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THE EFFECT OF REPEATED WELDING CYCLES ON THE MICROSTRUCTURE AND FERRITE CONTENT OF 25Cr SUPER DUPLEX STAINLESS STEEL WELD METAL BY AUTOMATIC ORBITAL TIG WELDING

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ABSTRACT

The objective of this research is to evaluate the macrostructure, microstructure, chemical elements and ferrite content of 25Cr Super Duplex Stainless Steel (SDSS) UNS S32750 weld metal after the condition of repeated welding cycles. TIG automatic orbital is used to weld tubing test specimen size 9.53mm diameter and 2.1 mm thickness at heat input 0.248 kJ/mm, the torch is orbiting surface circumference and melting down in 2G position with shielding gas protection of 99.99% Argon in DC negative polarity, this welding process able to melt down two opposite square-end of base metal without filler metal. All test specimens are evaluated by simulating of three repeated welding cycles consist of original welding, R1, R2, and R3. The results of this research are indicating there are correlation between metallography, chemical analysis and ferrite content to the increasing number of welding cycles.

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

INTRDUCTION

The application of attempting repeated welding is correlated with welding repair. There is maximum limit of welding repair can be attempted on the same location and for 25Cr super duplex application the reference of performing welding repair can be obtain 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 and NORSOK M-601[2], Section 7, allows only one attempt of repair is acceptable in the same area. Based on the industrial practice, welding repair can be minimized but difficult to avoid, hence this study is used as a reference for recommendation on performing repeated welding cycles for 25Cr super duplex with the same welding process and specimen size.

There is not many research have performed on the number of attempting repeated welding cycles on 25Cr super duplex. Majority of the researcher have studied the effect of cooling rates, thermal cycles, heat input, microstructural evolution [3-10] and some others have performed investigation on the effect of repeated welding on stainless steel 316L, 304, martensitic grade and carbon steel API 5L X52.

Iman Agha Ali [11] *et al*. studied the effect of repeated welding on mechanical and corrosion properties of stainless steel 316L. The welding is performed by SMAW on a 316L plate of original weld, 1 time repair until 4 times consecutive repair and evaluating microstructure, hardness, impact, tensile and corrosion properties. The summary of end conclusion is that 4 times consecutive repair is not deteriorate the mechanical properties but at a chloride environment the repair is suggested not more than 2 times.

O.E Vega [12] *et al*. 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. And the conclusion is the mechanical properties of the 4 times repair is satisfied the requirements of the different standards.

Chun Ming Ling [13] *et al*. investigating the effect of repeated weld repairs on the microstructure, texture, impact and corrosion properties of AISI 304L stainless steel. The base material is welded originally by GTAW and subsequently repaired by SMAW. Based on the research it is concluded that the number of repeating welding or welding repair is affecting the microstructure and corrosion pitting, and impact fracture surface. The microstructure is observed using optical microscopy, XRD, SEM/TEM, and electron back scattering diffraction.

Based on the above literature review, repeated welding can impair the weld properties, this can be observed through the result of tensile test, hardness test, metallography, and chemical analysis. In this research paper, the study is performed specifically to evaluate the alteration of microstructural properties, chemical analysis and ferrite content under repeated welding cycles of 25Cr super duplex.

EXPERIMENTAL DETAIL

Test specimen used on the research is tubing diameter 9.53mm and 2.1mm thickness at 150 mm length, material grade UNS S32750. The tubing ends are prepared with 90 degree flat-end and fit up with no surface offset, Figure-1 is the illustration of test specimen preparation. Four set of test specimens is prepared to simulate repeated welding. Preparation of each test piece is as illustrated in Figure-1 and welded in accordance to parameter in Table-3. The tested weld identification is based on the number of welding cycles, ORI and subsequently R1, R2, R3.

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

C	Si	Mn	P	S	Cr	Ni	Mo	N
0.03 max	0.8 max	1.2 max	0.35 max	0.02 max	24 - 26	6 - 8	3 - 5	0.24-0.32

Table-2. Mechanical properties of UNS 32750[13].

