Weld defects analysis of 60 mm thick SS316L mock-ups of TIG and EB welds by Ultrasonic inspection for fusion reactor vacuum vessel applications

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Abstract

The present paper reports the nondestructive examination of weld defects for 60 mm thick AISI SS316L weld samples fabricated by multipass TIG welding and electron beam welding techniques. Vacuum vessel and other subsystems fabrication in advanced fusion reactor systems utilize higher thick section steel welding by different kind techniques. The weld quality inspection of the joints is to be carried by non destructive evaluation (NDE) for the final qualification. Visual examination, Liquid penetrant tests, X-ray radiography and ultrasonic scan tests have been carried on the weld samples and the qualification procedure has been evaluated. Ultrasonic scan test examination has been carried by employing different probes and DAC calibration curve has been generated to measure the cut-off weld defect size. The ultrasonic inspection revealed the some critical weld defects like porosity which are not exclusively exposed by X-ray radiography examination in such higher thick welds.

1. Introduction

Austenitic stainless steel are the prominent structural materials widely used for various components in fusion reactor fabrication. Thick steels are required for the major systems like vacuum vessel, diverters, cryostats and other structural components fabrication. Welding of thick plates has several challenges including process and their qualification for the long term survival without any failures due to the severe plasma operation conditions[1-3]. The development of these structural components is carried by different joining techniques like TIG, MIG, laser beam welding and hybrid laser-TIG welding and electron beam welding (EBW) for the fabrication of various sub systems with appropriate weld process parameters. However, due to the complexity involved in welding process, the joints are prone to have weld defects like porosity, undercuts, blow holes, slags inclusion, incomplete penetration, lack of side wall fusion and excess penetration etc. Depending on the in service conditions of these components like thermo mechanical loads, the fabricated components catastrophe can lead to the failure situations for the operation of the fusion reactor. Hence, weld quality inspection is vital for the qualification of the fabrication of these components. In case of thick section steel welds inspection, the techniques like X-ray and gamma ray radiography and ultrasonic scan tests are prominent for the evaluation of the weld defects throughout the weld depth. Liquid penetrant tests are useful for the detection of subsurface cracks/voids/discontinuities. The present paper reports the weld quality evaluation of 60 mm thick plates fabricated by multipass TIG (Tungsten Inert Gas) welding and EBW (Electron beam welding) process. In case of advanced fusion reactors like ITER, vacuum vessel and other structural components have utilization of 60 mm thick austenite steels and have several technical challenges towards realization of weld quality evaluation due to the paucity of NDT techniques readiness developed for higher thickness welds.

Table 1. Over view of Weld defects for thick stainless steel joints.

Typical weld defects	Nature	Candidate technique
Volumetric type	Slag (GMAW) / Tungsten (GTAW) inclusions / Gas porosity	Radiography, Gamma , Ultrasonic, Phased array
Planar type	Crack /micro cracks/ Lack of fusion/ lack of side wall fusion	LP testing, X-ray radiography, Ultrasonic, magnetic particle testing
Geometric type	Hollow bead, excess penetration, under cut, shrinkage	Radiography, Visual,

2. Experiments

AISI SS316L plates 60 mm thick are selected for the experiments for the fabrication of TIG and EBW weld coupons. The samples are fabricated by TIG welding by using 60 mm thick plates of size 150 mm X 150 mm and final size of weld sample is 300 X 150 X 60 mm. The multipass TIG welding (typical process parameters Current: 160 A, Voltage:~20 V ,Weld speed :~ 90 mm/min, no. of weld passes:75) has been carried out and the narrow weld groove design is used (as per Fig.1(a)). Similarly using EBW welding technique, the samples of 300 mm X 200 mm X 60 mm are fabricated by double pass electron beam welding (typical process parameters ~250 mA, 60kV, 500 mm/min, no. of passes: 2, double side) and the geometry is shown in Fig. 1(b).

