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Laser Welding Technology for the ITER Toroidal Field Coil Components

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Abstract

The radial plate (RP) of TF coils consists of 10 segments with 120 mm in thickness of high nitrogen content austenitic stainless steel. It is important to suppress the welding deformations so as to satisfy tolerances required. In the preliminary tests, we investigated feasibility of application of high power laser welding to the thick plate welding, and found out proper conditions of welding for the RP material. The cover plates (CP) were welded onto the RP with the insulated conductor to support mechanical loads and form double pancake (DP). Since the CP were thin plates and hundreds of plates were welded onto the RP, the prevention of the welding deformations and the heat input to the insulation wound around the conductor were key issues.

Keywords: High power laser weldiing, welding deformation, ITER, Troidal Field Coil, Radial plate, Cover plate

1. Introduction

The ITER TF coil unit is composed of coil structures (TFCS) and a winding pack (WP) as shown in Fig.1. As for the ITER tokamak machine, 18 units are precisely aligned in the toroidal direction to produce magnetic field for plasma confinement. WP consists of seven Double Pancakes (DP) which consists Radial Plate (RP) for the base plate for superconductor packed by Cover Plate (CP). RP manufacturing flow is shown in Fig.2. Grooves for superconductor are machined from 120mm thick high nitrogen content austenitic stainless steel (SUS316LNH) for ITER (Table 1[1),2)]). The size of RP is 13×9m, and to satisfy the accuracy requirement and prevent the occupying the machine to reduce the lead time for manufacturing, RP is joined with 4 sectors made of 10 segments. By machining of sector after joining of segments and application of the precise high power laser welding, the flatness of 1mm and profile of 1mm are achieved. After inserting the

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superconductor to RP, CPs are put on the RP grooves and welded. Hundreds of CPs are welded for one DP, and the total length of CP welding is about 1.5km, then the prevention of welding deformation and obtain high productivity are important. The requirement of flatness after CP weld is 3mm.

In this report, the Laser welding technology for high accuracy and high productivity applied to the actual production of ITER TF coil components will be reported.