UTS min	Ys min	Elongation min	Hardness
800 MPa	550 MPa	15 %	32 HRC

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
Heat Input	0.248 kJ/mm

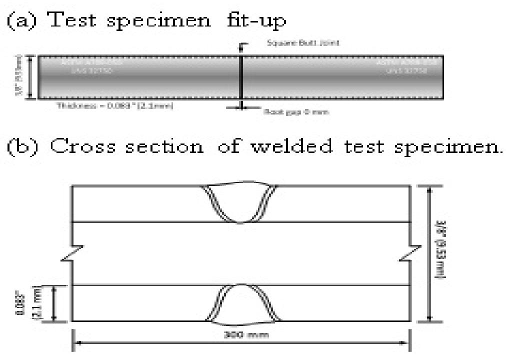

Figure-1. Tubing test specimen size diameter 9.53 mm and 2.1 mm thickness.

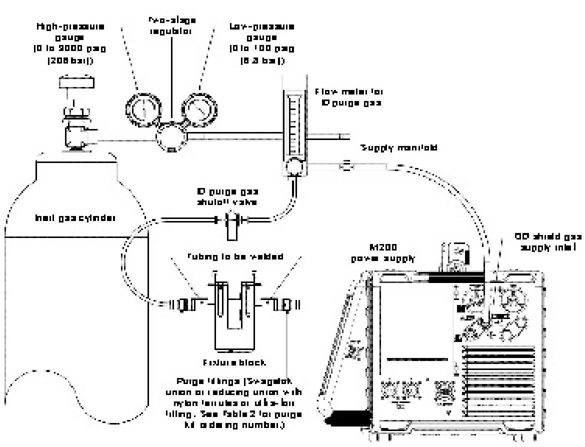

Figure-2. Diagram of automatic Orbital TIG welding Swagelok M200[14].

Automated TIG welding machine used for this research is Swagelok M200 as displayed on Figure-2. The setting of welding parameter in Table-3 is logged in and saved in the welding machine. To perform welding, the test specimen is placed inside the jigs and locked to prevent movement and followed with the TIG weld head installation. The welding is performed at 2G horizontal position with 99.99% Argon gas protection. Figure-3 illustrates closed head welding torch type which rotates the electrode in circumference direction and fused two opposite base metal edges. EWTh-2 size 1.2mm is used for TIG electrode, the tip shall be sharpened all time prior to the welding to focus the arc and penetrate the base metal thickness, a Tungsten sharpener tool shall be used instead of hand grinder. Shop environment is gradually checked for no wind disruption and air pressure tools leakage, during welding wind barricade is installed surrounding the weld joints. Risk assessment is compulsory to be performed prior to the job execution, this is to identify the hazards of three affected areas which consist of fire, mechanical, gas hazard. To avoid the hazard, all activities shall be done with the proper Personal Protective Equipment (PPE) i.e. welding visor UV and radiation protection, welding hand gloves, safety glass, safety shoes, ear plug, etc.

No preheating required for welding of 25Cr SDSS and limit maximum inter pass temperature of 150 ^{o}C to avoid the initiation of intermetallic phases. Test specimens welded with the same welding parameter (Table-3) to simulate repeated weld cycles as follows, ORI is 1st welding cycle, R1 is 2nd welding cycles, R2 is 3rd welding cycles and R3 is 4th welding cycles. The test specimen is cool down to room temperature without air accelerator upon completion of each welding cycles.

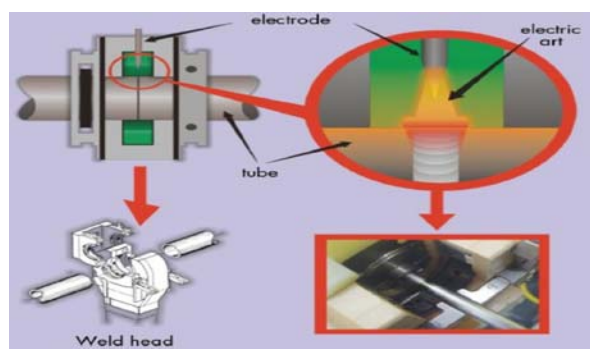

Figure-3. Illustration of a closed-head welding torch of automatic orbital TIG welding [15]

The repeated welding is attempted at the same location by re-melting the weld using consistent parameter in Table-3 and once it is cools down the test specimen is repeatedly welded until all cycles are completed for evaluation. Once welding completed, visual inspection is carried out to observe and measure the weld size. Observation performed for this research is to study the effect of repeated weld cycles to the metallography, ferrite content and chemical analysis.

