Fatigue failure behavior of Super304H welded joint at elevated temperature

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Introduction

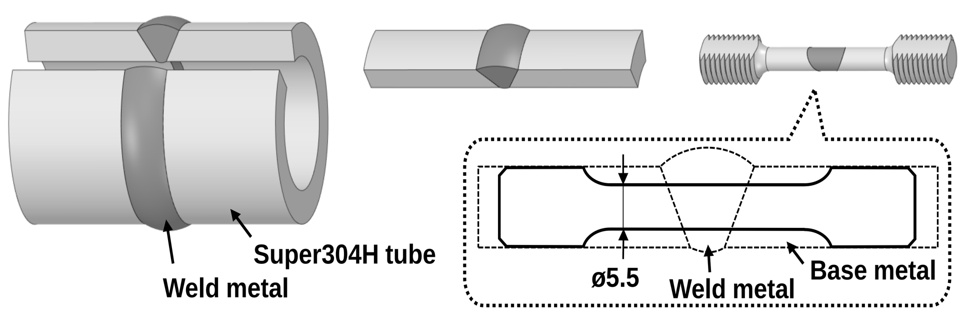
- Super304H is attracting great attention as a promising candidate material for heat exchanger tube at ultra-supercritical conditions, due to its desirable combination of superior thermal conductivity, corrosion and oxidation resistance, and creep properties.
- Heat exchanger tubes are used in various complex shapes to meet design requirements and improve thermal efficiency, and hence, the welding of Super304H tubes to other components is imperative. Welded parts, however, are known to be the most vulnerable sections, impairing strength, ductility, and creep and corrosion resistance.
- The mechanical properties of the Super304H welded joint, in particular its fatigue properties, are a key factor in ensuring the structural reliability.
- In this study, we explored the microstructural evolution of the base metal and weld metal of Super304H welded joints during fatigue deformation (i.e., thermal aging) at 600 ºC and their effect on the local mechanical properties of both weld regions.

Experimental method

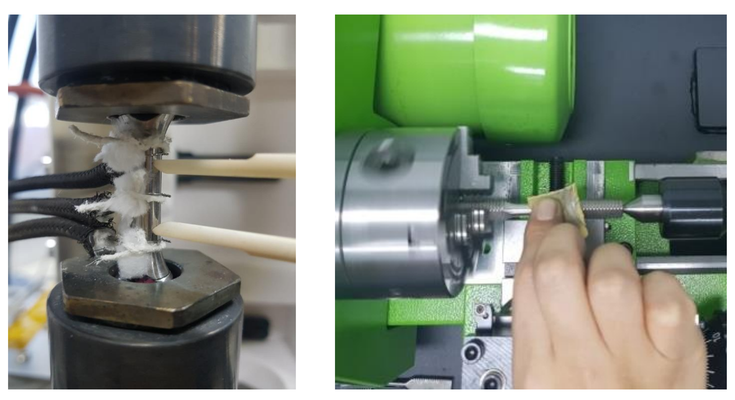
Materials

Material	Element (weight%)												
	C	Si	Mn	P	S	Ni	Cr	Mo	Cu	Nb	N	Al	B	Fe
Base metal (Super304H)	0.07-0.13	0.3	-	0.04	0.01	7.5-10.5	17-19	0.85-1.05	2.5-3.5	0.3-0.6	0.05-0.12	0.003-0.03	0.001-0.01	Bal.
Filler metal (T-304H)	Max. 0.13	0.90	3.50	0.03	0.03	15-18	17-20	0.7-1.3	2.5-3.5	0.80	0.05-0.25	-	-	Bal