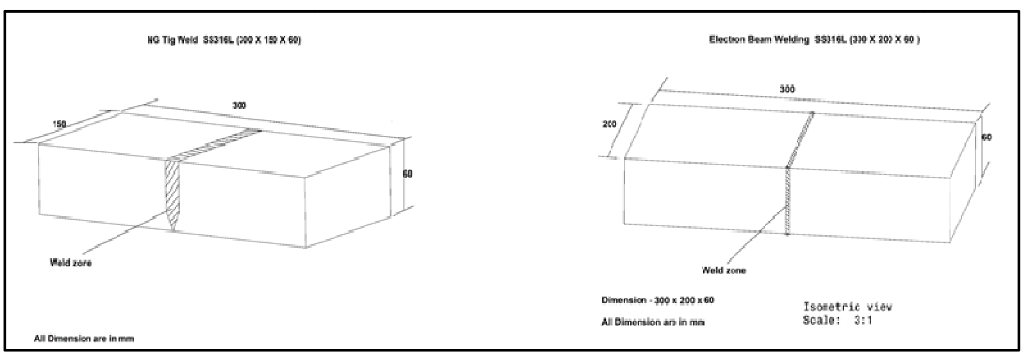


Fig. 1(a) Schematic of TIG weld geometry

Fig.1(b) EBW weld geometry

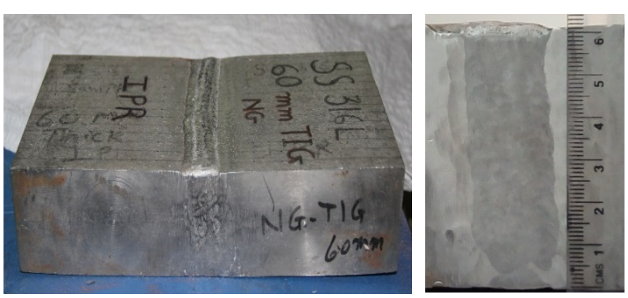


Fig.2(a) TIG weld sample (macro)

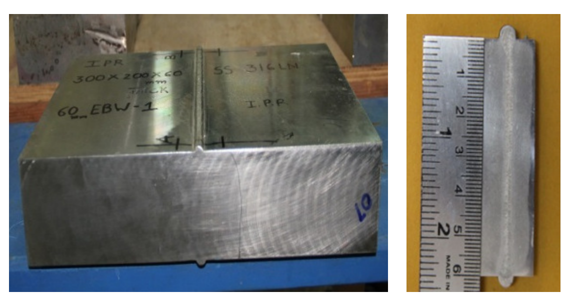


Fig.2(b) EBW sample(macro)

The final weld samples with narrow groove V joint fabricated by multipass TIG process and two pass EBW are shown in Fig. 2(a) and 2(b) for reference. The samples fabricated have analyzed for the weld bead profiles by macroscopic examinations and found as weld bead of ~ 15 mm for TIG welded samples and ~ 2.5 mm for the EBW samples. The weld cross section macro images are shown in same Fig 2(a)& (b)for reference. The weld cross sections revealed full weld penetration without any noticeable imperfections/discontinuities as per visual inspection. In order to check the weld quality throughout the welds, detailed NDT inspections have been carried on the fabricated weld samples.

3. Results and discussion

The weld preparation have been carried with careful protocols and the samples are examined for the evaluation of weld quality joints with different conventional NDT techniques namely Visual inspection, Liquid penetrant examination, X-ray radiography and Ultrasonic scan examination for the weld defects analysis.

3.1 Visual inspection

The visual inspection has been carried on all the weld samples to evaluate the primary identification of the weld quality on weld surfaces and across the cross sections for detection of visible cracks, imperfection, under or over fill, discontinuities observed any if present. Both samples of TIG & EB have not revealed any imperfections at the weld surfaces and cross sections.

3.2 LP testing

Liquid Penetrant (LP) Examination is one of the most common and quick method to check the weld inspection for discontinuities, subsurface openings on weld surfaces. In this method first surface of the samples is cleaned by the cleaner, penetrant is applied and kept it for sufficient dwell time. By removing excess penetrant form the sample, developer is applied to examine the weld surface. Liquid penetrant examination has been carried on the both the type of joints TIG and EBW 60 mm thick welds.

