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Study of Weld Joints Qualification as Per ASME Code: SCRF Cavity, a Case Study

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Abstract – Efforts are on-going towards development of Superconducting RF cavity manufacturing technology at RRCAT. The aim of fabrication of prototype cavity is to gain experience in this highly specialized technology. The SCRF cavities are made of high purity niobium and joined by Electron beam welding.These welded joints are required to qualify as per the code, Section IX which covers welding and brazing qualifications. Niobium being a non-code material as per ASME Section II, Part D, it requires special condition to qualify as per Section VIII, U-2(g). This paper involves a case study being carried out for qualification of some of niobium weld joints for SCRF Cavity. The paper aims to describe various requirements for weld joint design, preparation of related documents like WPS, PQR, preparation of test coupon and welding. The paper will also describe initial testing done and test results.

Keywords— ASME BPVC, SCRF, Niobium, Electron Beam Welding, Testing of Welded Joints.

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1. INTRODUCTION

Efforts are on-going towards development of Superconducting RF cavity manufacturing technology at RRCAT. They are key component for the particle accelerators. The SCRF cavity made of Niobium falls under the category of external pressure vessel operating at cryogenic temperature. In the present paper the main area of focus is qualification of welded joints of the cavity satisfying the code.

The cavity design that satisfies level of safety equivalent to that of a pressure vessel code is affected by the use of non-code material (niobium). It requires special condition to qualify as per Section VIII, U-2(g). For such cases, the examination of the weld sample for each joint with Tensile testing, Guide Bend test and Microscopic examination is done to assure a level of safety equivalent to that of ASME codes [1]. In this context a study is carried out to ensure the level of safety for various weld joints of SCRF cavity.

2. REVIEW OF JOINTS

The weld joints are classified in categories A, B, C and D as specified in ASME Section VIII, UW-3. The different categories of joints are shown in Fig. 1 [2].

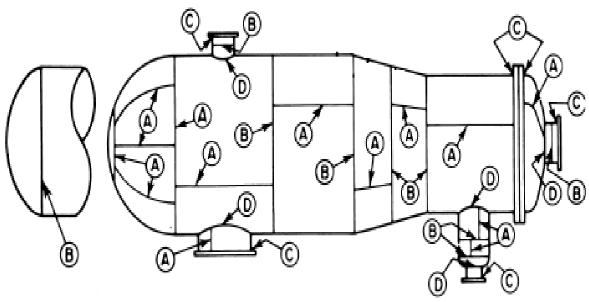

Fig. 1 Types of joints

The SCRF cavity for the case study has been reviewed to categorize its joints as per code. The joints of different thickness in the cavity along with joint category are shown in Table I [2].

Table VIII Types and category of weld Joints

Joint Thickness (mm)	Material	Weld Type	Joint category	Joint Efficiency
2	Nb-Nb	III	B	0.6
2.5	Nb-Nb	III	B	0.6
3.4	Nb-Nb	III	B	0.6
4	Nb-Nb	III	A	0.7

Joint Thickness (mm)	Material	Weld Type	Joint cate gory	Joint Efficiency

Weld-type- I - Full Radiograph, II – Spot Radiograph, III – No Radiograph.

Joint category- A- Longitudinal weld joints within the main shell, B- Circumferential weld joints within the main shell, C- Welded joints connecting flanges to main shell, D- Welded joints connecting communicating chambers to main shell.

In this paper the qualification of weld joints of 4 mm thickness in the SCRF cavity as per ASME section IX will be considered. The niobium welded joints will undergo testing as per the safety requirements. The testing will be performed as per the welding procedure specification and performance qualification record as specified in QW-100. The testing is carried out at room temperature and by establishing a relation its safety for actual application at cryogenic temperature will be approved.

3. WPS, PQR AND WPQ

As per ASME Section IX, QW- 100, the purpose of the Welding Procedure Specification (WPS) and Procedure Qualification Record (PQR) and Welder Performance Qualification (WPQ) is to determine that the weldment proposed for construction is capable of having the required properties for its intended application.