High temperature low-cycle fatigue test



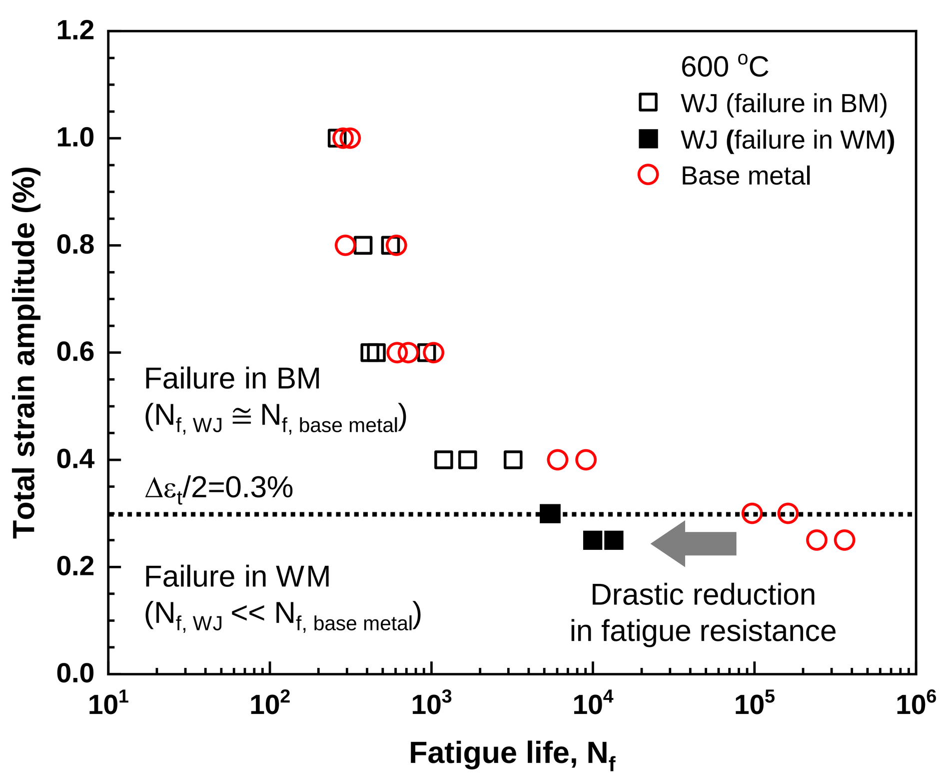
- Low-cycle fatigue test specimens were machined from Super304H welded tubes.
- The machined specimen included with base metal (BM), heat affected zone (HAZ), and weld metal (WM), where the WM was placed at the center of the gauge section.

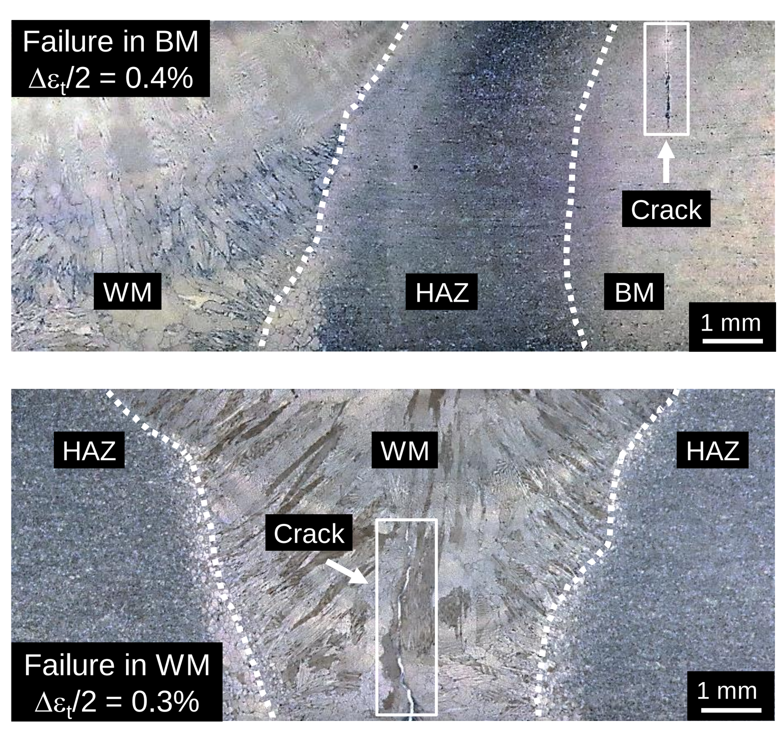


- Hydraulic material testing machine with a capacity of 100 kN (Landmark, MTS, USA)
- Fully reversed strain control mode with a triangular waveform
- Strain rate : fixed at 5 × 10^{-3} s^{-1}
- Total strain amplitudes : 0.25 ~ 1.00%
- Test temperature : 600 ºC