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Test specimen of are cut into half in cross section and surface polished by sand paper and alumina to achieve plain and flat surface. The use of etchant solutions 40% NaOH is optimum to reveal structure and phases. Result of metallography is evaluated in two different magnifications of 3.5x and 500x by optical microscope. Scanning Electron Microscope (SEM) is performs in additions to evaluate the microstructure morphology and chemical analysis at weld metal for the repeated welding cycles.

RESULTS AND DISCUSSION

a) Macrostructure examination

The macrostructure examination is performed on all test specimens ORI, R1, R2 and R3 correlated to weld size and number of weld cycles as illustrated in Figure-4, the image is observed under 3.5 times magnification.

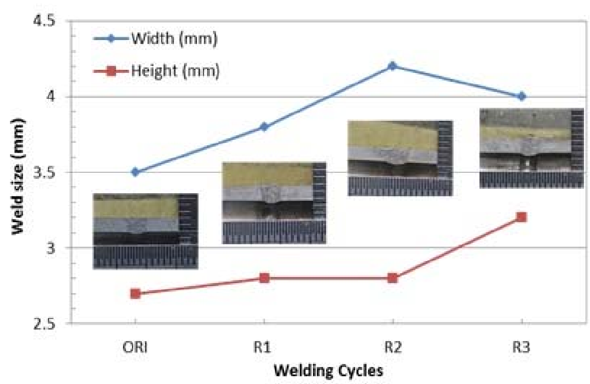

Figure-4. Macro image and visual measurement of cross section weld at 3.5x magnification

Macrostructure image displays a complete fusion of weld where can clearly identify the region of base metal, heat affected zone and weld metal. The weld cap and root height is less than 1 mm with no presence of surface or volumetric weld defect. The weld size expands by the increase number of repeated welding cycles since it is repeatedly re-weld at the same location and causing additional base metal dilutions. Although the R3 weld width is lowering down, it does not compromise the increasing of weld size trend line.

b) Microstructure examination

The weld metal microstructure of ORI, R1, R2 and R3 is evaluated with 500x optical magnification as illustrated on Figure-5, Figure-6, Figure-7 and Figure-8 and Scanning Electron Microscope (SEM) is used in additions. It is observed that austenite and ferrite is appeared on the weld metal with fine cluster dark area at the grain boundary.

To perform this evaluation, the tubing test specimen is cut into half to have polished and etched cross section surface by 40%NaOH. Welding parameter in Table-3 produce heat input 0.248 kJ/mm, it is lower to the allowable DNV-OS-F101 heat input range 0.5 – 1.8 kJ/mm.

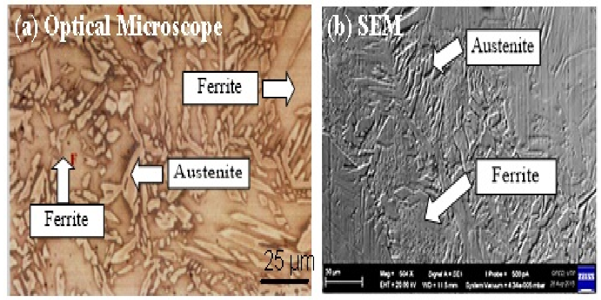

Figure-5. Microstructure of ORI welding 25Cr super duplex.

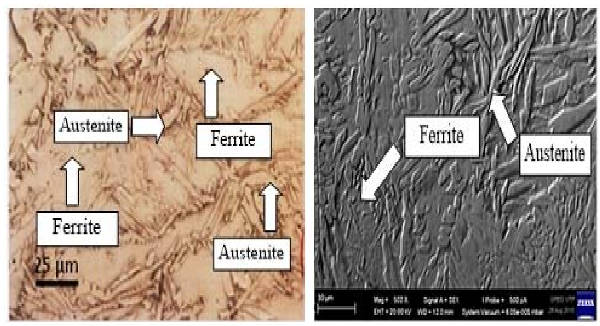

Figure-6. Microstructure of R1 welding 25Cr super duplex.