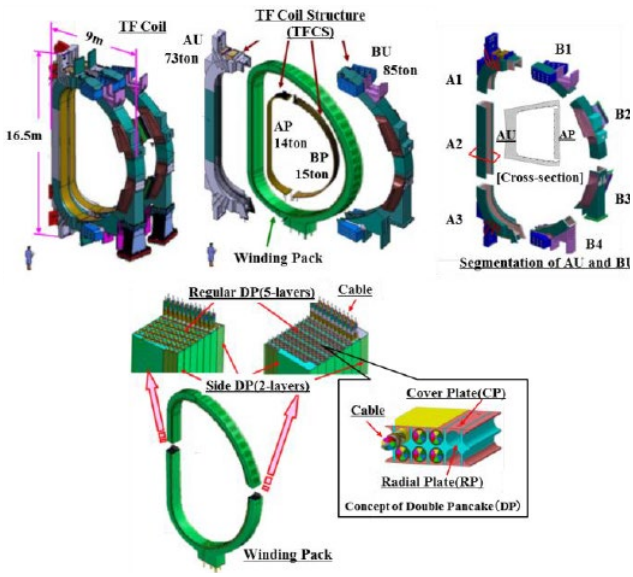

Fig. 1. Structural Concept of Toroidal Field Coil

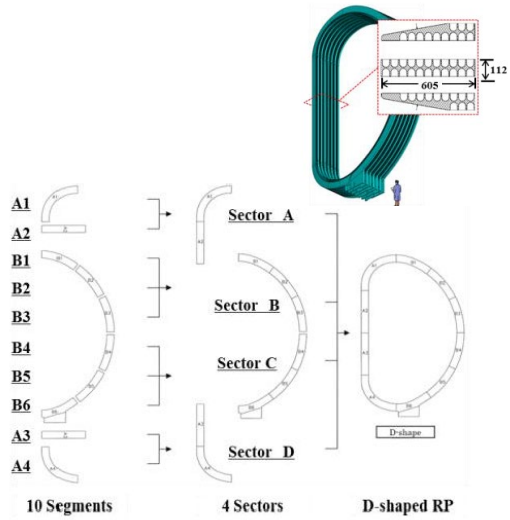

Fig. 2. Structural Concept of Radial Plate

Table 1. Chemical composition and mechanical properties of RP and CP

Material	C	Si	Mn	P	S	Ni	Cr	Mo	N	C+N	Tensile strength (Mpa)	Yield strength (Mpa)	Fracture toughness ($Mpam^{1/2}$)
316LNH	0.030 or less	0.75 or less	2.00 or less	0.03 or less	0.020 or less	10.00 - 14.00	16.00 - 18.50	2.00 - 3.00	0.150 - 0.220	0.180 or more	>580	>280	>180
											>560	>260	>180
ref. SUS316LN (JIS)	0.030 or less	0.75 or less	2.00 or less	0.045 or less	0.030 or less	10.50 - 14.50	16.50 - 18.50	2.00 - 3.00	0.12 - 0.22	-	-	-	-

Note 1 : P+S<0.050 mass%
Note 2 : Values of tensile strengths and yield strengths are shown at room temperature
Note 3 : Fracture toughness is obtained at 4K
Plate thickness , top: less than 200mm, bottom: 200mm or more

2. Welding technology for RP

As shown in Fig.2, the radial plate consists of 10 segments with 120 mm in thickness. It is important to suppress the welding deformations so as to achieve the tolerance requirement. In order to suppress the out of plane deformation, deep penetration laser beam welding of the center area of thick plate is applied. The material is full austenite stainless steel for ITER, there were some difficulties to prevent defects such as hot crack and porosity and to improve the productivity.

In the preliminary tests, we investigated the applicability of high power laser welding for the thick plate welding, and found out proper conditions of welding for the RP materials. The 30 kW fiber laser of the world highest power for actual production was introduced. The welding is carried out by a combination of laser welding and narrow gap TIG welding. In laser welding, partial penetration welding is carried out from both sides including inversion, and the remained part is welded simultaneously from both sides by narrow gap TIG welding. Configuration of welding joint is shown in Fig.3. The appearance of the welding equipment is shown in Fig.4. The portable laser welding equipment is moved to the joint part of segment or sector and welding is conducted. With this system a large driving device is unnecessary, and the parallel preparation work can be carried out except for the welding part. The root face thickness for laser weld was 50 mm at the beginning of the production, but was increased to 70 mm at present. In addition, from the viewpoint of productivity improvement, overhead position laser welding method which enables to eliminate the turnover operation of RP has been developed and put into practical use to reduce lead time. In order to realize overhead welding, some issues such as defects caused by molten metal dropping and optical system damage due to sputter were solved by optimization of welding conditions (Fig.5) and development of a sputter protection, and satisfactory overhead welding of more than 40mm was achieved. The macroscopic test result and the joint performance test result show that the weld was shown in Fig.6. To understand the welding shrinkage, evaluation test was also carried out. Measurements are carried out at every 100mm for the welding direction in this test. Evaluation results of welding shrinkage are shown in Fig.7. The welding shrinkage was in a range of 0.5 to 1.0 mm after the LBW and range of 0.5 to 1.2mm after TIG welding. So it is possible to satisfy the profile requirement by carrying out the dimension adjustment machining in consideration of the above-mentioned welding shrinkage before the welding assembly of sectors for the D-shape of full RP (Fig.8).

3. Welding technology for CP

The heat treated conductor was inserted into the RP groove and electrical insulation tapes were wound around the conductor, taking care not to damage the conductor by large strain over 0.1%. After the insulation processes, the cover plates (CP) were welded onto the RP with the conductor insulated to support mechanical loads and form double pancake. Since the CPs were thin plates and hundreds of the CP were welded onto the RP, the welding deformations and the prevention of heat input to the insulation wound around the conductor were key issues. The configuration of the DP was shown in Fig.9. Here, the total welding length of the CPs is more than 1.5 km per DP. Low heat input laser welding by automatic robot system is applied in order to suppress the deformation and achieve high productivity. The filler wire feeding laser welding is applied in order to prevent defects such as undercut and under fill while ensuring the fitting flexibility of CP. The configuration of the welding equipment is shown in Fig.10. High efficiency and good weld beads are achieved by adjusting welding conditions according to the scanning results of weld line and groove gap with laser sensor. The cross section of weld bead is shown in Fig.11. In addition, 1.5 km welding of 462 CP plates are required for the standard DP, and it is necessary to balance the out of plane deformation caused by welding of the front and back side in order to ensure flatness. Therefore, the welding procedure for the front and back sides and in-plane width direction was decided by the welding deformation analysis in