Results

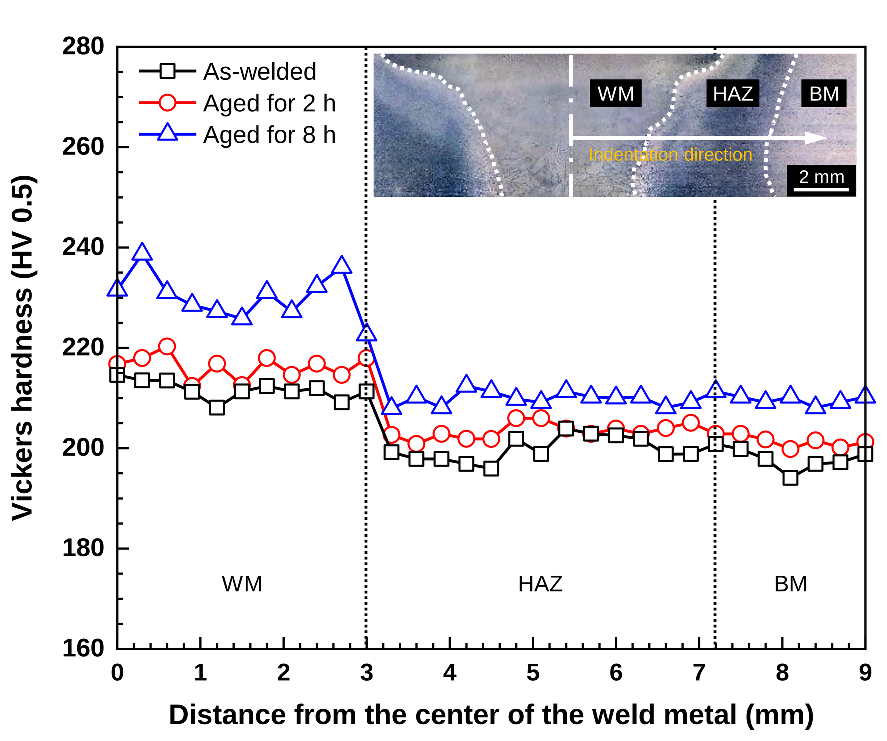
Fatigue resistance

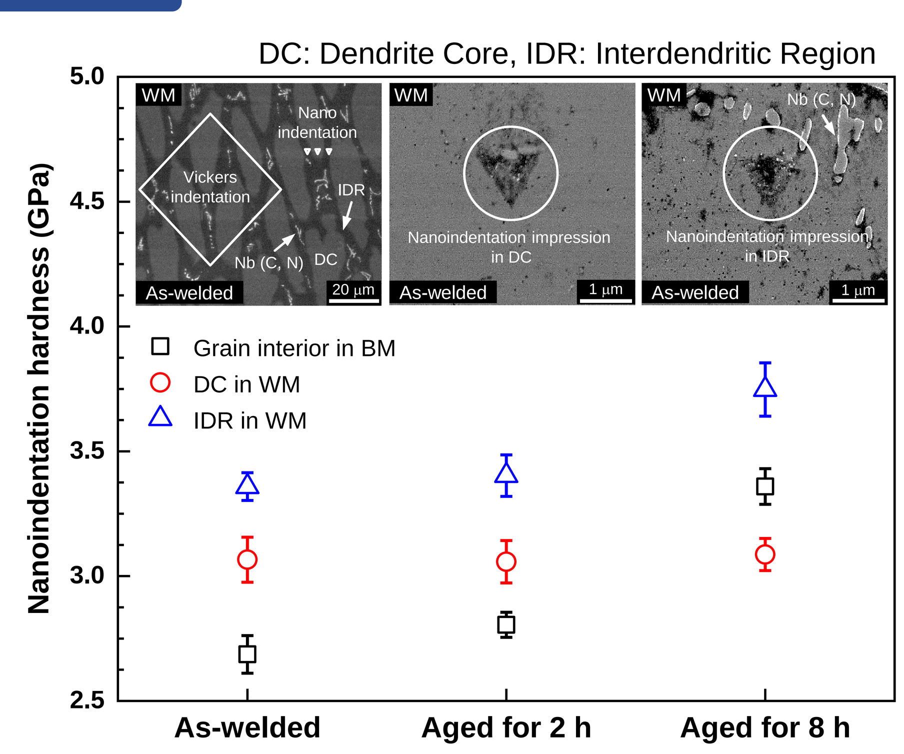




- Drastic reduction in the fatigue resistance of the welded joint as compared to that of the base metal as the strain amplitude reduces to less than 0.4%.
