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Manufacturing and assembly of IWS support rib and lower bracket for ITER vacuum vessel

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Abstract. ITER Vacuum Vessel (VV) is made of double walls connected by ribs structure and flexible housings. Space between these walls is filled up with In Wall Shielding (IWS) blocks to (1) shield neutrons streaming out of plasma and (2) reduce toroidal magnetic field ripple. These blocks will be connected to the VV through a supporting structure of Support Rib (SR) and Lower Bracket (LB) assembly. SR and LB are two independent components manufactured from SS 316L(N)-IG, Total 1584 support ribs and 3168 lower bracket of different sizes and shapes will be manufactured for the IWS. Two lower brackets will be welded with one support rib to make an assembly. The welding between SR and LB is a full penetration welding. Total 1584 assemblies of different sizes and shapes will be manufactured. Sufficient experience gained from manufacturing and testing of mock ups, final manufacturing of IWS support rib and lower bracket has been started at the site of IWS manufacturer M/s. Avasarala Technologies Limited (ATL). This paper will describe, optimization of water jet cutting speed on IWS material, selection criteria for K type weld joint, unique features of fixture of assembly, manufacturing of Mock ups, and welding processes with NDTs.

1. Introduction

Support Rib (SR) and Lower Bracket (LB) assembly is a supporting structure of ITER Vacuum vessel to support the IWS blocks. SR and LB are two independent components manufactured from SS316L (N)-IG material through waterjet cutting followed by CNC machining. Manufactured SR and LB components welded by combination of Tungsten Inert Gas (TIG) Welding and Shielded Metal Arc Welding (SMAW). 1584 assemblies of different size and shapes to be manufactured to support approximately 5000 blocks

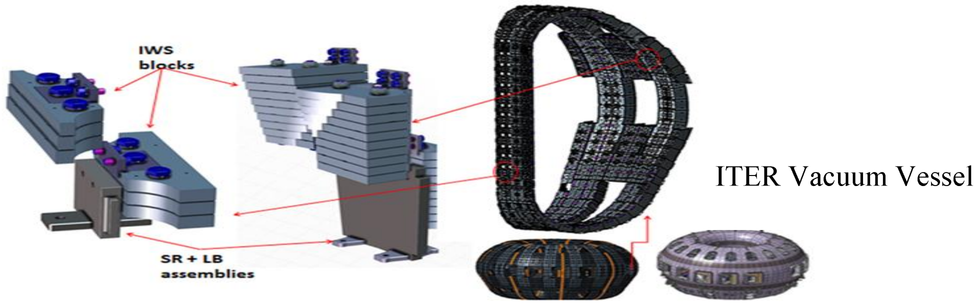

Figure 1. SR+LB assembly with IWS blocks

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2. Waterjet Cutting

Waterjet cutting is a cutting method used to cut wide variety of materials using a very high-pressure jet of water, or a mixture of water and an abrasive substance. When the cutting performed by only water jet is called pure waterjet cutting and when the cutting performed by a mixture of water and abrasive is called abrasive jet cutting or simply water jet cutting. The abrasive jet cutting is generally used to cut hard materials.

The main advantage of waterjet cutting is it doesn't superheat the area adjacent to the cut, hence it prevents Heat Affected Zone (HAZ) on the material. This is also a necessary requirement for IWS and its components.

The waterjet cutting is comparatively slow and costly process hence the optimization of waterjet cutting is required for IWS material to cost and schedule estimation for IWS.

3. Optimization of Waterjet Cutting Speed

During the optimization of waterjet cutting speed, considered the various parameters like maximum cutting speed, water jet pressure, nozzle diameter and type of abrasive powder etc. Figure 2 shows the waterjet cutting of sample piece with various cutting speeds and the result shows in table 1.

The waterjet machine used for waterjet cutting has the following specifications. The machines with these specifications are commonly used over the world to cut the various SS material.

Max. pressure: 3800 bar, Cutting pressure: 3600 bar, Material cutting thickness 40 mm.

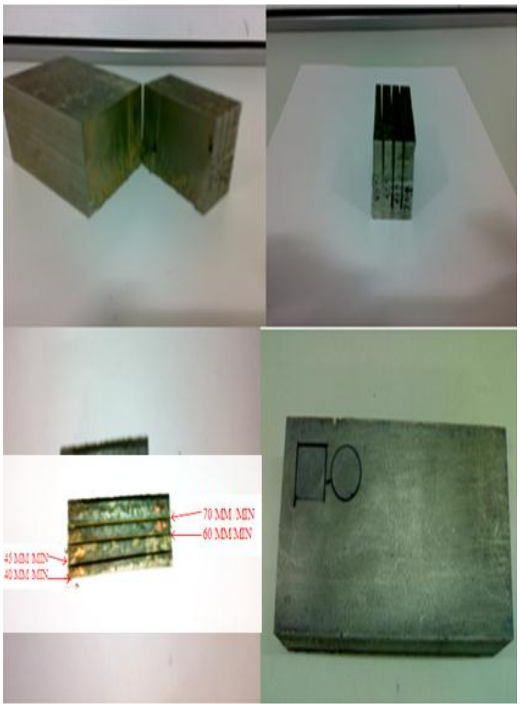

Figure 2. Waterjet cutting on a sample piece with various cutting speeds.