Fig. 3 LP tests on 60 mm TIG welds (no cracks/surface defects found)

No indicative weld defects are observed on the weld surfaces for discrete cracks/micro cracks or porosities. The examinations revealed that there were no any critical flaws like micro cracks or discontinuities on top of the weld bead surfaces across welds. Fig. 3 is shown for the reference of TIG weld sample subjected to LP test and no visual imperfections are noted.

3.3X-ray radiography examination

The fabricated thick weld joints are subjected to the X-ray radiography examination for the weld defects evaluation throughout the weld zone (test process as per Table 2). The samples with TIG welding have been found to be free from any visible weld defects like porosity, lack of penetration or lack of side wall fusion defects. As the thickness is higher, the intensity of the X-ray source requires high to get the proper penetration for the results. The examined images are shown in Fig.4(a) for reference for TIG welds and it has shown no observation of the any weld defects present. And as shown in Fig 4(b) for EBW sample, there is no noticeable weld defect present in the weld zone.

Table 2. Test procedure parameters for X-ray radiography

Material	SS316L
Thickness	60 mm
Radiation	Ir-192
Technique	SWSI
Radiographic Standard	ASME SEC-V
Acceptance Standard	ASME SEC-VIII UW-51

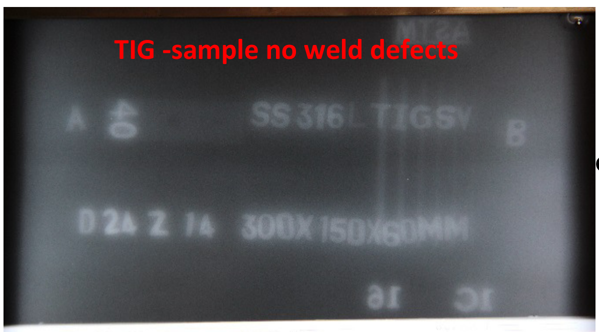


Fig.4(a) X-ray radiography of TIG weld

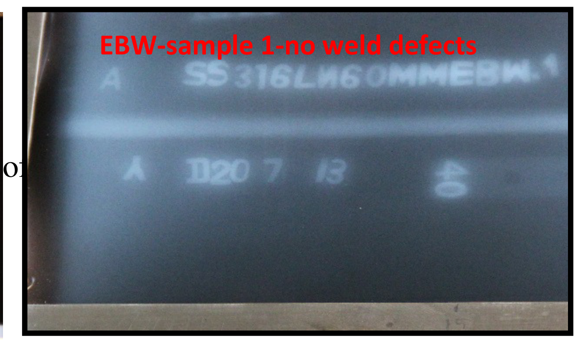


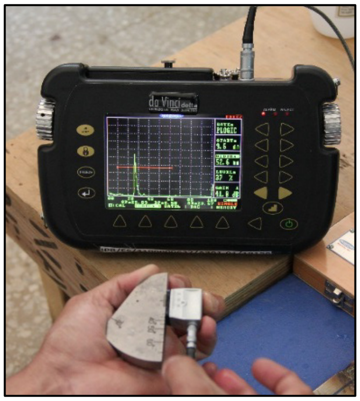
Fig.4(b) X-ray radiography of EBW weld

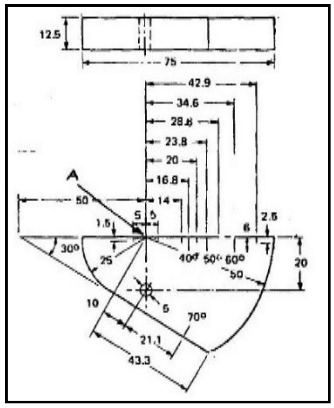
3.4 Ultrasonic examination procedure

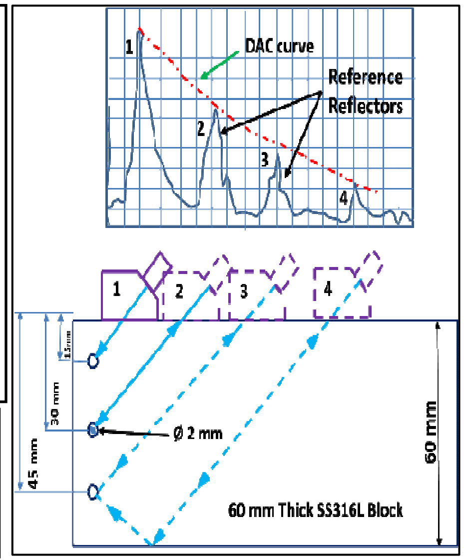
Ultrasonic A-scan examination has been carried out on the 60 mm thick TIG and EBW samples. Pulse Echo reflection technique with A scan procedure is implemented on the weld pads and the similar procedure which was carried is given in reference [2,4-6]. In case of TIG weld sample, the samples are examined with the 45^0 probe and 4 MHz, and the samples observed with A-scan examination thoroughly. The details of the procedures implemented are given below.