the welding procedure decision. The concept of welding procedure is shown in Fig.12, and Table 2 shows an example of the comparison of the degree of out of plane deformation caused by the difference in welding procedures for each surface. It is found that the out of plane deformation suppression effect can be expected by adjusting the welding pass sequence procedure. The results of CP welding by the selected procedure are shown in Fig.13. As predicted by the preliminary analysis, out of plane deformation after welding was suppressed not more than 3mm.

4. Conclusion

The ITER toroidal field coil is the huge and heavy component and the precise dimensional accuracy is required. In order to accomplish the ITER requirements, the various kinds of the welding technologies have been applied.

As for the RP assembly, feasibility of the laser beam welding for the thick plate has been investigated, and the proper process conditions for the special material of SUS316LNH for ITER have been selected. 30kW laser which has one of the highest power for actual production in the world is applied, and both side welding of more than 50mm root thickness has enabled to suppress the out of plane deformation after welding.

As for the CP welding, robot laser welding systems with groove sensing are applied in order to reduce the lead time, and welding procedures which are decided by the welding deformation analysis has enabled to satisfy the accuracy of DP required by ITER organization.

These welding technologies have already been applied to the actual production, and we will be keeping the quality of manufacturing for the success of ITER Project.

Acknowledgements

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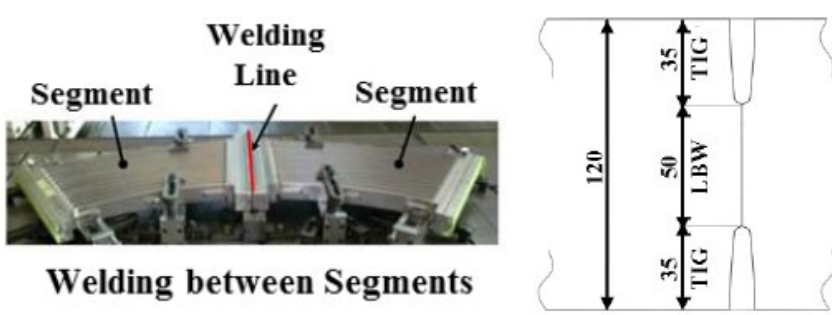