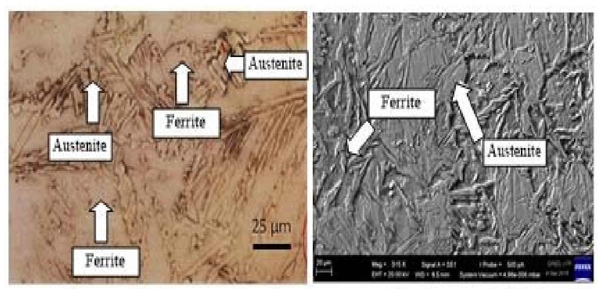

Figure-7. Microstructure of R2 welding 25Cr super duplex.

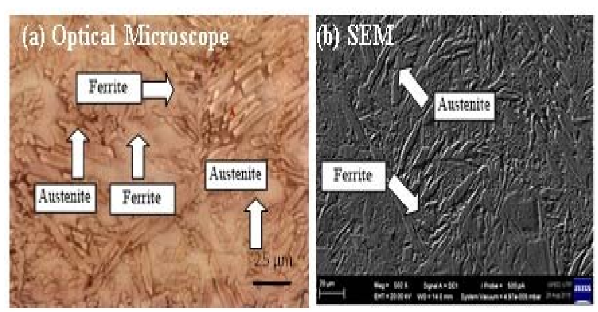

Figure-8. Microstructure of R3 welding 25Cr super duplex.

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The microstructure of ORI, R1, R2 and R3 weld metal still appears as coarse grain ferrite and Widmänstatten austenite and the ferrite grain is coarsened by the increasing number of repeated welding cycles, this is due to the repeated heating and slow cooling that suffers the weld metal. The small and fine dark image accumulated at austenite grain boundary is intermetallic phase or sigma phase which initiated by slow cooling and repeated weld. The most coarsened ferrite grain is visually observed at R3 weld metal, the measurement is obtained at Figure-12 where the highest ferrite result achieved at the last welding cycles.

c) Energy-dispersive X-ray spectroscopy (EDX)

EDX performed at weld metal on each welding cycles to evaluate the chemical elements at spectrum points are as displayed in Figure-9. Result of spectrum analysis is summarized in Table-4 and Figure-10. The formation of sigma phases and intermetallic phases on 25Cr super duplex is more rapid [16] and occurs during solidification time by the cooling rate as illustrated in Figure-11

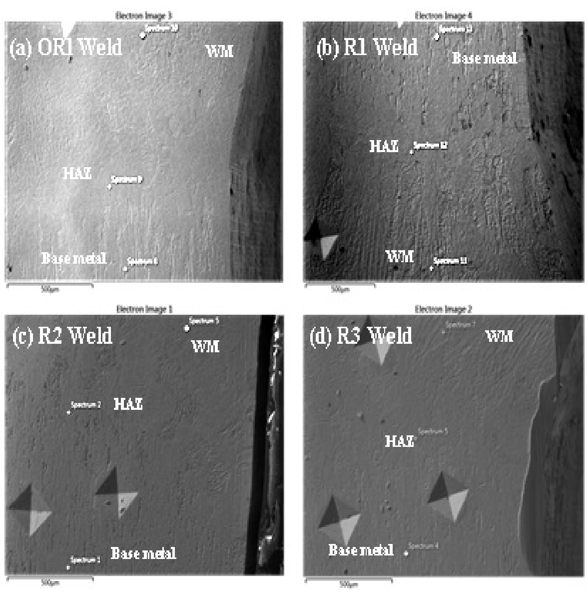

Figure-9. EDX locations performed for each welding cycles.

Table-4. Chemical analysis based on the material certificate[17].

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

Table-5. Chemical elements result based on EDX locations on Figure-9.

Weld Metal	Si	Cr	Ni	Mo	Fe
ORI	0.41	24.54	5.92	3.28	57.20
R1	0.36	26.19	5.63	3.39	58.07
R2	0.41	23.51	5.83	3.61	55.15
R3	0.33	22.27	4.93	3.03	52.73

Based on summary of EDX result diagram on Figure-10, there is metallic elements depletion by the increase number of welding cycles. The elements of Cr, Fe, Ni, and Mo is forming intermetallic phases at austenite grain boundary because of slow cooling and repeated welding cycles during weld metal solidification.

d) Ferrite content

Ferrite content is measured by manual point count in accordance with ASTM E562 for each welding cycles at base metal, heat affected zone and weld metal on each welding cycles. The ferrite content result at all locations can be obtained from Figure-11.