The WPS for EBW is prepared as mentioned in QW-260 is a written document that provides direction to the welder or welding operator for making production welds in accordance with Code requirements. WPS specify the conditions (including ranges, if any) under which welding must be performed. WPS is prepared as mentioned in QW-482.

As mentioned in QW- 483, Procedure Qualification Record (PQR) is prepared which documents what occurred during welding the test coupon and the results of testing of the coupon. The PQR shall document the essential variables and other specific information identified for each process used during welding the test coupon and the results of the required testing.

As per QW- 100.1, In Welder Operator Performance Qualification (WPQ), the basic criterion is to determine the ability to deposit sound weld metal and to operate the equipment. Electron beam welding being a computer automated operation welding system, the preparation of WPQ is omitted.

4. PREPARATION OF WELD SPECIMEN

The weld specimens are prepared of niobium plates of dimension 300 mm x 80 mm, 4 mm thick, as shown in Fig. 2.

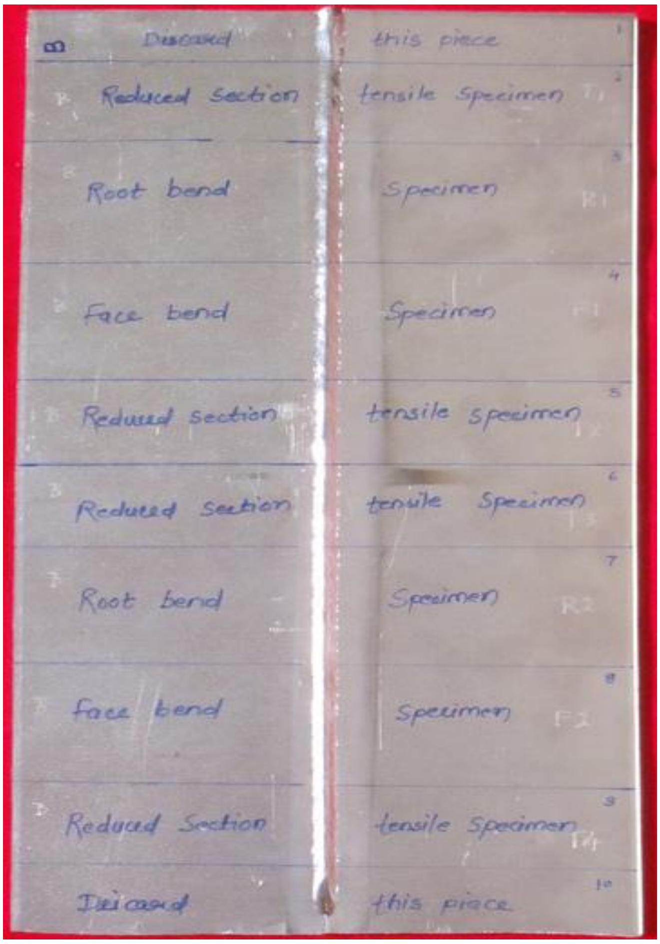

Fig. 2 Weld plate before cutting

The two plates are welded as per QW-121.1 in 1G position along the length with full penetration without backing strip, as per weld joint Type-A, using electron beam under vacuum environment to simulate the actual welding condition of the cavity. All the welding process details are recorded in WPS. The detailed WPS document could not be included in the paper due to paucity of space.

As mentioned in QW- 463.1(a) for plate less than 19 mm thickness the various test specimen preparation guide is mentioned shown in Fig. 3. The welded plate was machined for obtaining the parallel surfaces on both sides.