- Shift of the fatigue failure location from the base metal at high strain amplitudes of ≥ ~0.4% (Figure 1b) to the weld metal at low strain amplitudes of < ~0.4%.

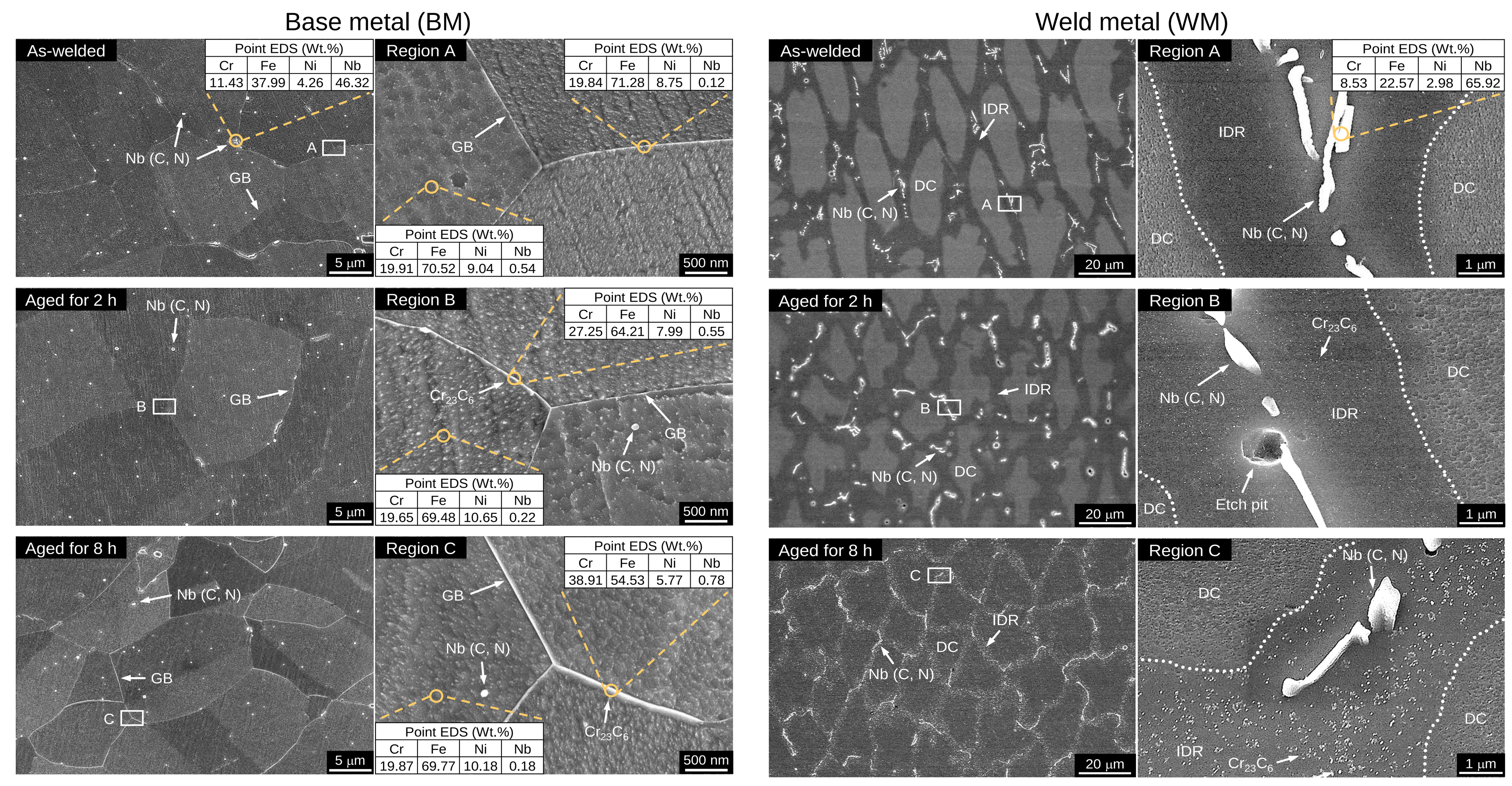
Local mechanical property and non-uniformity of deformation