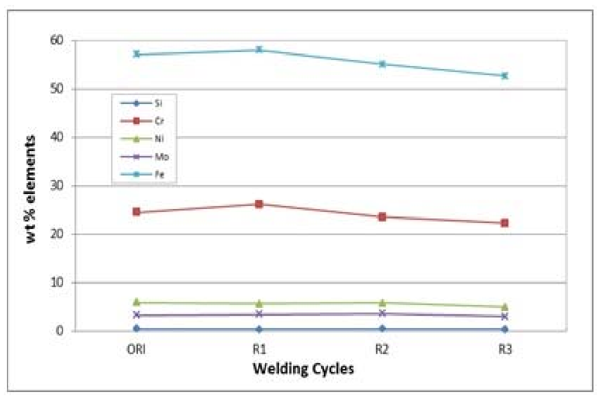

Figure-10. EDX summary of spectrum analysis result.

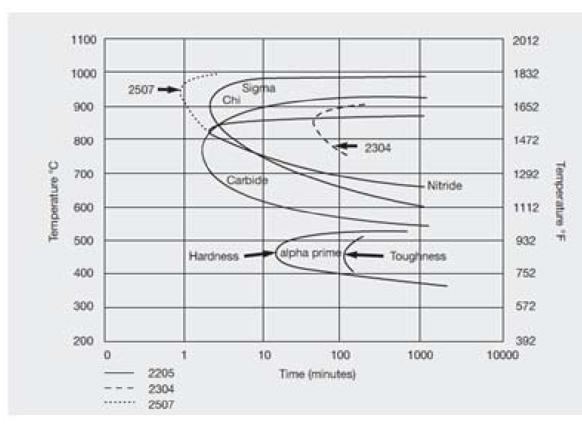

Figure-11. Isothermal precipitation diagram for 2205 duplex stainless steel[18].

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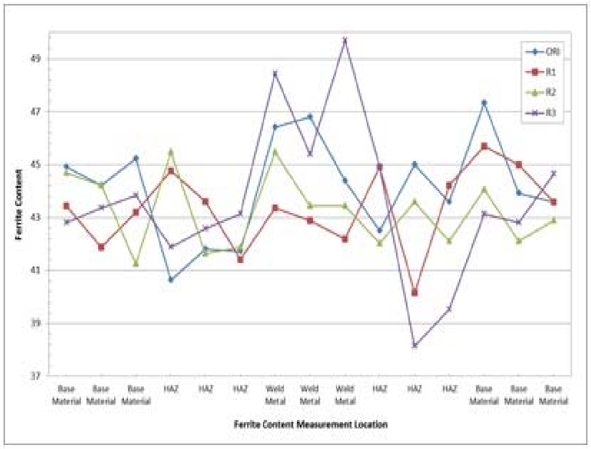

Figure-12. Result of ferrite content at base metal, HAZ, weld metal for ORI, R1, R2, R3 welding.

Although it is observed that the result are still within the acceptance range of NORSOK M601, the weld metal ferrite content result obtained is conclusively related with the microstructure. From Figure-11 it is observed that ferrite content after ORI weld is reduce down at R1 and R2 but significantly increased at R3 weld. The ferrite content correlated with cooling rate during solidification time where the faster solidification rate will cause insufficient time for austenite to nucleate and coarsening ferrite grain. The weld HAZ and reheated weld metal invariably have areas that experience single or multiple exposures to the temperature range 570 – 1000 ^{o}C, where sigma phase and other intermetallic phases form [16].

CONCLUSIONS

From the above evaluation and discussion of this research, it is can be concluded as below:

- The microstructural properties of four times repeated welding cycles of 25Cr super duplex (UNS S32750) diameter 9.53mm and 2.1mm-wt is still within the acceptable range of NORSOK M601[2].
- The measured weld height and width based on macrostructure image is expanded by the increasing number of welding cycles.
- The weld metal microstructure appears is Widmänstatten austenite and ferrite. The coarsened ferrite grain is observed as a result of weld metal solidification. Sigma phase is spotted as fine dark image at austenite grain boundary.
- EDX observation is performed at 100x magnification at weld metal. There is significant reduction of Cr and Fe by the increasing number of weld cycles which indicating the forming of sigma phase and intermetallic phases.
- The weld metal ferrite of R1 and R2 is reduce down but increased to the highest result on R3. This result is fully determined by cooling rate where sufficient time is required to nucleate austenite.

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