Table 1. Cutting results.

Sr No.	Max. cutting speed	Cutting result	Remark
1	70 mm/min	Material not cut properly	1.1 m
2	60 mm/min	Material not cut properly	0.2 m
3	45 mm/min	Material not cut properly	Hammering required to separate the material
4	40 mm/min	Material cut	Very less Hammering required to separate the material
5	30 mm/min	Material cut	No hammering required for straight profile but for circular profile hammering required.
6	25 mm/min (Optimized speed)	Material cut	No hammering required for straight and circular profile.

As a result of this study, Optimised waterjet cutting speed for IWS material is 25 mm/min.
The cutting area with optimised speed requires post CNC machining for desired surface roughness.

4. SR+LB design

The SR and LB assemblies will be subjected to following load conditions in vacuum vessel:

(1) Dead weight: weight of IWS block
(2) Electromagnetic load

Hence it is designed in such a way to take above loads. The selection of weld joint and welding process to bear the static and dynamic loads of IWS blocks are described in next section. The 3D models and 2D drawings of SR and LB assembly are shown in figures below.

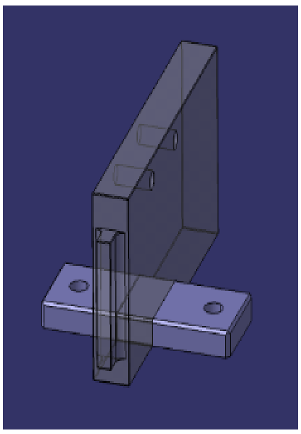

Figure 3. Old Design

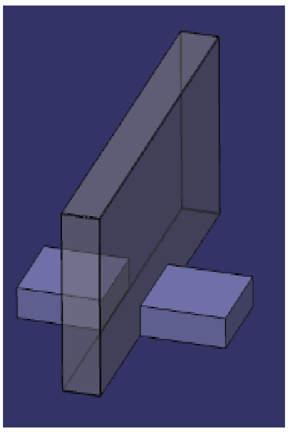

Figure 4. New Design

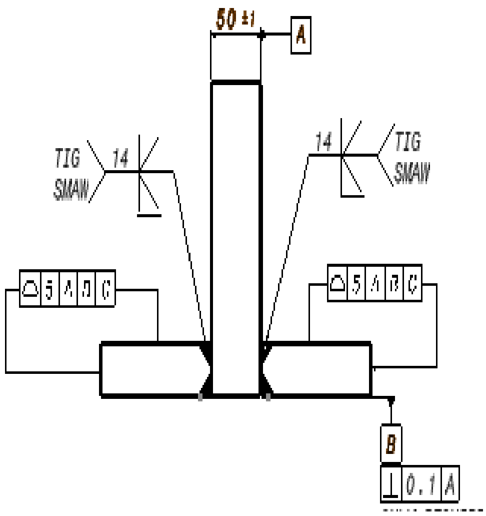

Figure. 4.1. New design drawing

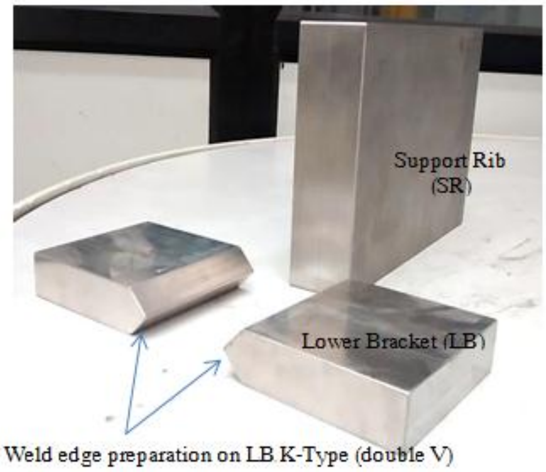

Figure 4.2. K type weld edge preparation on Lower bracket

5. Selection of Weld Joints and Welding Processes

The SR and LB are two independent components and welded together to support the IWS blocks in ITER-Vacuum vessel for life long. Hence it is necessary to select the weld joint and welding processes in such a way that it takes the static and dynamic load of IWS blocks.

5.1. Weld Joint

The following two weld options have been suggested by experts to support IWS blocks.

(1) K-type &
(2) Single side (Single Vee) type joints.

From the above options, K-Type weld joint was chosen for lower bracket with support rib due to following reasons;

- For strength wise, if it is a full penetration weld, both Single V groove and Double V groove joint have the same strength.
- As per Section IX of ASME, Single V groove is not acceptable for more than 16 mm thick, our requirement is 29 mm thick.
- Filling area will be 40 % less in Double V (K type) groove in comparison to single V groove. Therefore heat input will also be reduced, which further reduced the welding distortion.

