Mock-up Tests for Multiple Welds of Zircaloy Specimen

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1. Introduction

Zirconium alloys are widely used in the nuclear industry because of their combination of good nuclear properties (low neutron capture cross section), good corrosion resistance and good mechanical properties. For these reasons, the core region and surrounding heavy water vessel (HWV) of research reactors are fabricated from the zirconium alloy. The mechanical properties of it are well known and codified in the relevant standards.

The purpose of this paper is to verify the integrity of the multiple welding by using the Zr-4 weld coupons. The coupons of repetitive welding and original material, made by the same procedures according to the ITP (Inspection and Test Plan) and relevant codes, have been tested for tensile, bending, macro-examination, micro-examination, micro hardness, and corrosion. According to the IPT and ASME [1], tensile and bending test are mandatory as a go / no-go criteria but the other material tests and examination are not mandatory i.e., only for reference. However the non-mandatory test and examination performed to compare the original weld and the repetitive repair weld.

2. Inspection and Test Plan

Mock-up tests for the Zr-4 were performed in accordance with the ITP which consists of test processes, type of tests, and acceptance criteria. The major processes of the ITP have proceeded in the sequences as shown in Fig.1.

Coupon A : The coupon to be welded once
Coupon B : The coupon to be welded five times

3. Test Specimen

The base metal(Zr-4 ASTM B352 R60804, Plate 20t) and filler metal(Zr-4 ASTM B351 R60804, Wire Φ2.4) used for the mockup test was the same material as the production item. It was verified by inspectors through checking of actual base and filler metal and its CMRTs.

The welding of the Zr-4 coupon was performed using the Gas Tungsten Arc Welding, in which welding torch was supplied with a argon Gas. In addition, supplementary shielding jig was used for preventing the following weld beads from an ambient air until the temperature of the weld bead is less than 200 °C. All the welding variables were inspected and recorded during the welding.

For the coupon B, 5 times excavations and 5 times of the repair welding was performed in accordance with the diagram in Fig. 2, which describes various kinds of HAZ zones so that the mockup test could verify the worst case of the production welding.

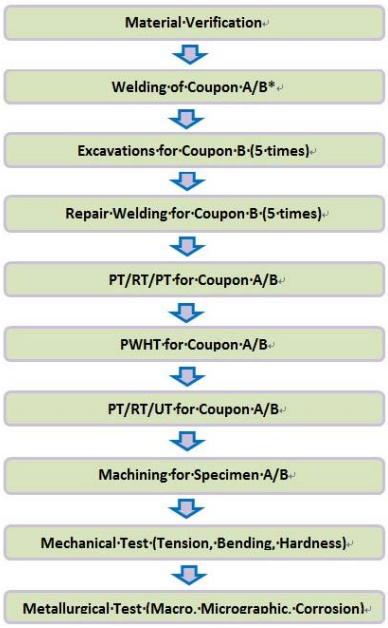

Fig. 1. Major processes of the ITP

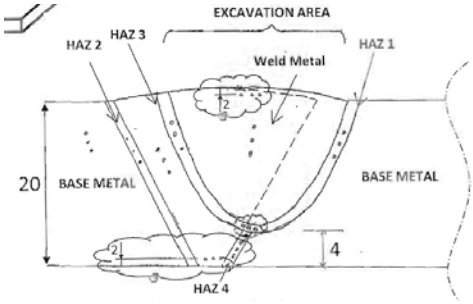

Fig. 2. Diagram for Excavation

The NDE of PT/RT/UT, both before and after post-weld heat treatment (PWHT), was performed to make sure that the welding coupon does not have any weld defects. The PWHT for the welding coupon was performed in accordance with the same procedure as the case of the production.

Two specimens for tensile and bending test were made for the welding coupon A and B in accordance with the ASME IX, QW 150 and QW 160 [1]. One specimen for the macro-graphic and micro-graphic observation was made for coupon A and B. Three specimens for the corrosion test were made for welding coupon A and B respectively.

4. Mock-up Tests

Most Tests have been performed at KTR (Korea Testing & Research Institute) where is an authorized government agency to conduct the tests. The corrosion test was carried out at KAERI which has many research experiences and test facilities of the Zircaloy.

4.1. Tensile Test

According to ASME Section IX QW-150/153, the specimen shall have a tensile strength that is not less than the minimum specified tensile strength (385 MPa) of the base metal. The tensile test result clearly indicated that the soundness of the weld zone in both coupon A and B was very fine. The measured tensile strength of all tested specimens was more than 500 MPa, which is much higher than the acceptance criteria.

4.2. Bending Test

The aim of bending test is to evaluate the soundness of the weld part of Zr-4 against the side bending deformation. In accordance with ASME Section IX QW-160/163, the soundness of the weld zone in both coupon A and B was very fine. Any open discontinuity (such as crack and convex surface) was not observed after the bending. In addition, no difference was shown at comparison of the surface appearance between the coupon A and B,

4.3. Macro-graphic Examination

Visual examination of the cross section of the weld metal and the HAZ shall show complete fusion and freedom from cracks according to ASTM E381[2] and ASME Section IX QW-183 for fillet weld, but it is an examination on the groove weld only for reference. After the observation of the cross-sectional direction in magnification of x 10, any defect such as pores or cracks was not observed at the weld zone or the HAZ in both coupon A and B.

4.4. Micro-graphic Examination

The weld defects would be observed in the micro-graphic examination according to ASTM E407 [3] and ASME Sec. III NC-5320, 5330 [4]. From the micro-graphic observation for the cross-sectional direction in magnification of x 200, any defect such as micro-pore, micro-crack, or unusual precipitate was not observed at the weld zone and the HAZ in both coupon A and B specimens. The formation of the Widmanstatten structure was observed at the weld zone in both coupon A and B. The mechanical strength or hardness would be increased by the formation of this structure.

4.5. Macro-Hardness Test

The small range variation of the hardness can be measured by the micro-hardness test method according to ASTM E384 [5]. The micro-hardness value is used to evaluate the brittleness of the Zr-4 and the maximum hardness shall be less than 260 Hv in accordance with RCC-MRx RS 3434.4(EU). The maximum value in both coupon A and B specimens was lower than 260 Hv, which was measured in the weld zone. Thus it is said that the hardness value measured will not cause any problem in the future.

4.6. Corrosion Test

Specimens of zirconium are exposed to the high pressure steam at the elevated temperatures (400°C) for 72 hours in ASTM G2 [6]. The weight gain of specimen shall be not more than 22 mg/dm^2 after the planned test in accordance with ASTM B352 [7]. The corrosion weight gains of all specimens were measured ranges which are far less than the acceptance criteria. All the samples had a same corrosion behavior in the test condition of 400°C steam environment in pressure of 1500 psi for 72h. Specimens after corrosion tests exhibited a continuous black without an abnormal evidence of white or brown. And this behavior was same in both original weld and repair weld parts.

5. Conclusions

From the results of the six (6) tests specified in the ITP, the weld specimens of both coupon A and B showed good reliable performances and no adverse effect on the material properties as well as the mechanical strength. It is concluded that the multiple weld specimens for Zr-4 have not shown any deficiencies in its mechanical strength or material properties. All the quantitative test results are satisfied with the acceptance criteria.

Acknowledgements
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REFERENCES

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[6] ASTM G2, S.T.M. for Corrosion Testing of Zirconium
[7] ASTM B352, S.S. for Zirconium for Nuclear Application