# §15. Evaluation of Bonding Strength for a Dissimilar-metal Joint between 9Cr-ODS and JLF-1 by Four-point Bending Tests and Finite Element Method Simulation

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9Cr-ODS is a kind of advanced reduced activation ferritic/martensitic (RAFM) steel with high density of oxide nano-particle dispersions. Because of its excellent high temperature strength and irradiation resistance, it can be used partly as structural materials in fusion blanket systems to increase the allowable application temperature by about 150°C. Electron beam welding (EBW) is a good bonding technique with merits of high accuracy and high bonding quality. In this study, it was utilized to bond the dissimilar-metal joint between 9Cr-ODS and a conventional RAFM steel, JLF-1.

The chemical compositions are Fe-9.08Cr-0.14C-1.97W-0.23Ti-0.29Y-0.16O-0.013N for 9Cr-ODS and Fe-9.00Cr-0.09C-1.98W-0.20V-0.083Ta-0.015N for JLF-1, respectively. Dissimilar-metal butt joint between 9Cr-ODS and JLF-1 steel plates with a thickness of 5mm were fabricated by EBW with an output of 15mA and 150V, and a welding speed of 2000mm/min. The electron beam position was at the butting position for the plates. Post-weld heat treatment (PWHT) was carried out at 780°C for 1h for tempering for the EBW joint to relieve hardening of the weld metal (WM) and heat-affected zones (HAZs). Tensile tests were carried out for the joint before and after PWHT. However, because the bonding strength is higher than the strength of JLF-1 base metal (BM), the specimens always fractured at JLF-1 BM during tensile tests. The bonding strength cannot be obtained in this case. Thus symmetric four-point bending tests which can concentrate the stress precisely at the WM were executed to get the bonding strength of the joint at room temperature (RT) and 550°C. By elastic deformation theory, the bonding strength can be calculated by the formula,

$$\sigma_{\text{elastic}} = \pm \frac{3}{2}\frac{P}{H}\frac{S-L}{B^2} \qquad (1)$$

Where, P is the load applied on the upper jig. H and B are thickness and width of the bending specimen, i.e. 1.5mm. S and L are outer span 12.5mm and inner span 5mm, respectively. However, the formula is only available for the calculation in elastic phase (< 0.25% strain). Above this, it is not applicable any more. Thus finite element method (FEM) was used to simulate the large plastic deformation behavior during four-point bending tests, to get the bonding strength of the joint. 2D model was constructed in the software ANSYS. Element size of the joint and the contact areas between BMs and jig was 0.1 mm. Friction coefficient between BMs and jig was fitted by simulation for bending behavior on BM-single-material specimens. According to the coincidence of the displacement-load curves of the upper jig between simulation and experiment, the friction coefficient was determined as 0.3 for the contact between 9Cr-ODS and jig at RT, 0.5 and 0.55 between JLF-1 and jig at RT and 550°C, respectively.

On the simulation for the dissimilar-metal joint, by inputting the friction coefficient above obtained, the displacement-load of the upper jig is obtained, which is almost coincident with the experiment with deviation about 10N, as shown in Figure 1 (a) at RT and (c) at 550°C. The maximum displacement of the bottom center of the specimen is 1.68mm at RT and 2.21mm at 550°C, which are almost coincident with, 1.69 mm at RT and 2.25mm at 550°C, the deformation of the specimens measured after the experiment. The simulation successfully calculated the stress distribution in the specimens up to strain of 20.0% at RT and 23.5% at 550°C. Figure 1 (b) and (d) shows the displacement-normal stress at the bottom center of the joint (in WM) at RT and 550°C. In the elastic phase, the yield stress is 538MPa at RT and 410 MPa at 550°C, almost coincident with that calculated by formula (1), 535MPa (RT) and 413MPa (550°C). The maximum stress applied to the weld metal of the joint is estimated as 854MPa at RT and 484MPa at 550°C. The bonding strength is estimated to be larger than these stresses. The FEM simulation successfully made better estimation for bonding strength than tensile tests and conventional analysis on bending tests with elastic deformation theory.

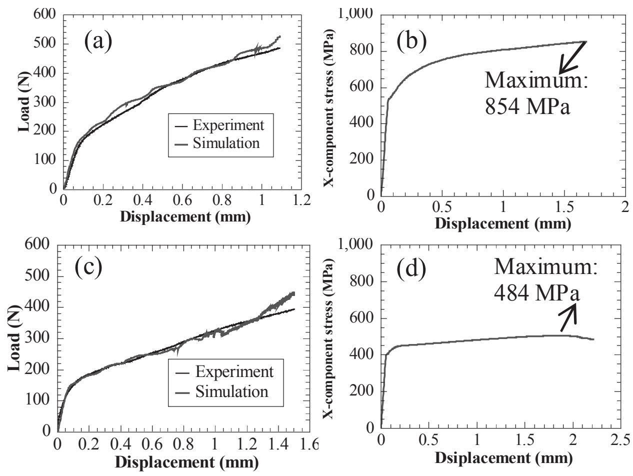


Figure 1 FEM simulation results for the EBW joint, (a) displacement-load of the upper jig at RT, (b) displacement-normal stress of the joint bottom center at RT, (c) displacement-load of the upper jig at 550°C, (d) displacement-normal stress of the joint bottom center at 550°C.