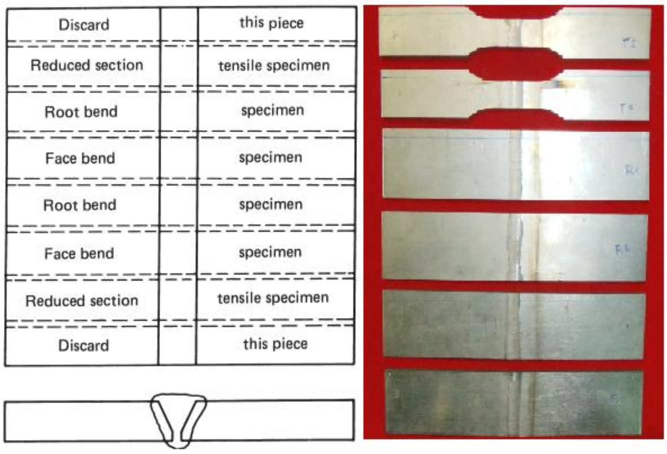

Fig. 3 Weld plate after Cutting

Total six weld coupons are cut from weld plate; two for tensile test, two for root bend test and two for face bend test and others for micrographic examination as shown in Fig. 3.

5. TESTING

The welded test coupons of 4 mm thickness are tested and details are documented in PQR. The PQR is not mentioned due to paucity of space.

5.1 Visual Examination

The visual examination of the weld coupons is carried out on the surface of weld coupons as per QW- 194. The surfaces of weld coupons are found to be free from cracks. The weld joint has shown full joint penetration with complete fusion of weld bead. The results obtained by the visual examination are found to be acceptable.

5.2 Tensile Test

The mechanical tests are carried out as per QW-141. As per QW- 150, tensile testing of the weld coupon of dimension 160 mm x 26 mm and 4 mm thick is carried out at room temperature.

Fig. 4 Tensile test specimen after testing

Fig. 4 shows the weld specimen after testing. The obtained value of testing is compared with the established material properties as shown in Table II. As per the acceptance criteria mentioned in QW-153, we can see that the test results satisfy the parent material values.

Table IX Established properties of niobium

Material	Property	Material
	Yield Strength (MPa)	**Ultimate Strength (MPa)**
	300 K	300 K
Parent Niobium	>50	Parent Niobium
Welded Niobium Sample	52	Welded Niobium Sample

The Table III below shows the minimum allowable stress values at 300 K for niobium [3], [5].

Table XI Allowable stresses

Yield Strength	Tensile Strength	ASME Sec VIII Div.1
		Allowable stress for non-ferrous metal
		Take the smaller of
		2/3*Y.S
(MPa)	(MPa)	(MPa)
38	130	25

From Table III, the minimum allowable stress for the joints in the cavity is 25 MPa. We can say that the weld joint strength is within the safe limit, hence found acceptable.

5.3 Guide Bend Test

The guide bend test is carried out for determining the ductility of the weld joint as referred in QW- 160. The jig is designed as per QW-466.1 as shown in Fig. 5 and fabricated. Specimens for face bend test and root bend test are prepared as per QW- 462.3 (a). Both the face and root bend test are performed on sample and bend sample is shown in Fig. 6.

As per QW-163, the analysis of specimen is done, the specimen is found free from any open discontinuities and cracks around the weld area on the convex surface and found to be acceptable.