Angle Probe Calibration:

Ultrasonic equipment and the probe setup used for testing of weld or material flaw detection, need to be calibrated prior to the inspection. One of the mandatory initial step is the well-known time base calibration that can be defined as the process developed to establish a correspondence between the distance and time taken by the wave to travel from the known reflector. In this calibration process, it is necessary for the accurate measurement and to overcome the expected error in the signal measurement. Angle probe (45^0, 10 mm diameter with 4 MHz) has been used and testing has been carried by setting the proper parameters and tuning the functions zero and material velocity (velocity 3250 m/s) over reference signals using a V2 reference block. Multiple echo signals from the standard V2 Reference block (IIW-standards), first peak is selected using gate line which shows sound path reflected from the edge is 12.52 mm. The actual distance ofthe standard V2 reference block is 12.50 mm. The procedure adapted is shown in Fig.5 for the DAC generation and defect size optimization.







45 degree angle probe was calibrated with Standard Reference IIW V2 Block. Echo signal shows the reflected signal at 25 mm edge distance which indicate the probe index and probe calibration.

Fig. 5. DAC curve generation calibration and defect size optimization

Construction of DAC curve:

Distance Amplitude Correction (DAC) curve provides an explicit view of reference amplitude sensitivity as a function of sweep distance on A-Scan presentation method. 60 mm thick SS316L reference block with side drill hole (SDH) of 2 mm diameter at T/4, T/2 and 3T/4 thickness was fabricated and DAC curve is constructed with angle probe (45^0, 10 mm diameter, 4MHz) to generate subsequent peak amplitude response of the reference reflector by scanning the probe. The DAC is generated by plotting a curve through these amplitudes generated with scan response data measured.

