Welding Distortion Control in Double Walled KSTAR Vacuum Vessel Fabrication

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1. Introduction

The KSTAR(Korea Superconducting Tokamak Advanced Research) vacuum vessel is designed to be a double walled structure made of 12mm thick 316LN stainless steel with a D shaped cross-section about 4 m height. Vacuum vessel was pre-fabricated in two parts, 180 degree and 157.5 degree sectors in toroidal direction to meet the transportation purpose. These two parts have to be welded on site with ±2mm allowable fabrication tolerances. 1/3 scaled mock-up model was used to estimate the welding distortion and to ensure the weld quality of vacuum vessel. Gas Tungsten Arc Welding(GTAW), which has been approved by procedure qualification test, was used during mock-up test and vacuum vessel site fabrication. Welding distortion could be managed by allowing for distortion in opposite direction, by applying high restraint using lots of strong backs, by controlling the welding heat input with symmetrical welding sequence. The integrity of the site welding joint was assured by radiographic test, ultrasonic test and leak test with helium detecting method.

2. Methods and Results

2.1 Mock-up Test

1/3 scaled vacuum vessel with 15 segment of 22.5 degree section was assembled in two parts, 180 degree and 157.5 degree as shown in Figure 1.

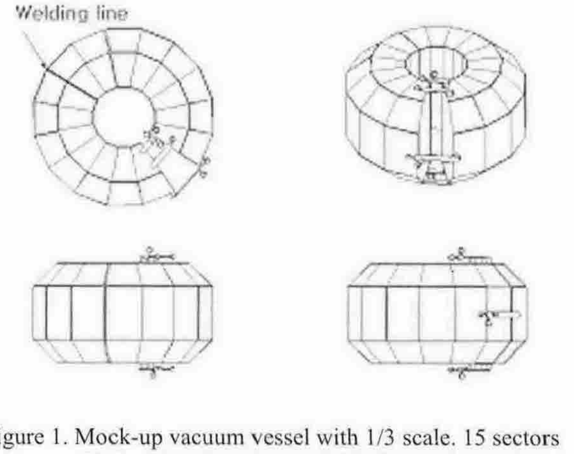

Figure 1. Mock-up vacuum vessel with 1/3 scale. 15 sectors was assembled and each sector had 22.5 degree in toroidal direction. Mock-up had 22.5 degree opening at the opposite side of the site welding line and these opening was used to measure the welding distortion with dial gage.

Three directions were measured with dial gage. X direction(horizontal), Y direction(toward the center in X direction) and Z direction(vertical) were interested.

About 5mm shrinkage deformation in X direction was measured at the outboard and 2.5mm shrinkage deformation at the center diameter show that there is a rotational deformation with the axis of outboard welding seam. This rotational deformation is due to 3mm gap at the outboard and 6.5mm gap at the inboard welding seam.

0.7mm misalignment in Z direction was measured and we may expect more than 2.1mm misalignment in 3 times larger vacuum vessel fabrication. More rigid restraint is required to minimize the Z direction deformation.

2.2 Allowance for Distortion

Due to 8mm gap at the inboard of vacuum vessel welding seam, more shrinkage deformation was expected compared with mock-up test of 6.5mm gap at the inboard of welding seam. 9mm shrinkage deformation(equals to about 3mm shrinkage at the inboard welding seam) was targeted out of 14mm allowance for distortion. 5mm allowance for deformation could be saved for the shrinkage deformation during 22.5 sector closing welding.

2.3 Restraint of the Vacuum Vessel Structure

To minimize deformation during first and second layer welding, 40mm thick strong back were welded

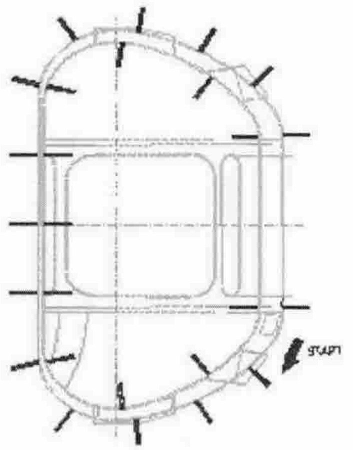

Figure 2. Strong back location

as shown in Figure 2. These strong back and symmetric welding sequence were very effective to control Z direction deformation up to nearly zero. Strong backs were removed after two layer welding except four strong backs near toroidal ring near outboard welding seam to allow rotational welding deformation with pivot at the toroidal ring.