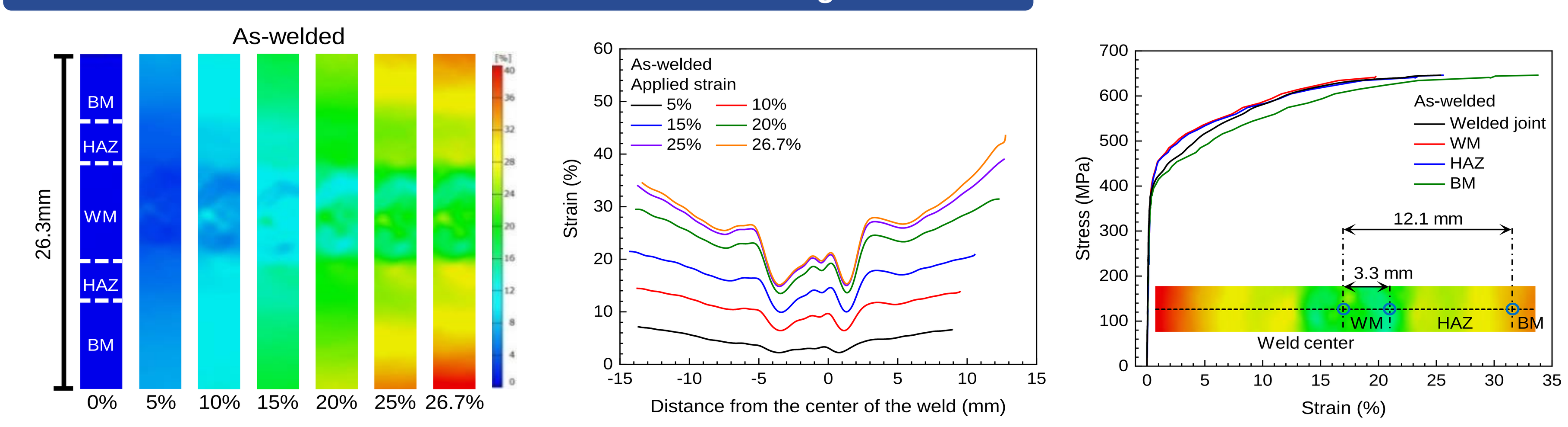
- According to the nanoindentation results, softest region in the welded joint is the base metal (grain interior) for the as-welded material; however, it shifts to the weld metal (dendrite core) for the material aged for 8 h.

