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Corrosion Behaviour of SS304L at Unapproachable Regions of Fillet Weld Joints in Fast Reactor Reprocessing Application

Shri Krishna Tripathi*, Avinash Kumar, R. Priya, P. Ramesh, Hemant Kumar, G. Ramesh
Indira Gandhi Centre for Atomic Research,
Kalpakkam – 603 102
*Corresponding author email: skt@igcar.gov.in
ORCID : SHRI KRISHNA TRIPATHI : https://orcid.org/0000-0002-4593-0717

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Abstract

The Purex process is opted for reprocessing of spent fuel from fast breeder reactors. The process employs nitric acid with concentrations up to 11M. Nitric Acid Grade (NAG) SS304L is opted as material of construction for equipments, process tanks and piping of such process plants so as to minimise the corrosion losses due to nitric acid. Practice C test as per ASTM A262-15(2021) (Standard Practices for Detecting Susceptibility to Intergrannular Attack in Austenitic Stainless Steels), with maximum average corrosion rate of 15 mils/year (mpy) for five cycles of 48 hrs, and 18 mpy in any cycle, is one of the criteria for qualification of material among others. A similar acceptance criterion is adopted for qualification of undiluted weld metal deposit of filler material and welding procedure specification (WPS) used therein. However, conventional tests may not always accurately represent the corrosion behaviour of surfaces at all locations. One of such are the surfaces which abut each other, and hence are not approachable for visual examination and thereafter cleaning, such as unwelded open abutted surfaces of fillet weld joint (root), partial penetration (pp) weld joints facing process fluids in abutted portions not in a welded portion of joint. Multiple factors like remains of heat tints, adjacent inter-spaces and type of surface finish may collectively contribute to corrosion rates exceeding acceptable limits. This study delves into the often-neglected corrosion behaviour of these challenging regions. The samples with abutting surfaces are prepared by using EDM cutting and and Gas tungsten arc welding (GTAW) and subjected to corrosion test. The samples made by using base material, filler and WPS that already qualified for corrosion test for groove weld joints and hence fillet weld joints as per ASME BPVC sec IX (2021). Higher corrosion rates are being observed in these weld joints than standard test specimens during study.

Keywords: Abutting surfaces, heat tint, gas tungsten arc welding, huey test.

1.0 INTRODUCTION

Austenitic stainless (ASS) steels are widely used for their superior general corrosion resistance [1]. However, failures in SS structures are widely reported due to localised corrosion in the vicinity of weld joint. Improper cleaning of welded surface or associated heat tints are one of the reasons. The heat tints are the colours that appear near the heated zone due to oxidation of base metal. These found to alter corrosion resistance of SS. Hence, the heat affected surfaces to be cleaned and passivated again to regain the corrosion properties of SS. Instances of significant failures (due to corrosion) are documented due to improper handling of heat affected surfaces of SS [2-6]. It has been observed that In spite of all the good practices followed, sometimes it becomes hard to ensure the cleanliness of certain hard to reach locations such as narrow gaps between closely abutting surfaces. The examples include the abutted surfaces extended beyond areas of weld penetration such as faces of tube to tube sheet joints; corner weld joints; fillet and partial penetration weld joints etc. Further it has been observed that these heat affected surfaces of such weld joints often come in contact with working fluids in piping or vessels, as the weld metal is mostly deposited from outside during welding.

Purex process is employed for reprocessing of spent fuel from nuclear reactors. Nitric acid upto 11 molar concentration is primarily utilised as a process fluid for extraction process in such reprocessing plants. The sensitised structural materials of 18Cr-8Ni type, used in nuclear application, face highly oxidising environment that affects grain face and weight loss in nitric acid environment [7]. The susceptibility to intergrannular corrosion under such environment for the base material, undiluted weld metal and welded area is assessed by huey test using standard of practice-C test as per ASTM- A262 [8,9]. A corrosion rate of 15 mils per year average of five cycles of 48 hrs duration and 18mpy in any one cycle is the criteria stated by standard design documents for the acceptance. The Nitric acid grade (NAG) SS304L SS material is commonly opted for such applications, which generally meet such requirements [10-14]. Gas Tungsten Arc Welding (GTAW) process with filler ER 308L [15] is mostly utilised during fabrication of piping, equipments and vessels. A standard test sample is extracted for corrosion testing (exposing HAZ cross section) from welding procedure qualification test coupon of groove joint. The welding procedure qualified using groove weld joints, qualifies the procedure to make a fillet weld joint [16]. Though, this may not be true for corrosion test especially for above stated locations.

