1. INTRODUCTION

The experimental tokamak fusion reactors have got special interest in the view of energy challenges for future requirements in safe and control way of generation. The fusion reactor consists of many major sub-systems like vacuum vessel, plasma facing first wall components, support structures and various other subsystems[1-3]. The fabrication process of these components utilize various grades of stainless steel materials in different shapes and sizes. These components mainly fabricated with different SS materials in various forms like plane plates, curved plates, T-joints according to the subsystems requirement. In addition one of the important aspect in upcoming fusion reactor components fabrication is the utilization of various thin and thick plates depending on the system requirements. These materials have exposure to conditions like plasma radiation, thermal loads, thermo-mechanical loads and high energetic (14 MeV) neutron irradiation effects. The components shall need to withstand all these typical conditions without any failures. The joining of various SS materials require different welding processes based on the system needs like thermal and structural properties[2]. TIG welding is commonly used for joining of the stainless steel materials for fabrication of different structural components. In addition to this, Laser beam welding (LBW), Electron Beam welding (EBW) and Hybrid Laser-TIG weld processes are proposed due to requirements like low HAZ, fatigue strength, structural and thermo-mechanical properties of the fabricated components [4]. The qualification of developed welded structures is very important in order to meet the protocols of the requirements and standard guidelines. Non Destructive Evaluation of these materials in various stages is indispensable. The present paper reports the studies made with non destructive testing (NDT) of different weld samples developed with SS 304 and SS 316 materials by different welding techniques.

Key words : Welding, NDT, Radiography, Ultrasonic testing

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tests before the mechanical properties characterization process. The present section describe the used weld process parameters and the developed procedure with different type materials of SS 304 and SS 316 samples.

2.1 TIG welded samples

TIG welding is the process which utilizes heat of electric arc between the non consumable Tungsten electrode and work piece for melting of exposed material with a shield gas environment. In addition, it uses filler wire with suitable grade for the joining materials. SS 316 samples with 10 mm and 20 mm thickness are developed with TIG welding process with filler wire material ER316. The samples are machined as per standard Single V groove and Double V groove designs. As the filler wires are used in multipass TIG welding, there are possible chances in the welded sample to have pores, voids, inclusions, and some micro and macro cracks development in the samples. The typical weld parameters used are in range of weld current 70-100 Amp, voltage ~15V, Argon shield gas flow rate 7-9 lpm. In Figure 1(a), SS 316 sample developed with TIG welding was shown.

The final dimensions are 300 mm X 300 mm X 10 mm and with single V-groove design. All the TIG welded samples are characterized with non destructive tests with X-ray radiography and Ultrasonic testing methods.

2.2 Laser welded samples

The Laser beam welding is one of the important proposed welding technique for production of good quality welds in some critical components of fusion reactor systems. This process generates low HAZ and good mechanical properties of the joints and longer life. SS 304 and SS 316 materials are obtained in the form of 5 mm thick sheets and are fabricated with CW CO₂ laser welding process. The fabrication of the samples was carried out by Magod Laser, Bangalore under contract. The two sample plates of SS 304 each with dimensions of 150 mm X 150 mm X 5 mm and the welded final sample dimension is 300 mm X 150 mm X 5 mm. The similar process is followed for the SS 316 sample plates with same dimensions. The necessary preparation process like samples cutting, surface finish, and proper cleaning has been carried out before the CO₂ laser welding. The typical welding parameters of CO₂ laser system used for the fabrication of these welded samples are Laser Power 2.2 kW, Speed 0.75 m/min, Argon shielding gas 3 bar, Laser Spot diameter 0.75 mm, Beam angle 90°. In Figure 1(b), the Laser welded sample with SS 304 material was shown.

2.3 Electron Beam welded samples

Electron beam welding is one of the powerful weld process technique which offers sound good quality welds with very low heat affected zone(HAZ), high joint strength, long life of the components with more fatigue life and resistance to corrosion. SS 316 samples of 300 mm X 100 mm X 10 mm are developed with Electron Beam Welding process. The samples development was carried out by Asaco Pvt Ltd., with their existing EB welding facility under contract. The typical operated parameters of fabricated samples are Beam Current of 85 mA-120mA, Voltage ~ 60 KV, Vacuum 10⁻⁵ mbar. The process speed is of around 700-800 mm/min. The parameters in terms of beam current are optimized and prepared with single pass operation of electron beam. The samples produced with 10 mm samples are studied for the quality of weld fusion process with radiography and ultrasonic tests.

