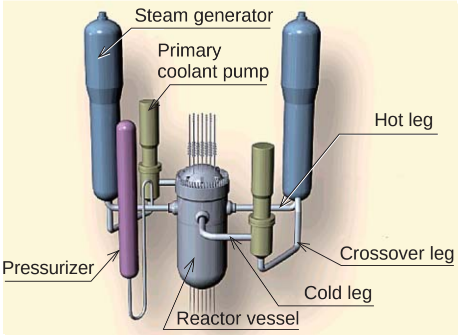

Field Application of the Cladding of the PWR Reactor Vessel Outlet Nozzle

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1. Introduction

It is already known that 600 alloy welds used on primary cooling systems of PWR are susceptible to Primary Water Stress Corrosion Cracking (PWSCC) when allowed to remain exposed to high tensile stresses for an extended period. The performance of inspections on the 600 alloy welds is therefore mandatory. A U.S. nuclear power plant experienced an incident in which fissures originating from PWSCC developed in a 600 alloy welds between the reactor vessel (**Fig. 1**) and the RCS (Reactor Coolant System) pipe grew and broke through the metal wall, causing primary coolant leakage. The residual stress generated by major repair welding performed on the affected section is considered to have influenced that accident. Because the factors behind the occurrence of cracks consist of "material," "stress," and the "environment," preventive maintenance can be achieved if any one is eliminated.

Internal face cladding is a technique whereby the PWSCC contributory factor linked to "material" is removed by depositing 690 alloy cladding on the inner surface of a dissimilar metal joint (600 alloy welds) between the nozzle and safe end, to form a wetted part. Since post weld heat treatment (PWHT) is hard to carry out on actual installations, we made it possible to apply the said technique to operational equipment by establishing a suitable temper-bead welding method.

2. Work plan

In applying internal surface cladding to the reactor vessel outlet nozzle, we produced a joint profile which did not allow cladding to protrude into the pipe interior in order to secure reactor coolant flow pass and inspection access to the area which was worked on (**Fig. 2**). To carry out cladding – because although the base metal of the nozzle is low-alloy steel, requiring PWHT, the safe end built with austenitic stainless steel is likely to become sensitized when undergoing such treatment – we devised a 3-layer temper-bead technique, allowing PWHT to be eliminated, to permit its application to real installations. Also, as personnel have to work inside the reactor vessel where they are prone to doses of high-radiation, a platform incorporating a radiation shield 150 mm in thickness was placed in use (**Fig. 3**).

3. Verification test

3.1 Establishment of a temper-bead welding technique

Temper-bead welding is a technique which tempers Heat Affected Zone (HAZ) of low-alloy steel, which has been subjected to welding heat, by utilizing subsequent passes to allow it to recover toughness and ductility. The soundness and performance of welds produced by this method were verified through the use of a destructive mechanical test (tensile, bending and impact), and a cross-sectional macrostructure examination and hardness test (**Fig. 4**).

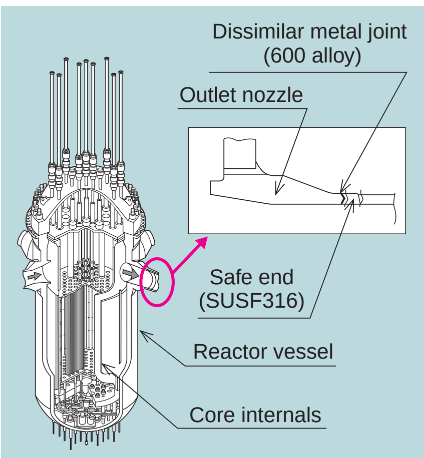

Fig. 1 Reactor vessel outlet nozzle

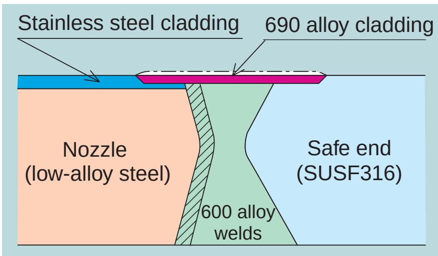

Fig. 2 Profile of clad welds

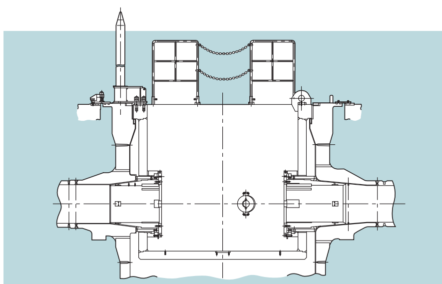

Fig. 3 As-installed view of shielde platform

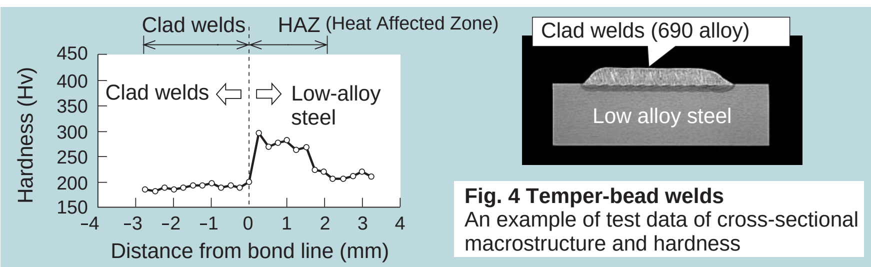

Fig. 4 Temper-bead welds
An example of test data of cross-sectional macrostructure and hardness