The meagre availability of study on the corrosion behaviour of such abutting surfaces in open literature persuades authors to carry out some studies in this direction. This study delves upon this often-neglected corrosion behaviour of these challenging regions. A comparison has been made for the corrosion behaviour of abutting surfaces in different arrangements of welding and base metal using practice-C of ASTMA 262.

2.0 EXPERIMENTAL PROCEDURE

Corrosion rates for IGC Practice C has been carried out as per ASTM A 262 on the samples of fillet welds made with different purging conditions, by ensuring that the unfused abutting surfaces are exposed to the testing conditions. Corrosion testing of base metal with a groove made by EDM wire cut is also carried out for the comparison. The samples are fabricated from base and filler material procured for fabrication of the actual components. Following sub-sections give the details of materials, welding process, sample extraction plans and about the corrosion test.

2.1 Materials

Two nos. of Nitric acid grade (NAG) 304L stainless steel plates having wall thickness 6 and 12 mm and ER 308L grade filler wire having diameter 1.6 and 2.0 mm were used in the present study. The chemical compositions of these two materials have been carried out by Spark Atomic Emission Spectroscopy technique and given in **Table 1**. The filler wire composition has been obtained from all weld deposit. In bare condition, these two materials were qualified for IGC Practice C as per ASTM A262 and observed to be within acceptable limits.

2.2 Welding process

Gas tungsten arc welding process is used for making the test coupons. GTAW machine of make ESAB (Yetazu) Easy Weld, with specification of Current = 0-600 A (least count of 20 A), Voltage = 0-125 V (least count of 5 V), measurement uncertainty expressed at 95.45%, with coverage factor K=2 is used for welding. Electrode with classification SFA 5.12, EWTh-2 (2.5 mm Ø) with direct current electrode negative (DCEN) polarity under shielding of high purity argon gas has been utilised during this work.

2.3 Preparation of the test samples

The samples were prepared with and without heat tints, and with different abutting surface. The finished samples contain the surfaces that include different combinations (i) Welded, (ii) EDM cut, (iii) Wrought, (iv) Heat tints and (v) Shear cut.

The samples were prepared such that it comprises of abutting surfaces with and without weld. The gap is measured using video vision imaging system. Standard samples (without abutting surfaces) with similar heat conditions were also

Table 1 : Chemical composition of NAG 304L stainless steel and ER 308 Filler Wire

Description	Size (mm)	Elements (wt.%)										
		Fe	C	Si	Mn	P	S	Cr	Ni	Mo	Cu	V
304L(NAG) Stainless Steel	6	64.90	0.016	0.28	1.71	0.027	0.007	18.36	9.21	0.08	0.1	0.09
	12	69.94	0.023	0.45	1.75	0.032	0.010	18.02	9.20	0.11	0.13	0.05
ER-308L Filler Wire	1.6	Bal	0.022	0.35	1.81	0.021	0.005	19.82	9.12	0.072	0.062	-
	2.0	Bal	0.023	0.40	1.52	0.020	0.005	19.85	9.15	0.062	0.10	-