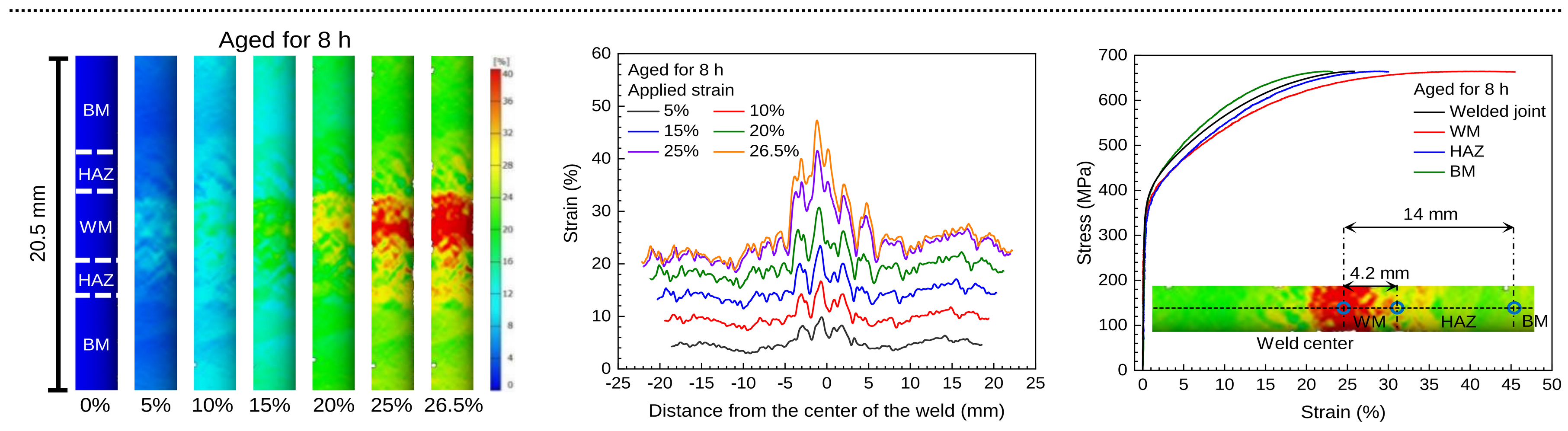
SEM micrographs (Microstructure evolution)



- With increasing fatigue test, $Cr_{23}C_6$ carbides precipitated in the interdendritic region of the weld metal and at the austenitic grain boundary of the base metal and Nb (C, N) phases precipitated in the interior of austenitic grain in the base metal, which increased local hardness.
- There was no significant microstructural change in the dendrite core of the weld metal, retaining its initial hardness.

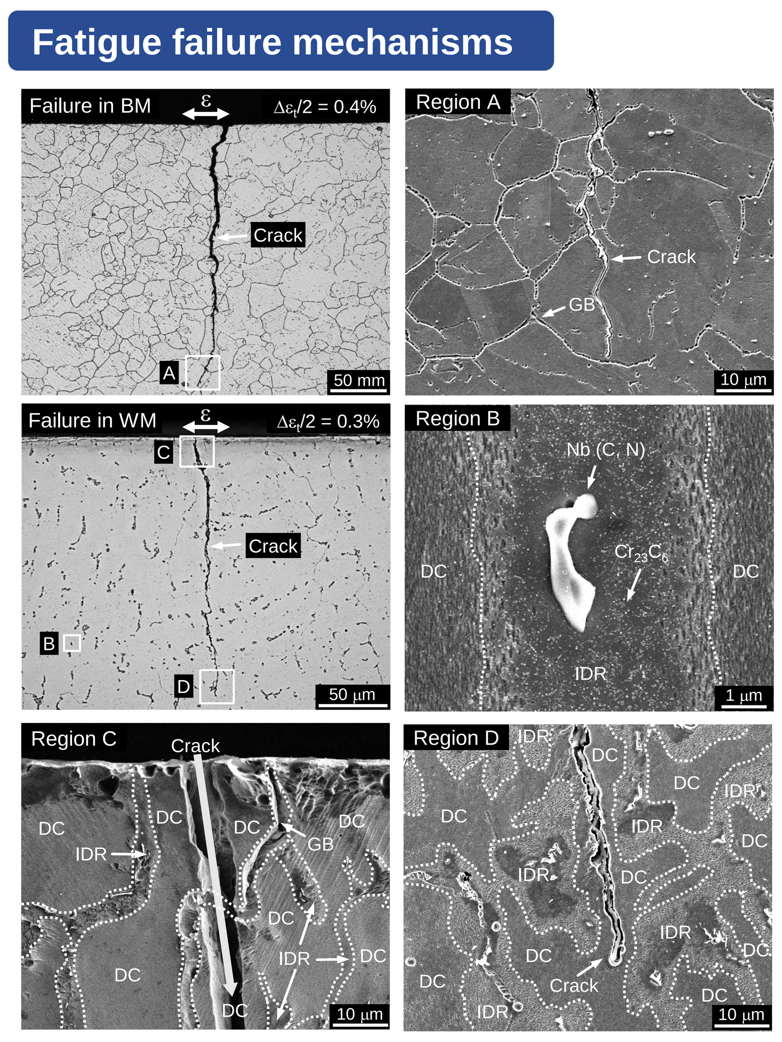
Characterization of Strain localization behavior during tensile test