5.2. Welding Process

The following two options have been suggested by experts to for welding of selected weld joint is
(1) TIG, (2) SMAW, (3) Combination of TIG and SMAW
A combination of Tungsten Inert Gas (TIG) welding at root and Shielded Metal Arc Welding (SMAW) is chosen for welding of assembly due to the following conditions
If only TIG is selected then:
(a) very slow process, (b) more welding distortion (c) Total 29 number of passes will be required to fill the weld joint (d) a costly process.
If only SMAW is selected then:
(a) As the electrode diameter is more in SMAW then the filling of root of selected joint is an issue and result can be lake of fusion at root.

5.3. Unique Fixture for SR +LB Assembly

The 1584 assemblies of different sizes and shapes will be manufactured within fastened tolerance to support IWS blocks in Vacuum vessel, Hence it is necessary to make an unique fixture to perform the selected welding process on different size and shapes assemblies.

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Fixture is designed in such a way that whole assembly is held in single setup rigidly and welding is carried out on both sides of k-type weld joint. Lower bracket is arrested in fixture to avoid dis-location, and to minimize distortion during welding. Uniform purging of argon gas is planned by design of closed perforated envelope to avoid blow holes in the weld.

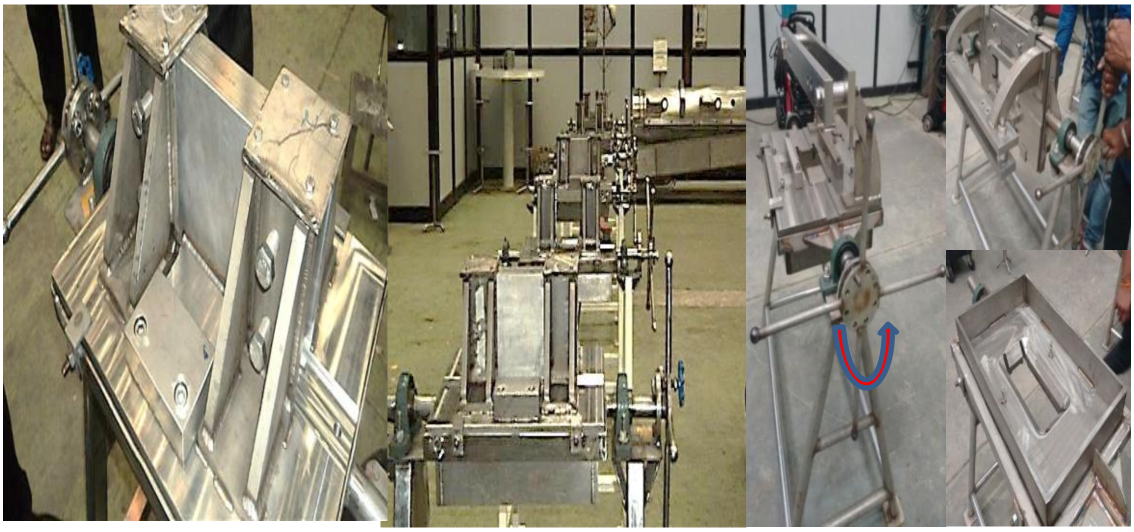

Figure 5. Welding fixtures for poloidal segment (PS) 1 and 2.

6. Welding Qualifications and NDT Criteria

Various mock ups have been manufactured to establish and validate the manufacturing processes, welding and inspection procedures. Process qualification documents WPS (welding procedure specification), PQR (procedure qualification record) and WPQR (welder performance qualification record) have been prepared and approved. Following figures show the manufactured mock-ups. Applicable NDTs are shown in table 2.

Figure 6. Weld edge preparation and welding.

Table 2. NDT of assembly

Sr. No.	NDT	Standards
1	UT (ultrasonic testing)	ASME section V article 4&5, and ASME section VIII div. 1
2	LPT (Liquid penetrant testing)	ASME section V article 6, and ASME section VIII div.1

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With the gained experience from mock-ups, actual manufacturing of IWS has been started.

7. UT Challenges and Resolutions.

Ultrasonic Testing of austenitic stainless steel welds has been considered as difficult and very challenging due to high level of scatter and attenuation. It prevents to characterize defects due to low signal to noise ratio, beam splitting, skewing effects and spurious echo from weld. It is much more complicated to perform UT on typical T, K, Y type weld joints.

Hence UT is a very critical and challenging job for IWS SR and LB assembly. This is also impacting IWS and VV schedule. From number of discussions, it is concluded that a comprehensive UT examination and its comparison for welded samples with different probes and methods is required Based on number of discussions and study on coupons UT procedures has been finalized.

ATL successfully completed the UT of SR+LB assemblies of poloidal segment (PS)1 of vessel sector (VS) 6 & 5 and poloidal segment 2 & 4 of vessel sector 6.

8. Manufacturing Status of SR, LB and SR+LB

The continuous welding and inspection is going on to meet the agreed Factory acceptance (FA) date. Following figure shows the status of 164 assemblies out of 1584 assemblies. Status of FA of the completed assembly is shown table 3.

Table 3. Status of FA completed assemblies.

Sr. No.	Sector segment	Quantity
1	PS1VS6	48
2	PS1VS5	48
3	PS2VS6	54
4	PS4VS6	14

Acknowledgement

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ITER Disclaimer

The views and opinions expressed herein do not necessarily reflect those of the ITER Organization.

References

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