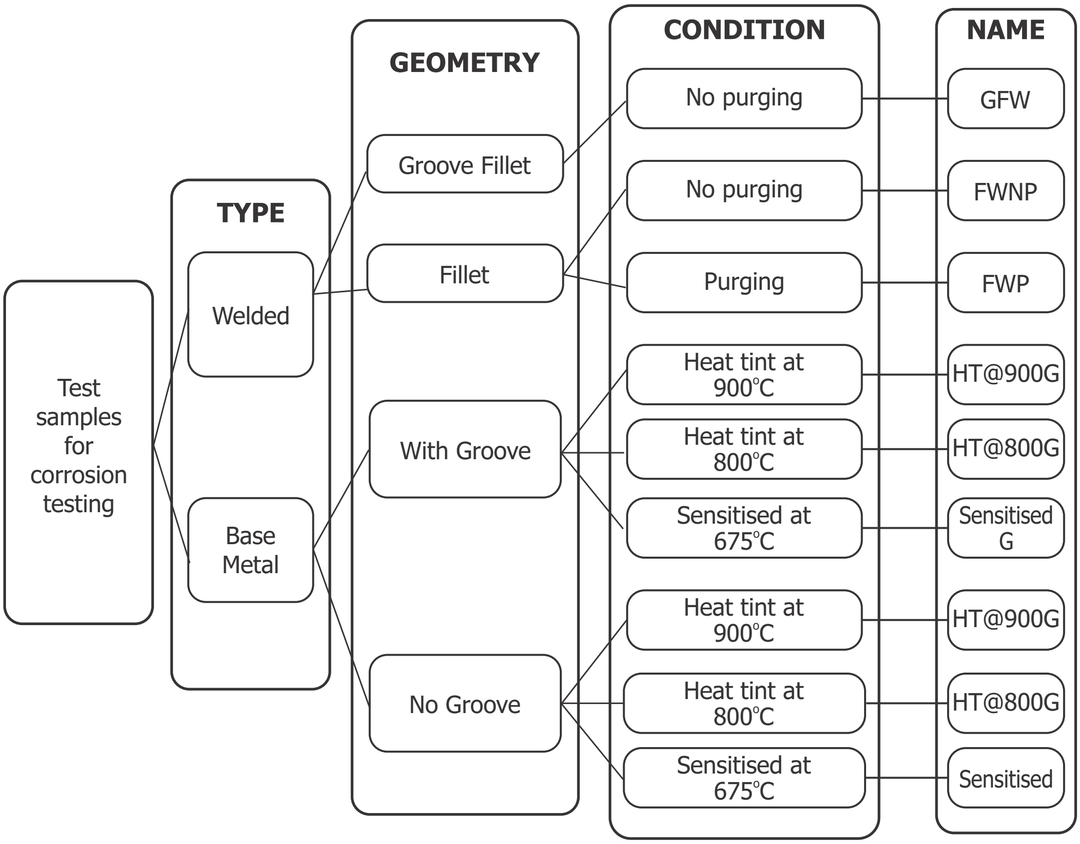

Fig. 1 : Samples plan for corrosion test

prepared for creating base information and for comparison of the results subsequently. Prior to corrosion tests, surface cleaning of all the samples were carried out as per standard procedure of ASTM A 380 [17]. **Fig. 1** describes the samples extraction plan for the corrosion test. Sensitisation heat treatment was only given to the samples extracted directly from base material, without heat tint and without welding.

2.3.1 Welded Type Samples

The specimens derived from (i) groove fillet and (ii) fillet weld joints, fabricated using plates of 6 mm and 12 mm thickness, as depicted in **Figures 2(a) and (b)** respectively. The abutting surfaces of the fillet weld joint were as-rolled (6 mm) and shear-cut (12 mm). Thorough cleaning of the surfaces was ensured. Welding executed with parameters of 60 A (current), 10 V, and a welding speed of 70 mm/min, employing a weaving technique in a horizontal welding position. High purity Argon gas is used at a flow rate of 10 LPM, wherever purging carried out.

For groove fillet welds, two passes were utilized, while single-pass welding was employed for fillet weld joints. The samples underwent visual inspection to assess root opening and detect signs of oxidation in both the weld metal and base metal (heat tint). Representative samples were extracted from all welded joints for subsequent corrosion testing.

2.3.2 Base Metal Type Samples

The specimens were made from 6 mm thick plate as per sketch shown in **Fig. 2(c, d).** A 5 mm deep groove was made at the centre of one face using 250 micron wire in EDM. Heat tints were developed on each type of samples by independently exposing these to two temperatures viz. 800°C and 900°C for five minutes. The corrosion testing of samples with heat tints was carried out without any sensitisation and further surface preparation.

Heat tints were developed on 304L samples of two types viz. (a) directly from 3 mm thick sheet and (b) from 6 mm plate and polished upto 600 grit size. The heat tinted samples of 6 mm were further sensitised and examined. The heat tints were developed at 400°C, 600°C and 800°C for 3mm thick sheet and 800°C and 900°C for 6 mm thick. The visual examination carried out as per ASME Section V of BPVC.