3. NON DESTRUCTIVE TESTS

In general the joining of materials utilize filler wires in case of TIG welding and no fillers in case of beam processes like laser beam welding and electron beam welding. The weld joint when get inspected, it may be found that the weld quality may not be meeting the qualification level. The weld defects may present are like porosity, inclusions, under-cut, lack-of penetration, reinforcement, incomplete fusion and cracks etc[5]. Even though the necessary precautions are taken during the preparation process of the welding procedures in filler wire TIG, due to the associated molten metal heating and cooling processes during solidification, the chances of weld defects in the developed samples are possible. In Beam processes like Laser beam welding and EB welding the high speed process there may be some problems like under-cut and lack of penetration at deeper locations. Some times the sample preparation also may contribute to the weld defects like under-
cuts due to poor quality machining. The welded samples developed with different weld processes are subjected to non-destructive tests with Radiography and Ultrasonic testing methods.

3.1 Radiography

The radiation used in radiography testing is a higher energy (shorter wavelength) version of the electromagnetic waves that we see as visible light. The radiation can come from an X-ray generator or a radioactive source. Discontinuities are interruptions in the typical structure of a material. These interruptions may occur in the base metal, weld material or HAZ. The presented data of the radiography conducted is done with 150 kV source and recording films of suitable size are used as per the dimensions of the required sample. The developed samples with each process TIG, Laser beam and Electron beam welding are subjected to X-ray Radiography tests for the weld quality analysis in terms of fusion process. Any significant defects like pores, lack of fusion or undercuts etc are present was studied. The results are discussed in further section.

3.2 Ultrasonic test

The weld samples developed with each process are tested with Ultrasonic Testing for defects identification. The technique applied is Pulse Echo reflection technique, A-scan procedure [6,7]. A-scan presentation displays the amount of received ultrasonic energy as a function of time. Relative discontinuity size can be estimated by comparing the signal amplitude to that from a known reflector. Reflector depth can be determined by the position of the signal on the horizontal sweep. With this technique advantages includes like sensitive to small discontinuities on both surface and subsurface, depth of penetration for flaw detection or measurement is superior to other methods. Only single-sided access is needed when pulse-echo technique is used. In addition high accuracy in determining reflector position and estimating size and shape has other uses such as thickness measurements, in addition to flaw detection. The equipment used was Modsonic make, Einstein II DGS model and probes are Angle probe for larger coverage and TR probe for short coverage resolution. The developed TIG, Laser and EBW samples were subjected to Ultrasonic testing procedure for the evaluation of weld quality. The details of system specifications of Ultrasonic test used are shown in Table 1.

<table>
<thead>
<tr>
<th>Probe</th>
<th>Range</th>
<th>Ref. dB</th>
<th>Scan dB</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angle (70°)</td>
<td>0-50 mm</td>
<td>50dB</td>
<td>56 dB</td>
<td>4 MHz</td>
</tr>
<tr>
<td>TR probe 10mm dia</td>
<td>0-20 mm</td>
<td>45dB</td>
<td>51dB</td>
<td>4 MHz</td>
</tr>
</tbody>
</table>

4. RESULTS AND DISCUSSION

The developed samples with TIG welding, Laser welding and Electron beam welding are subjected to NDT evaluation with X-radiography technique and Ultrasonic Testing. It is unavoidable to find weld defects free in samples even though highest care is taken during the preparation. In case of multipass TIG welded SS 316 samples it was observed that they had some porosity and incomplete penetrations in both 10 mm and 20 mm samples. The Radiography report has revealed clearly the indication of porosity. Single V groove samples were produced with least porosity and almost good quality weld path of 300 mm length. Where as in case of 20 mm thick plate welds, the incomplete penetration was observed and indicated the root gap has to be increased further for the sample at some positions of the samples. Also in addition some portion of 20 mm thick sample was observed with root porosity and Lack of penetration. The observation hints that the TIG weld process practice has to be improved.

Further, the samples are subjected to ultrasonic testing and similar observations are found. In case of Laser welded samples, under cut was observed in SS 304 samples at 3.8 mm depth of total 5 mm thick sample. This was shown in Figure 2(a). In addition some samples of Laser welded SS 316 are found to have lack-of penetration which was clearly observed around 4 mm depth at 100 mm length. The developed EBW sets samples are tested with radiography. Among all,
EBW produced sound good quality welds, but still there is some possibility of the materials used. Fusion reactor fabrication involves huge SS materials joining in form of thin and thick plates, T-welds, shells, pipes and diagnostic ports etc. All these are to be qualified with all the possible NDE in onsite and off-site scenarios with quick and quality measurements of welds. On-line weld defects monitoring advanced NDE techniques like Acoustic Emission, IR Thermography and Ultrasonic Phased array techniques have to be adopted towards these challenges ahead in fusion reactor materials fabrication.

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REFERENCES