisfied the requirements of the different standards.

Based on the above literature review, a repeated welding that performed at the same location will impair the weld properties. The testing is performed to observe the deterioration, such as tensile test, hardness test, metallography, and chemical analysis. There is currently limited research performed on super duplex welding hence this investigation is made to study the alteration of tensile and hardness properties with the correlation of welding size under repeated welding cycles.

EXPERIMENTAL DETAILS

The material used in this study was 25Cr SDSS (UNS S32750) tubing with the size diameter of 9.53mm and thickness of 2.1mm. Table-1 and Table-2 present the chemical composition and mechanical properties of base metal used on this research, respectively. The tubing was cut into 150 mm length each side, and the end surface shall be 90 degree flat to allow a symmetrical fit up. No surface offset is allowed to avoid lack of fusion

Table-1. Chemical composition of UNS 32750 [14].

C	Si	Mn	P	S
0.014	0.36	0.50	0.018	0.001
Cr	**Ni**	**Mo**	**N**	**PREN**
25.33	6.46	3.82	0.31	43.03

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Table-2. Mechanical properties of UNS 32750 [14].

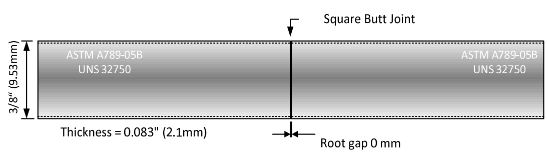
UTS min. MPa	Ys min. MPa	Elongation, min (%)	Hardness	
			Brinell	HRC
800	550	15	310	32

Four set test specimens as illustrated in Figure-1 were prepared to simulate the repeated welding cycles by the parameter given on Table-3. The initial weld performed is identified as ORI and subsequently R1, R2, R3, respectively.

Table-3. Welding parameter.

Weld Position	2G
Current	49.5 A
Voltage	9.4 V
ID Gas Pressure	4.978 mbar
Weld time	16 sec
Travel Speed	112.5 mm/min
OD Gas Flow (99.99% Ar)	11.799 LPM
ID Gas Flow (99.99% Ar)	9.439 LPM

(a) Test specimen fit up



(b) Illustration of cross section welded test specimen.

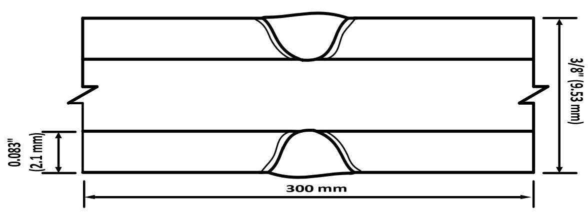


Figure-1. Tubing test specimen size diameter 9.53 mm and 2.1 mm thickness.

Figure-2 shows the welding machine diagram Swagelok M200 that is used on this research. The weld parameter in Table-3 is logged in prior to welding and once the program loaded, test specimen is gripped by the jigs to prevent movement during welding and the weld head is insert into weld the joint. Welding was performed at 2G position with 99.99% of Argon gas that flows from the cylinder to use as shielding and purging. The weld head used on this process is closed type as illustrated in Figure 3, allowing the electrode rotates in circumference direction and directly melts the joint.

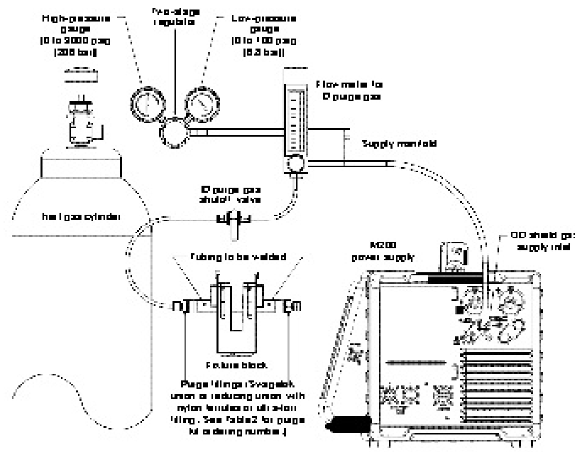


Figure-2. Diagram of automatic orbital TIG welding Swagelok M200 [15].