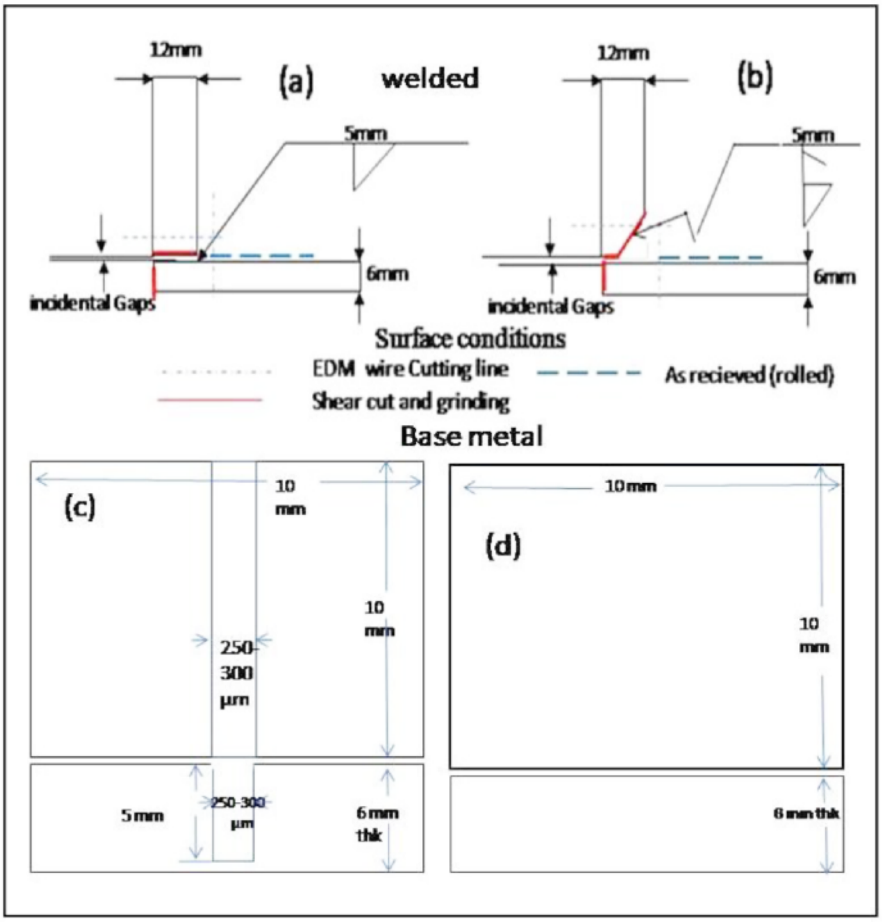

Fig. 2 : Schematics of specimens designated for corrosion testing, including weld joints with fillet (a), groove fillet (b), and base metal both with (c) and without groove (d).

3.0 RESULTS AND DISCUSSION

3.1 Visual examination

All the samples were subjected to visual examination and the details are noted. No significant defects or any deviation with the set variable are observed. The welded test coupons are shown in **Fig. 3(a)**. Incidental gaps can be seen between faying surfaces at root side of fillet weld joints as shown in **Fig. 3(b)**. Face of fillet weld joint is shown in **Fig. 3(c)**.

During the examination of root bend samples from fillet welds (**Fig. 4a**), no indications of oxidation in the weld metal were detected on the root side. However, on the root side, where no back purging was employed during welding, the faying surfaces displayed heat tints in shades ranging from red to blue and violet. These heat tints collectively appeared as a combination of various colours, as depicted in heat-tinted regions on polished or as-received samples shown in **Fig. 4(b)**. Conversely, no heat tints were observed in regions where purging was implemented during welding.

A gap of more than 250 µm is observed in grooved base metal sample as shown in **Fig. 5(a)**. The fillet weld sample indicated an incidental gaps of more than 150 µm between un-fused faying surfaces at root. There are meagre chances of crevice corrosion with this gap [18-19]. The The groove fillet weld has no incidental gap as shown in **Fig. 5(b)**.

3.2 Corrosion testing

The average corrosion rates for all sample types generally fall within an acceptable range, measuring below 15 mils per year (mpy), except for the fillet weld joint without back purging, as evident in **Fig. 6**. In a similar vein, notably higher average corrosion rates are observed in grooved base metal samples with heat tints in comparison to the standard test specimens as specified in ASTM A 262. It's worth noting that the presence of both the groove and heat tints in the base metal independently contribute to these higher corrosion rates, as illustrated in **Fig. 7** and **Fig. 8**.