2.4 Welding Sequence

Two welders welded the seam simultaneously according to welding sequence map to obtain balanced heat input. By keeping welding sequence it could be possible to control the welding deformation with effectiveness. Welding current and welding speed were also controlled at each layer.

2.5 Welding Distortion Result

Figure 3 shows the deformation result in X direction. Four different locations were measured including outboard and center diameter location. Two locations were also measured in vertical location, high and low location. 8.74mm shrinkage was obtained at the outboard location and this value was very close to the expected 9mm shrinkage. Figure 3 shows that there is a rotational deformation and lateral movement in X direction because of the deformation at the center diameter, about 5.5mm, is larger than the half of the outboard shrinkage deformation, about 4.5mm.

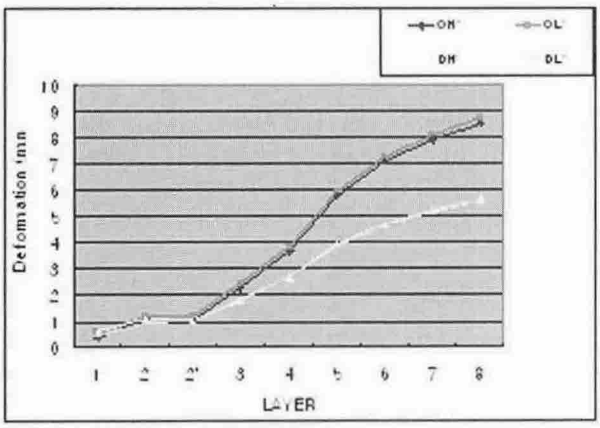

Figure 3. Welding deformation was measured at the outboard(O) of the 22.5 degree opening and at the center diameter(D) of the vacuum vessel. 2' was measured after removing the strong back restraint.

2.6 Weld Quality

Radiographic test was performed for the whole length of weld seam, inner shell joint and outer shell joint. Ultrasonic test was also performed for the suspected area by radiographic test. Due to back plated welding joint, some area was confirmed by UT.

Helium leak test at the vacuum condition showed no leak at the site welding seam.

Figure 4 shows the vacuum vessel without 22.5 sector(called sector 3) after seam welding.

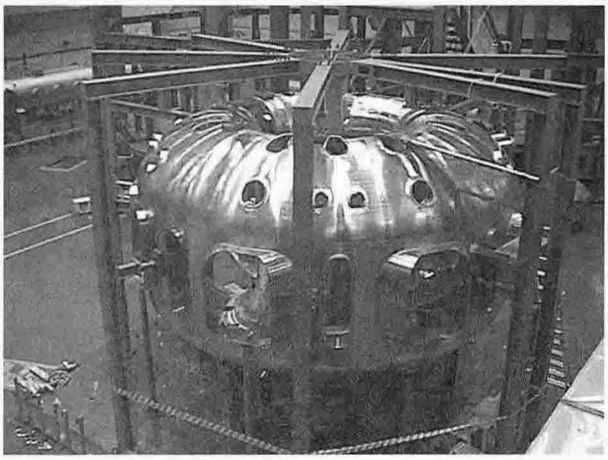

Figure 4. Overview of vacuum vessel after seam welding.

3. Conclusion

Vacuum vessel 180 degree sector (sector 1) and 157.5 degree sector (sector 2) have been successfully welded by controlling the welding deformation. Vertical direction deformation was almost zero and horizontal deformation(shrinkage) at the outboard was about 9mm as expected.

1/3 scaled mock-up test with 12mm thick stainless steel was useful to expect the welding deformation. Among various techniques to minimize welding deformation, allowance for deformation in opposite direction was very efficient in order to meet the tight fabrication allowance.

The integrity of the site welding joint was proved by non-destructive tests and helium leak test.