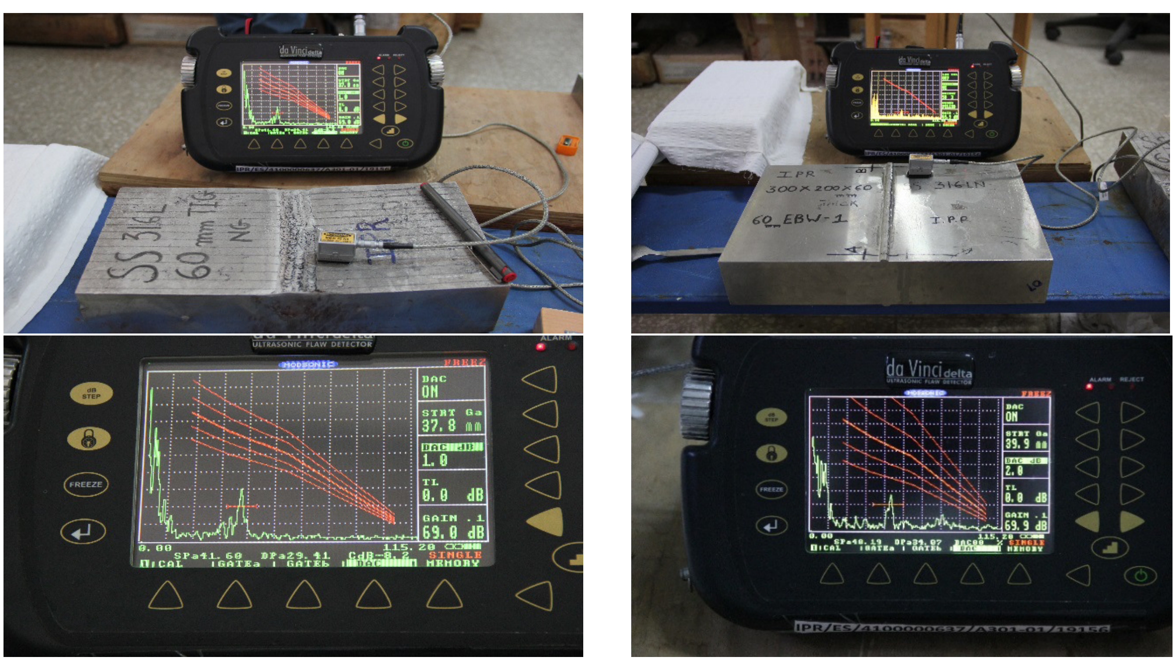


Fig.6. TIG weld sample defect (Porosity) Fig.7. EBW sample gas porosity

A-scan ultrasonic method is used to examine the weld samples of both types. In TIG weld sample, angle probe has shown the response of defects at different locations. As shown in Fig.6, the gas porosity was observed at depth of 29.41 mm and the defect signal is below the DAC curve indicating, size of the defect is less than 2 mm diameter. The same was not revealed by the X-ray radiography examination. Similarly in case of EBW coupons it was observed that gas porosity at a depth of 34.07 mm and is shown in Fig.7. The same was not revealed by X-ray radiography in such higher 60 mm EB weld joint. This show the strength of the ultrasonic technique potential application of the thicker steel welds for structural components in in advanced fusion reactor fabrication inspection methods. Further some work is needed to establish in the development of this technique to deal with the sub size weld defects below ~ 0.5 mm range in competent to the higher advanced phased array ultrasonic expensive technique implementation.

4. Conclusion

In the present investigation, the different weld samples of TIG and EBW samples which are of potential applications in fusion reactor components are examined with different NDT techniques. Visual inspection and LP test have been carried on the samples. The samples have not shown any significant sub surface defects or cracks in both TIG and EBW samples. X-ray radiography has not revealed the presence of weld defects like porosity in both the weld samples. Ultrasonic A-scan tests have shown response of welds defects like gas porosity at different depths with both samples. The characterization of weld defect with reference to the known size is carried by establishing a DAC curve with proper calibration. The ultrasonic examination technique has potential superiority to examine the high thick multipass TIG and electron beam welds and establishments of the weld defect study. In view of the expensive phased array technique, this technique provides cost effective solution for higher thick SS welds inspection and effective inspection procedure.

References

[1]. Ramesh Kumar Buddu, N. Chauhan, P.M. Raole, Mechanical properties and microstructural investigations of TIG welded 40 mm and 60 mm thick SS 316L samples for fusion reactor vacuum vessel applications, Fusion Engineering and Design 89 (2014) 3149–3158.

[2]. B. Ramesh Kumar, Weld quality analysis of TIG, laser and Electron Beam welded SS 304 and 316 materials with NDT techniques, NDE-2011, Chennai.

[3]. Rafael Martínez-Ona, Andrés García, MaríaC.Pérez, GiorgiaPirola, Andrés Dans, ÁngelBayón, Ultrasonic inspections in the fabrication of the ITER vacuum vessel sectors, Fusion Engineering and Design 88 (2013) 2155– 2159.

[4]. S.M. Tabatabaeipour, F. Honarvar, A comparative evaluation of ultrasonic testing of AISI 316L welds made by shielded metal arcwelding and gas tungsten arc welding process, Journal of materials processing technology, 210(2010)1043-1050.
[5]. Non Destructive Testing of Welds, Baldev Raj, Narosa Publishing, New Delhi (2000).
[6]. P.O. Moore (Ed.), Nondestructive Testing Handbook, vol. 7, Ultrasonic Testing, 3rd ed., American Society for Nondestructive Testing, Inc., Columbus, USA, 2007.