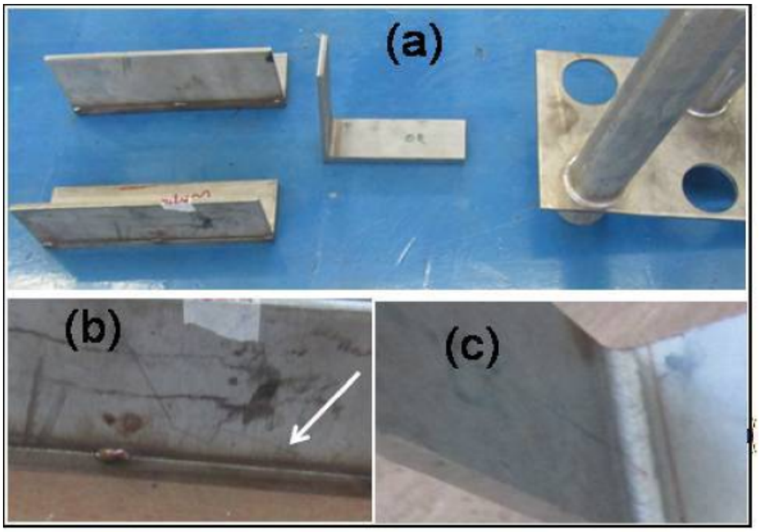

Fig. 3 : Welded test coupons, comprising all types (a), the fillet root
(b) with an arrow indicating an incidental gap, and the face of the fillet weld (c).

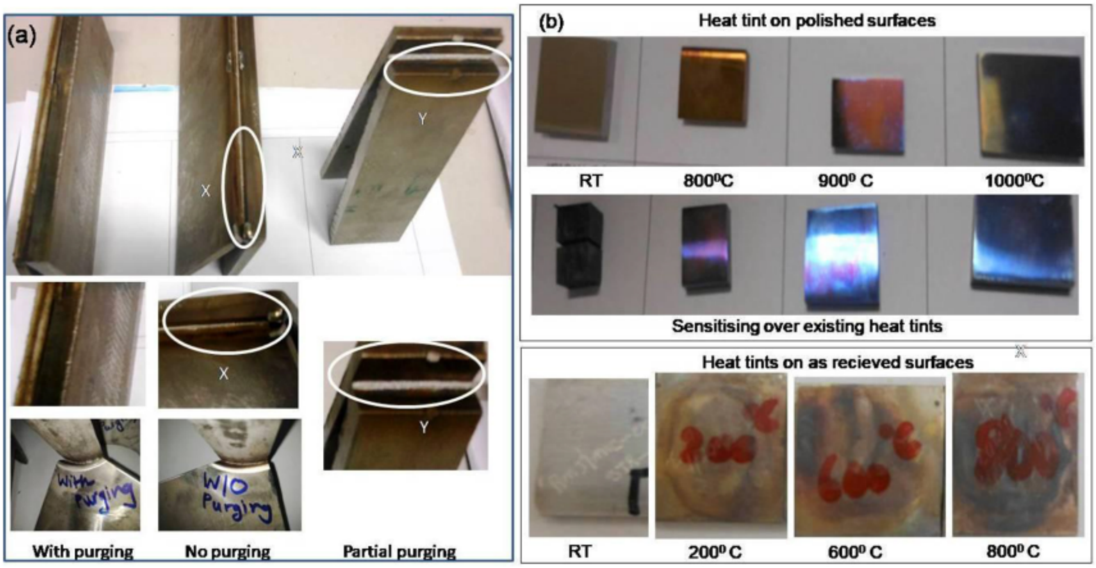

Fig. 4 : Heat-tinted areas (a) on the adjoining surfaces of the root side in fillet weld joints,
where no purging or partial purging was employed during welding, and
(b) produced on the base metal with both polished and as-received surfaces.