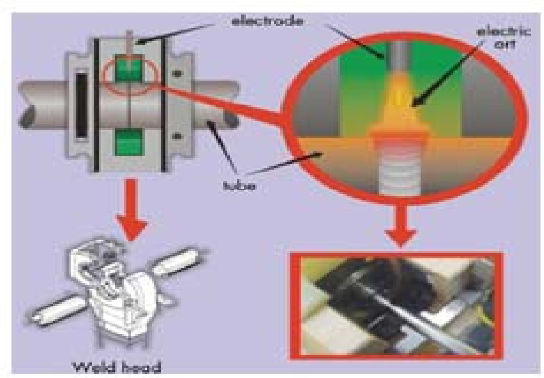


Figure-3. Illustration of a closed-head welding torch of automatic orbital TIG welding [16].

The tungsten electrode type used is EWTh-2 size of 1.2mm and shall be sharpened prior to weld to produce a focused arc that will penetrate the base material thickness. Tungsten sharpener shall be used instead of using hand grinder. The shop environment shall be gradually checked and ensure for no wind interruption where a wind barricade is installed in the surround weld area. Health safety and environment risk assessment is compulsory to identify the hazard, such as fire, mechanical, gas hazards. In order to avoid the potential hazard, all weld activities shall be done with proper protectors such as gloves, safety glass, safety shoes, ear plug, protective jacket, etc.

There is no preheating require for welding of 25Cr SDSS and the maximum inter pass of 150^0C is used to avoid the initiation of Sigma phase. All test specimens is welded with the same welding parameter to simulate repeated weld cycles, where initial weld (ORI) is after 1^{st} cycle of welding, R1 is after 2^{nd} cycles, R2 is after 3^{rd} cycles and R3 is after 4^{th} cycles. The detail on performing repeated welding on 2^{nd} cycles and it subsequent is to have

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test specimen weld through initial welding and cool down by room temperature in open air.

The welding is attempted at the same location by melting back the welded joint using parameter in Table-3 once it is reach room temperature. This process was performed repeatedly until R3 test specimen completed.

Mechanical test result was evaluated to study the effect of each repeated weld cycles. Ultimate tensile strength, yield strength and hardness HV10 is observed and performed according to ASME Section IX [17]. The tensile test specimen was pulled at weld cross-section direction by 50kN tensional load until finally ruptured and hardness testing HV10 performed by taking 3 indentations at base metal, HAZ and weld metal. All testing was performed at room temperature.

RESULTS AND DISCUSSION

Tensile and yield strength

UTS minimum required is 800 N/mm^2 and Ys minimum required 550 N/mm^2. The tensile fracture mode is ductile with the presence of "necking", the initial weld (ORI) is broken at weld metal and the rest are broken at base metal and all of the strength obtained from Figure-4 is more than the minimum requirement. This result justify that weld metal strength on all cycles are higher than the base material and it is observed that there is a decrease trend of UTS and increasing trend of Ys by the number of repeated welding cycles.

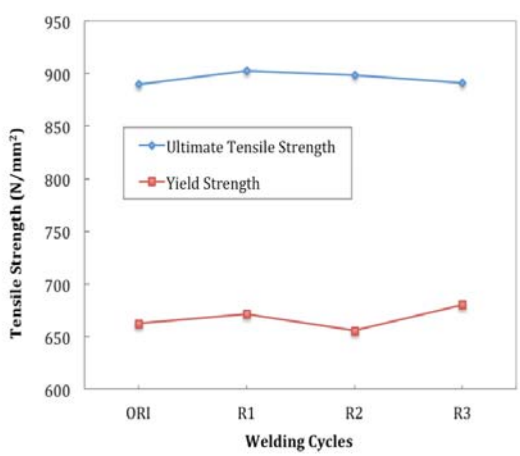

Figure-4. Ultimate tensile strength and yield strength line chart to the number of welding cycles

Hardness test (HV10)

The hardness test performed using Vickers method with a 10 kgf of load (HV10) at the surface of macro test specimen. The test is carried out to observe the hardness distribution at base material, HAZ and weld metal. Maximum acceptance hardness value for oil and gas industry is normally 330 HV10 and from the result of hardness test measurement it is observed below the maximum limit. Three indentations are made at each respective location as illustrated in Figure-5. Repeated weld cycles is significantly lower down weld metal hardness value, while at base material and HAZ shows a fluctuation. Weld metal is the area that exposed and suffers by the repeated cycles, it is observed that hardness is deteriorated by the number of repeated weld cycles.