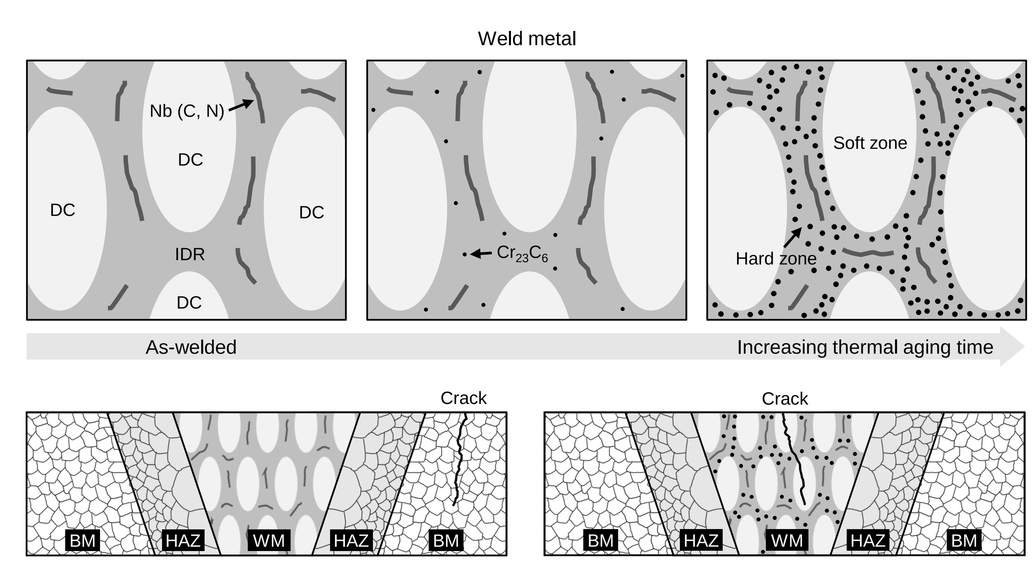




- Strain localization region in the welded joint is the base metal for the as-welded material; however, it shifts to the weld metal for the material aged for 8 h.

Fatigue failure mechanisms





- For the fatigue test at a high strain amplitude of ~0.4%, the test time was not sufficient to produce the thermal aging effect, and the base metal continued to be the softest region, where the applied strain was localized and led to failure.
- Fatigue test at the low strain amplitude of ≤ ~0.3% provides a longer test time, which is sufficient to produce the thermal aging effect.
- Different microstructural evolutions occur in each region of the welded joint, promoting inhomogeneity of local hardness and thereby altering the softest region to the dendrite core in the weld metal.

Conclusions

- There is a transition in the fatigue failure location (i.e., fatigue failure mechanism) from the base metal at a high strain amplitude (≥ ~0.4%) to the weld metal at a low strain amplitude (≤ ~0.3%) at 600 °C, and this leads to a significant reduction in the fatigue resistance of the welded joint as compared to that of the base metal.
- Longer fatigue test time at a low strain amplitude induces a thermal aging effect that promotes different microstructural evolutions in the base metal and weld metal, deepening material inhomogeneity in the welded joint, and thereby triggering strain localization in the weld metal.
- The intensified local hardness inhomogeneity caused the softest zone in the welded joint, wherein strain localization occurred, serving as a crack nucleation site and propagation path, to shift from the base metal to the weld metal (dendrite core).

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