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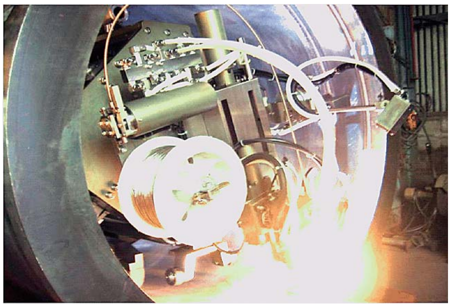

Fig. 6 Remote automatic TIG weld testing performed on inner surface of outlet nozzle mock-up

Fig. 7 Decontamination device testing performed on inner surface of outlet nozzle mock-up

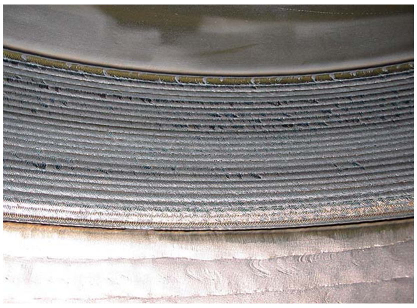

Fig. 9 Actual welding surface (before finishing)

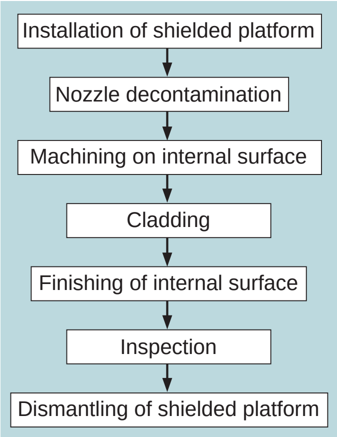

Fig. 5 Work procedure

Fig. 8 Installation shielded platform in R/V

Especially in light of the need to avoid delayed cracking, we ascertained that the HAZ of low alloy steel had been tempered to a hardness of less than Hv350. In addition, efforts were made to minimize impurities in the welding material and select optimum welding conditions, so that weld defects could be precluded and quality welding could be accomplished.

3.2 Verification of equipment

Fig. 5 shows the work procedure that was followed. We developed and introduced remote-controlled equipments to carry out the important steps such as decontamination, machining, cladding or inspection, and ensure operability in advance by utilizing a mock-up of the reactor nozzle. **Fig. 6** shows testing taking place on a remote automatic TIG welding equipment placed inside the mock-up of reactor vessel outlet nozzle. When conducting the work in the plant, physical decontamination was applied to the internal surface of the nozzle, besides the use of the shielded platform, to ensure good workability. The physical decontamination employed vacuum blasting from a machine head, which rotated in the peripheral direction of the nozzle and helped attain a high blasting medium recovery (over 99%) (**Fig. 7**). As the blasting grid material, stainless grit, which did not adversely affect the plant's water quality levels, was used instead of the more commonplace aluminum variety, accomplishing an identical decontamination effect.

4. Application to actual installations

Internal surface cladding was initially applied to the reactor vessel outlet nozzles at the Shikoku Electric Power Company's Ikata Unit 1 in November, 2004. To carry out the work, we took advantage of the core internals replacement then performed in that plant, as it involved the interior of the reactor vessel being exposed to the air (**Fig.8**).

The work proceeded simultaneously on two nozzles and took about 25 days to complete (the duration of time it occupied the inner space of the reactor was 22 days). A decontamination factor (DF) within the range 20 to 30 was attained, with radiation doses within the reactor nozzle reduced to the order of 2 mSv/h. None of the inspections conducted after the welding operation, which included visual inspections, dye penetrant testing, and ultrasonic examination, disclosed any defect in the work, and pressure/leak testing was also successfully completed. For reference, Fig. 9 represents what the welded part looked like. The work was carried through, with the total radiation dose rate restricted to 0.3 persons-Sv, roughly 1/3 of the predicted value.

5. Conclusion

To address the trend for nuclear power plants to remain operational for longer and ensure their continued operational safety, we will press ahead with the development and application of residual stress improvement, instrument replacement technology and actual installations of the cladding technique which are discussed in the present paper.

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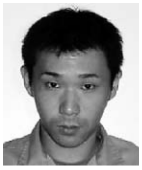

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