Study of Microstructure and Mechanical properties of Friction Stir Welded P91 Steel for Nuclear Applications

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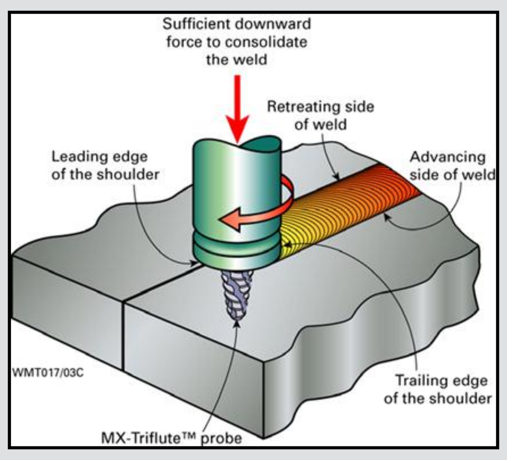
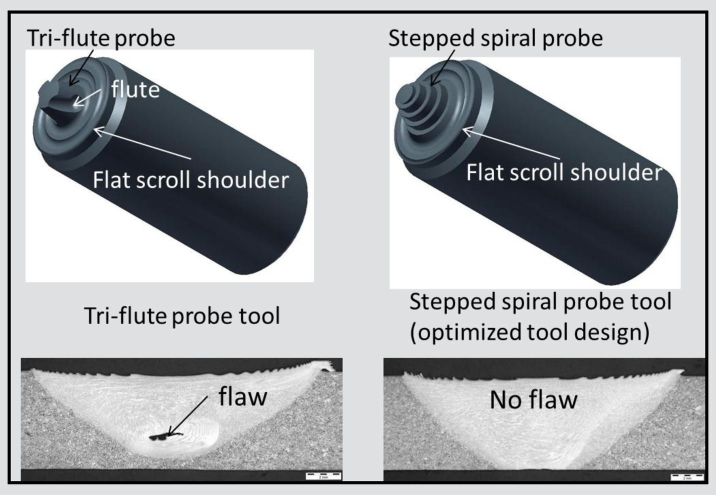
Introduction

- Ferritic/martensitic (F/M) steels and ODS steels are considered as candidates for the advanced fast nuclear reactor cladding/duct materials because of their excellent radiation resistance and low swelling rate compared to austenitic stainless steels.
- **Motivation:** Joining of these materials without destroying their characteristic microstructure is challenging. Consequently, suitable non-fusion techniques for joining of F/M steels and ODS steels are being developed for the Generation IV nuclear reactors.
- **Objective:** The research presented in this poster is mainly focused on the **Friction Stir Welding (FSW),** which is a pioneering non-fusion joining technique, with an objective to assess its suitability for joining of the advanced steels for the Generation IV nuclear applications.
- **Description of the work:** An extensive characterization of the friction stir weld produced from P91 steel was performed in comparison with its base material properties. Influence of the post weld tempering heat treatment (PWHT) on the mechanical and microscopic properties was studied.