Fig. 3. Configuration of Segment Welding Joint

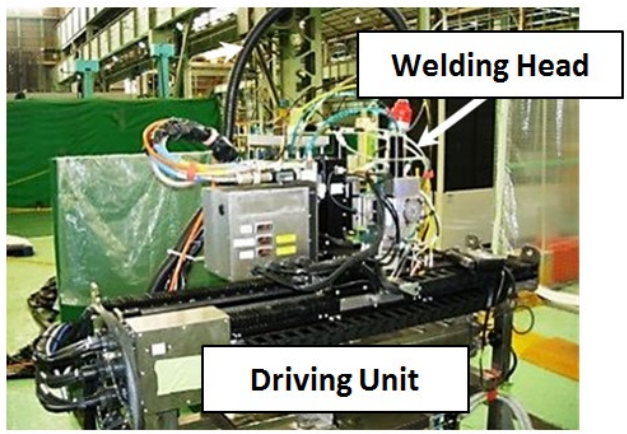


Fig. 4. Overview of welding system

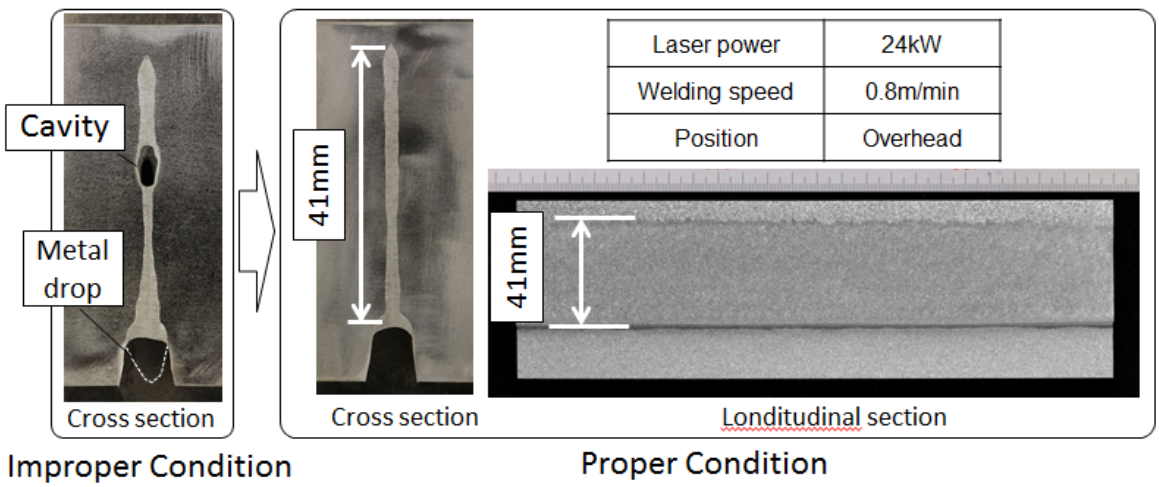
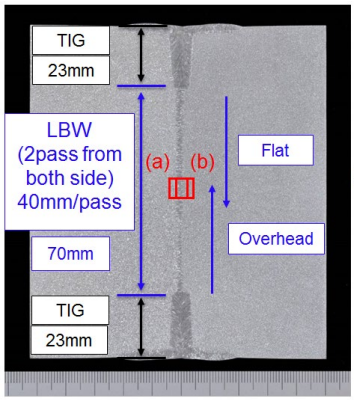
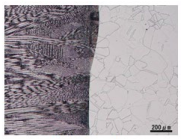


Fig. 5. Cross section and mechanical property of weld joint



(a) Center of weld metal



(b) Bond

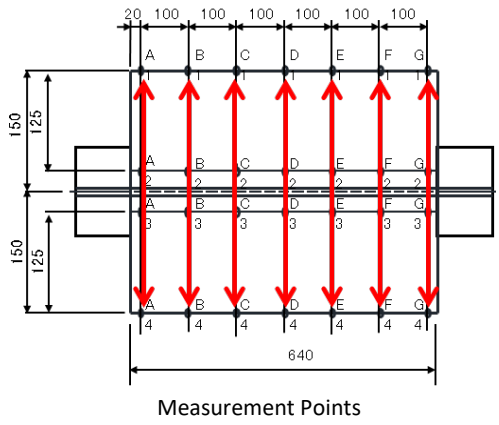
Welding Condition

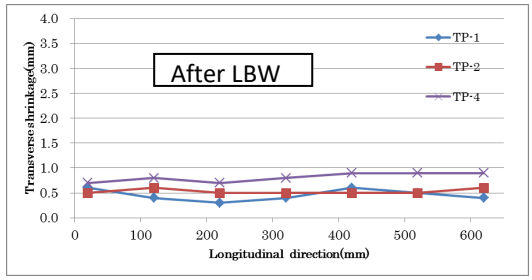
Laser power(kW)	24	28
Welding speed (m/min)	0.8	0.6
Position	Overhead	Flat

Mechanical Property

Item	Requirement	Test result
Tensile	≧900MPa	991～1167
Fracture toughness	≧180MPam$^{0.5}$	189～256