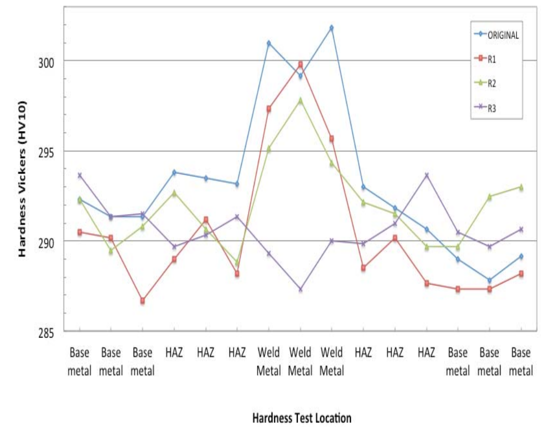

Figure-5. Hardness test result.

The evaluation is firstly made on the fractured surface characteristic of ruptured tensile test specimen. The fracture mode occurred on all tensile specimen are ductile as necking and cup-cone end shape is visible as shown in Figure-6. As mentioned earlier, test specimen ORI only broke at weld metal while the others specimen broke at base metal, where the ruptured location will not affect the weld quality. Industrial code requires result of UTS is more than the base material. At this case as mentioned on Figure-4, the UTS result achieved is over than 800 MPa. It is noted down that there is no specific attention to evaluate Ys unless normally for pipeline application which requires specified minimum yield strength (SMYS). In this study, both of UTS and Ys at each respective cycle can be observed through line chart. The UTS trend line is in the opposites of Ys to the number of weld cycle where decreased UTS is parallel with decreased Ys. The subsequent repeated weld performed after ORI may cause weld area expansion that supports the weld to restrain from tensional load and affect the break location as describe in Figure-5. This also causes uplift on UTS but then decreases down the following cycle.

The hardness test result as shown in Figure-6 with different line colour to represent the weld cycle. Maximum hardness acceptance for industry is of 330 HV10 or 32 HRC. Vickers method was used in this research to have an accurate result of hardness value at each respective area by a fine indentation. Results as shown in Figure-6 are still below the maximum acceptance, confirming that there is no presence of metallic carbides, which happened by excessive inter pass temperature.

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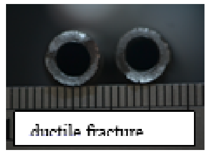
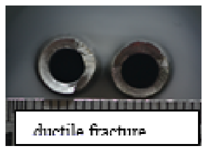
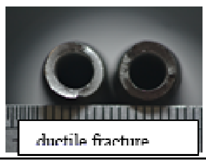
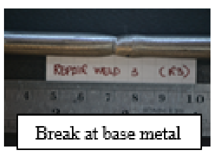
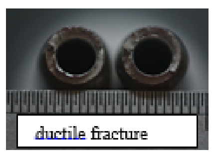
Welding Cycles	Fracture Location	Fracture Mode
ORI		
R 1		
R 2		
R 3		

Figure-6. Fracture location and mode of tensile test

The measured base metal hardness is in order, where this area is not affected by weld heat hence the properties will be remain the same as rolled condition. The HAZ growth at 0.5-0.8 mm width that was produced by weld heat input of 0.248 kJ/mm as the result of a low heat input and a narrow width of HAZ causing disorder hardness results. Although the result is still acceptable, HAZ hardness result is fluctuated and cannot be correlated with weld cycles. Result of hardness at weld metal is obvious where number of weld cycle affects the hardness properties. ORI test specimen is observed to have the highest hardness and the subsequent result is reduced down by the number of welding cycles, whereas R3 is observed to be the lowest hardness.

From all testing result obtained, it can be concluded that an increase in number of repeated welding cycle will deteriorate the welding properties, whereas the ultimate tensile strength is decreased with the increased of yield strength. This result is also supported by a decreased result of weld metal hardness.

There is no weld defect observed in particularly lack of fusion due to a low heat input or improper fit up. This confirms that the weld parameter used is optimum and able to produce a quality weld to meet industrial standard.

CONCLUSSIONS

The conclusion of this research can be summarized as follows:

1. The welding of 25Cr SDSS (UNS S32750) with the size diameter of 9.53mm and thickness of 2.1mm can be performed until 4 consecutive times by using the weld parameter provided in Table 3 with satisfactory result to meet the requirement of industrial standard i.e. ASME IX.
2. Tensile test fracture mode is ductile with the presence of localized “necking” and cup-cone fracture surface.
3. The increasing number of repeated weld cycle cause weld area expansion, supporting local strength to the result of UTS and ruptured location.
4. The repeated welding cycle deteriorates the properties such as tensile strength and hardness. It is observed that the UTS is decreased down while Ys is increases. And similarly with UTS, it is lowering down the hardness (HV10) value.

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