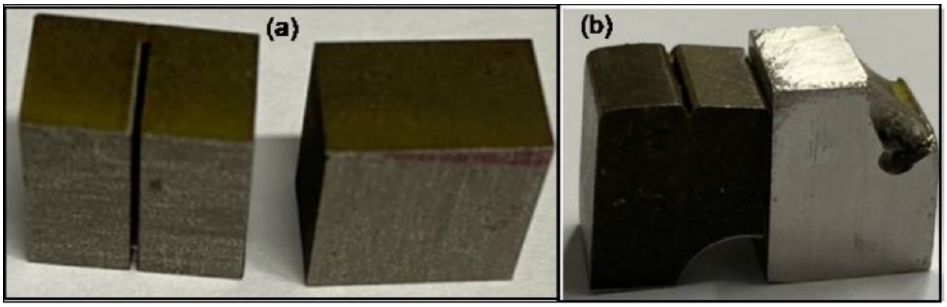

Fig. 5 : Samples of (a) base material and (b) fillet weld joint used for corrosion test

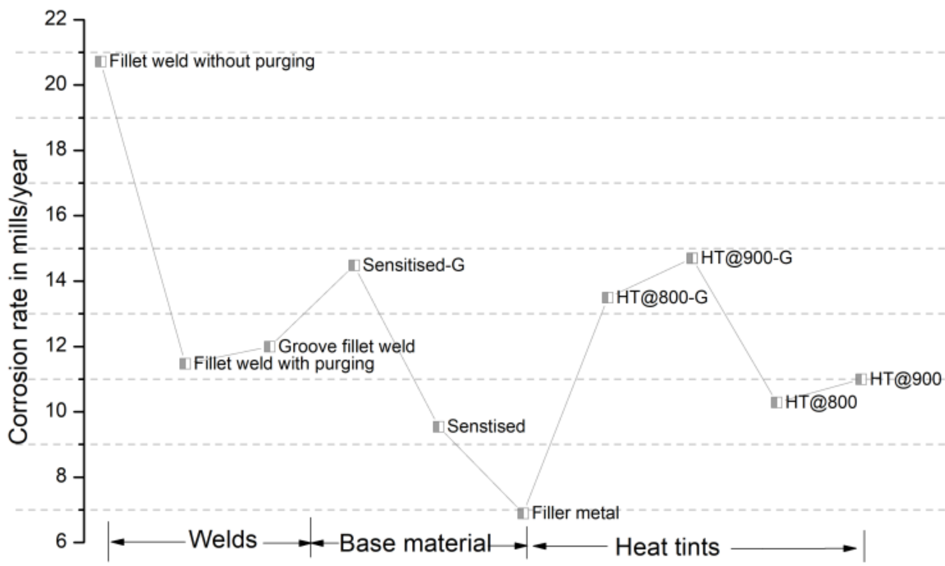

Fig. 6 : Average corrosion rate of all the samples after corrosion tests

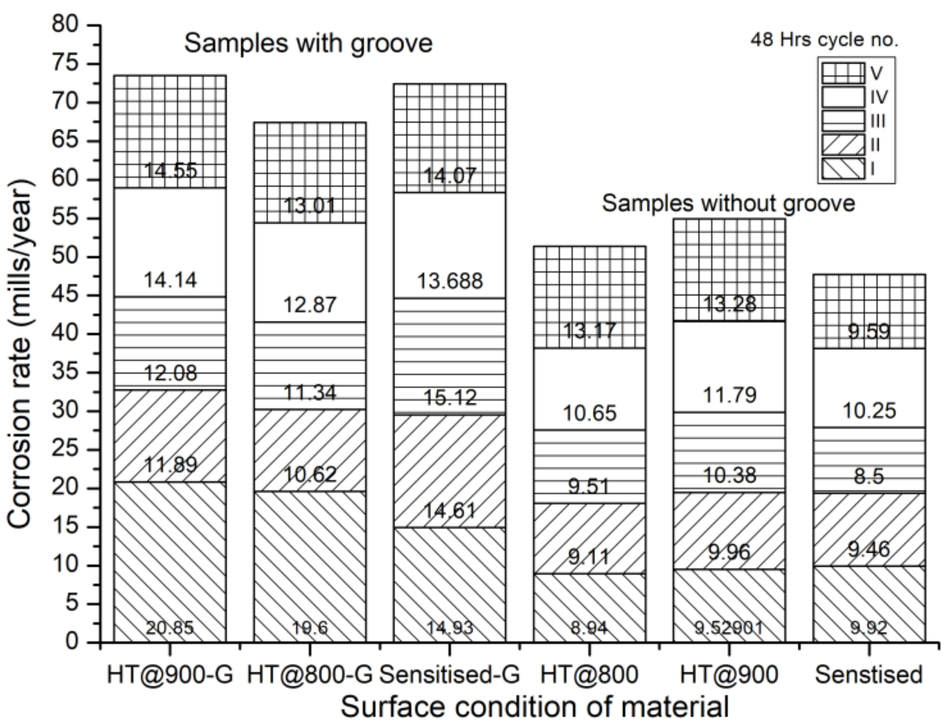

Fig. 7 : Comparison of corrosion rate for base material

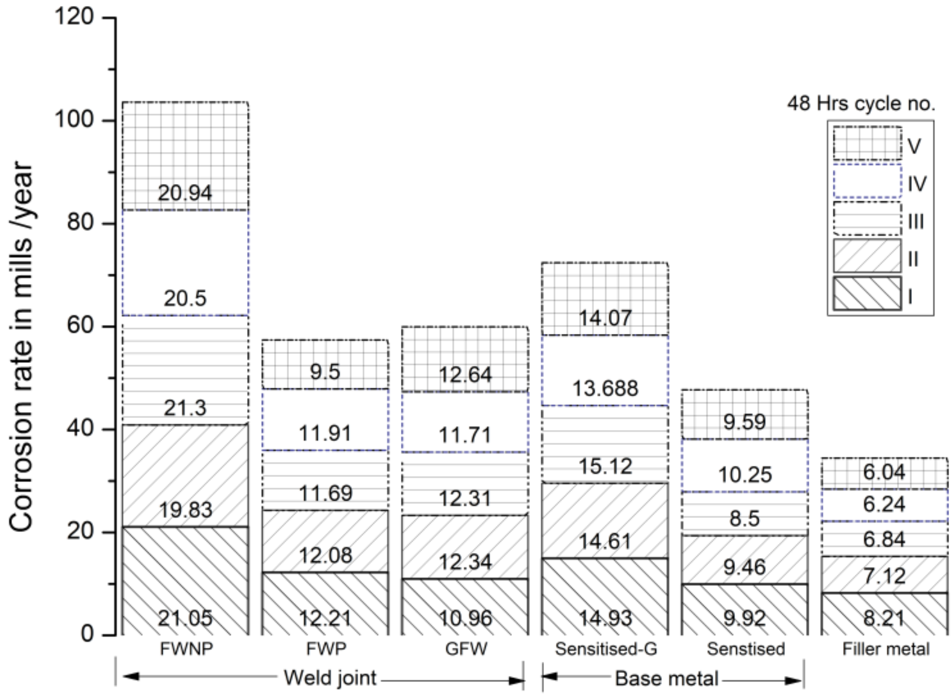

Fig. 8 : Corrosion Rate Comparison among Base Material, Weld Joint, and Un-diluted Filler Metal

Additionally, it becomes apparent that the heat tints developed at higher temperatures correspond to higher corrosion rates. Furthermore, when examining fillet welds with purging, a consistent reduction in corrosion rates is observed with each cycle, in contrast to the standard grooved fillet welded samples, which exhibit a slight increasing trend with each subsequent cycle.

4.0 CONCLUSIONS

Based on the study, formation of heat tints near to root side of SS 304L fillet weld joints during welding is detrimental towards corrosion performance as prevailing in the high concentration of nitric acid environment. Results also indicate that the acceptable rate of corrosion can be achieved if proper back purging with inert gas is provided during welding of such joints. Following are the major conclusions from the present study.

i. The average corrosion rates for all sample types are within the acceptable limit of 15 mils/yr based on the average over 5 cycles and a maximum of 18 mils/yr in any single cycle, with the exception of the fillet weld joint made without back purging.

ii. Oxidation of base metal in form of heat tints with no traces of weld metal oxidation on faying surfaces of fillet weld made without purging. Absence of heat tints in the fillet weld made with purging.

iii. Higher corrosion rates observed for samples with heat tints without any sensitisation heat treatment as compared to the standard sample without any heat tint and with sensitisation heat treatment. Heat tints if occurs, to be removed as far as possible for better corrosion resistance.

iv. Higher corrosion rate observed in the parts having discontinuity in the geometry, as compared to continuous one. The exposed parts of all the weld joints shall be properly fused.

v. Wherever partial penetration/fillet weld joints are made shall be purged from backside to avoid any type of oxidation or formation of heat tints. As higher corrosion rates than allowable are observed in such cases.

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