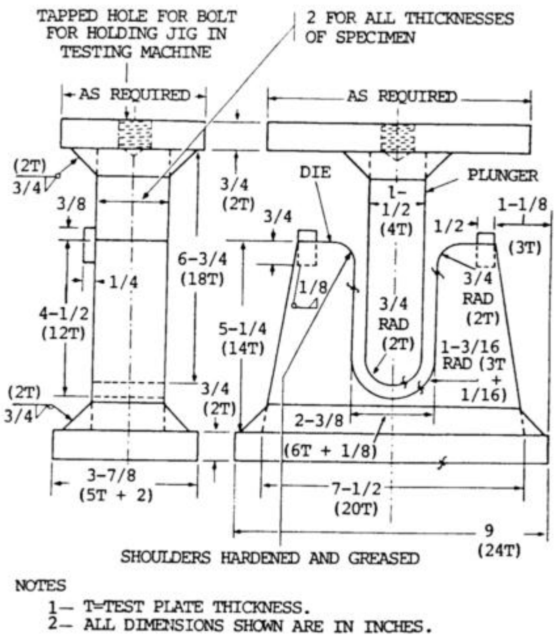

Fig. 5 Guide bend test jig

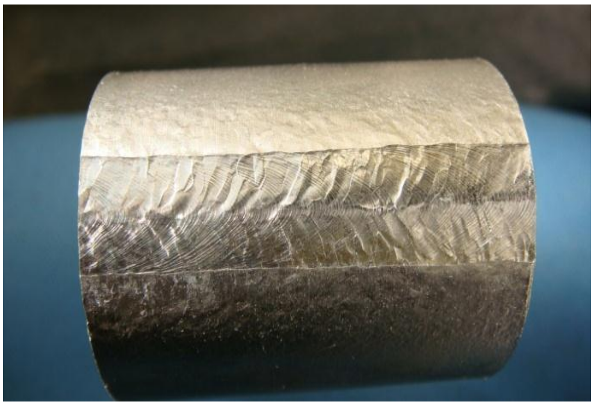

Fig. 6 Guide bend specimen after testing

5.4 Micrographic Examination

The micrographic examination of the welded joint is carried out, as mentioned in QW-183, on optical microscope. The samples are prepared by EDM cutting, then polished followed by etching [4]. The microstructure of the weld sample can be observed as shown in Fig. 7.

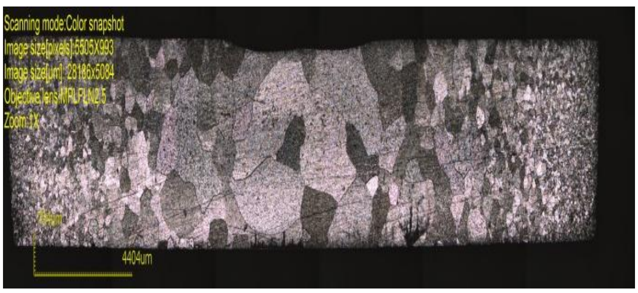

Fig. 7 Micrographic examination

The result shows that the weld sample has a complete fusion with no evidence of cracks or defects on the full cross section of weld joint. The grain growth in the HAZ can be seen prominently.

5.5 Radiographic Examination

No radiographic examination of welded joints as per Section VIII UW-11 is required when the vessel or vessel part is designed for external pressure only, or when the joint design complies with UW-12(c). Since SCRF cavity is an external vessel, radiographic examination is not required and so derating factor as specified in UW-12(c) is considered [2].

6. CONCLUSION

Various requirement of weld joint qualification in SCRF cavity have been studied for its qualification as per ASME code. Required WPS and PQR for proper documentation are prepared. Weld test coupon has been prepared and subjected to various tests. The visual inspection of the welded samples is satisfactory. The Yield strength of the weld sample is 52 MPa which is greater than 25 MPa. Ultimate strength of weld sample is 124 MPa. The guide bend test has no evidence of discontinuities and crack around the weld area. The micrographic examination results are also satisfactory. On the basis of test results, we can say that the weld joint meets the requirements as per ASME code.

7. DISCUSSION

The testing results of the Nb welded joints carried out at 300 K are found to be satisfactory. Further mechanical testing of the weld sample at cryogenics operating temperature is also required [6]. The testing at 4K requires a dedicated and special test setup with LHe facility. However, the testing at 77 K is an alternative which can be done using LN_2 setup, which is comparatively easier to establish. The Yield strength property of niobium at 77 K is ~ 80% of the yield strength at 4K [3], [5]. A correlation of 300 K test and 77 K test can be used to extrapolate the results at 4K [6].

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