Fig. 6. Cross section and mechanical property of weld joint





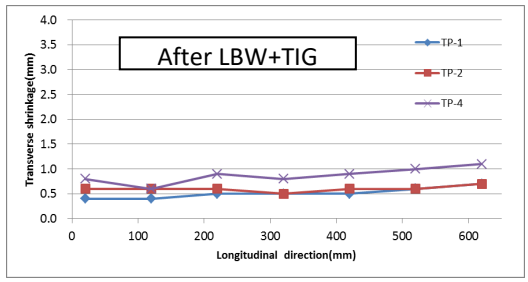


Fig. 7. Transverse shrinkage after welding along the longitudinal direction

Fig. 8. Over view of finished RP

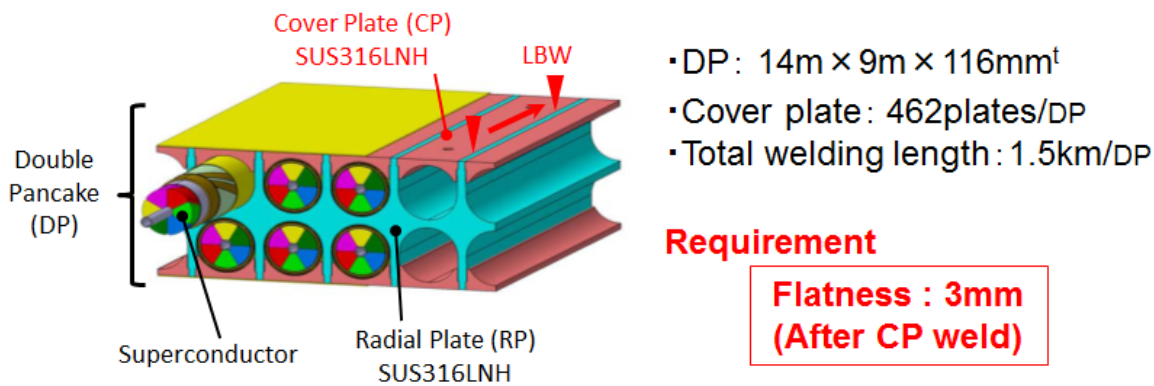


Fig. 9. Configuration of the DP

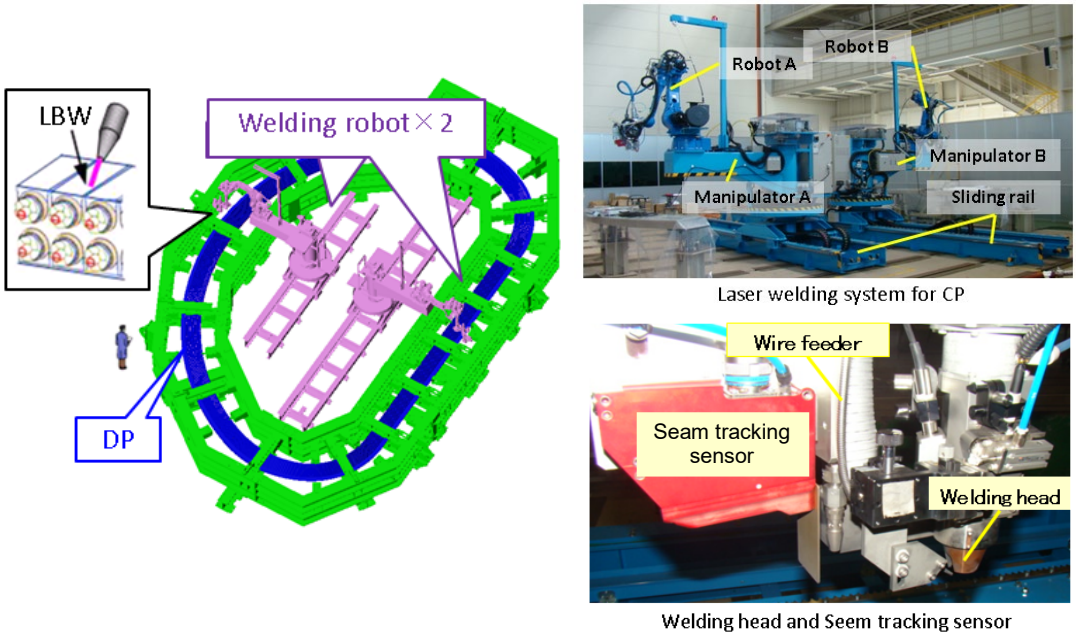


Fig. 10. Configuration of the CP welding system

<Welding Condition>

Laser Power (kW)	Welding Speed (m/min)	Wire Feeding rate (mm/min)	Position
2	1.0	300-750	Flat

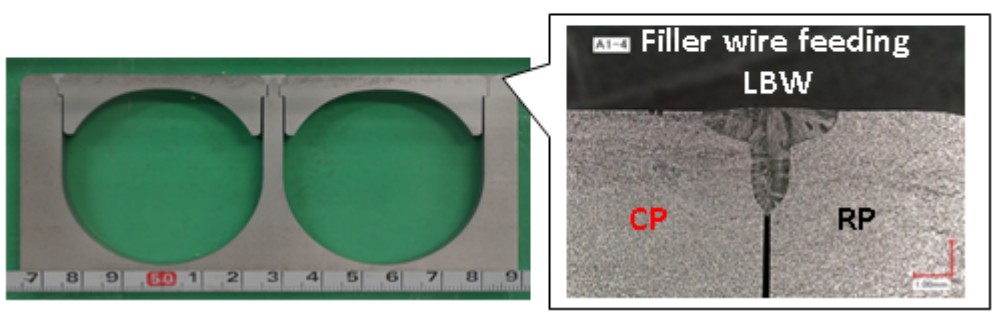


Fig. 11. Cross section of CP welding

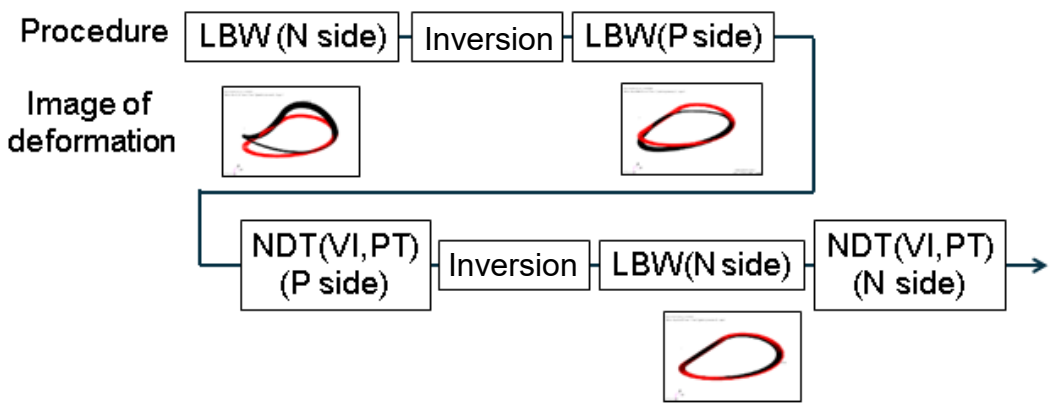


Fig. 12. The concept of welding procedure

Table 2. Comparison of out of plane deformation by the difference in welding procedures

case	Welding pass procedure	Final out of plane deformation (mm)
1	N side45%→P side100%→N side100%	+0.53
2	N side55%→P side100%→N side100%	+0.47
3	N side100%→P side100%	-2.30

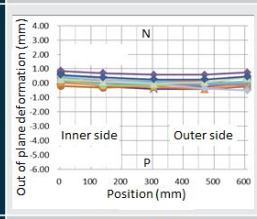
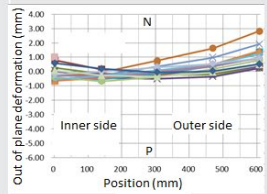
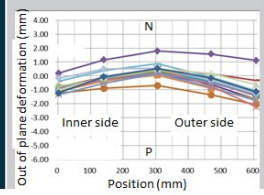
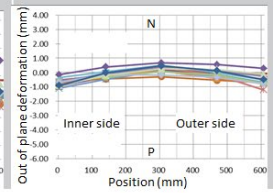
Step	Initial	After 55% N side welding
Flatness (mm)	1.51	3.49
Out of Plane Deformation		
Step	**After 100% P side welding**	**After 100% N side welding**
Flatness (mm)	3.99	2.03
Out of Plane Deformation		

Fig. 13. CP welding results by the selected procedure