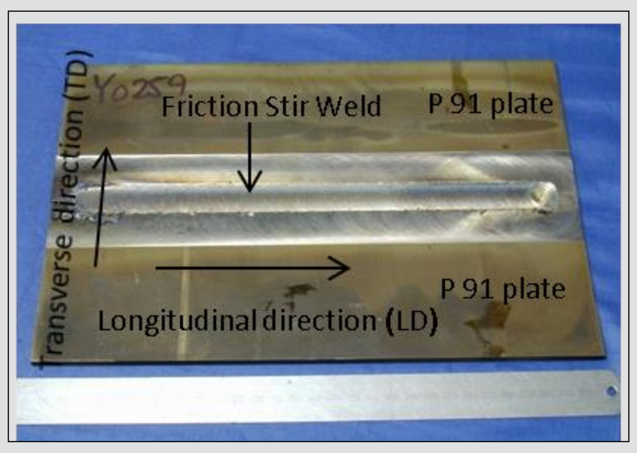
Experimental



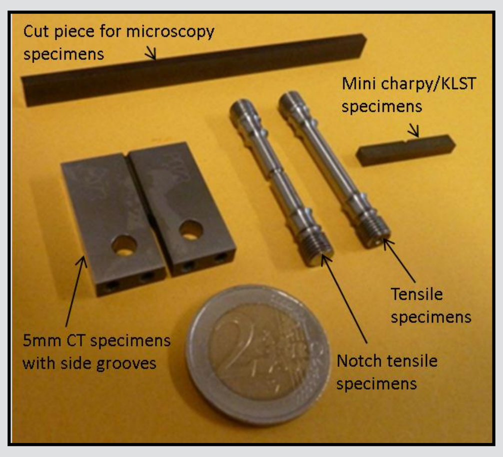
Friction Stir Welding Scheme



Tool design optimization



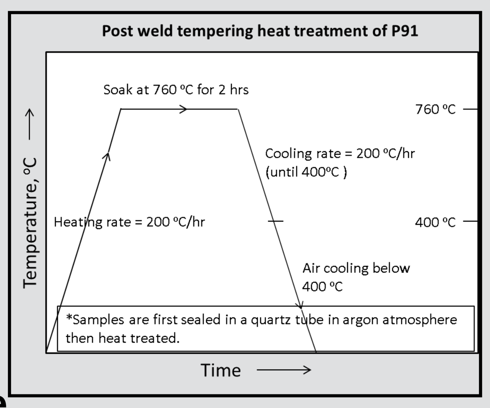
FSW P91 plate



Sample geometries

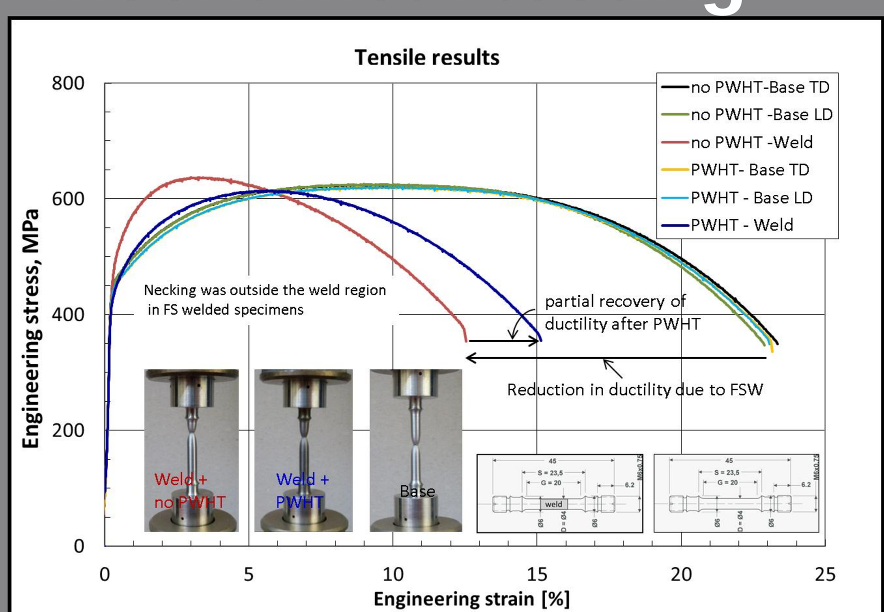
Test matrix

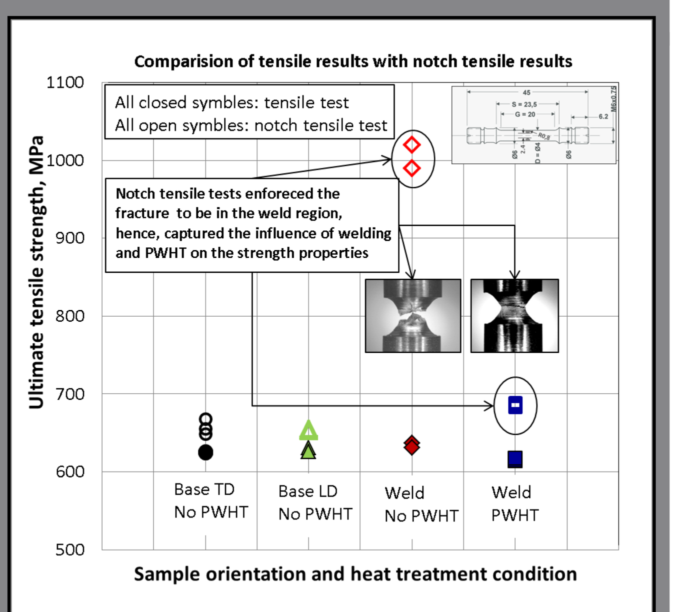
Test name			Tensile	Notched-tensile	Mini-charpy (KLST)	Fracture toughness (CT5)	Hardness/ microscopy/ XRD stress
No. of samples	Base LD	No PWHT	3	3	10	6	1
		PWHT	3				1
	Base TD	No PWHT	3	3	12	6	1
		PWHT	3				1
	Weld	No PWHT	3	3	8	2	1
		PWHT	3	3	8	1	1



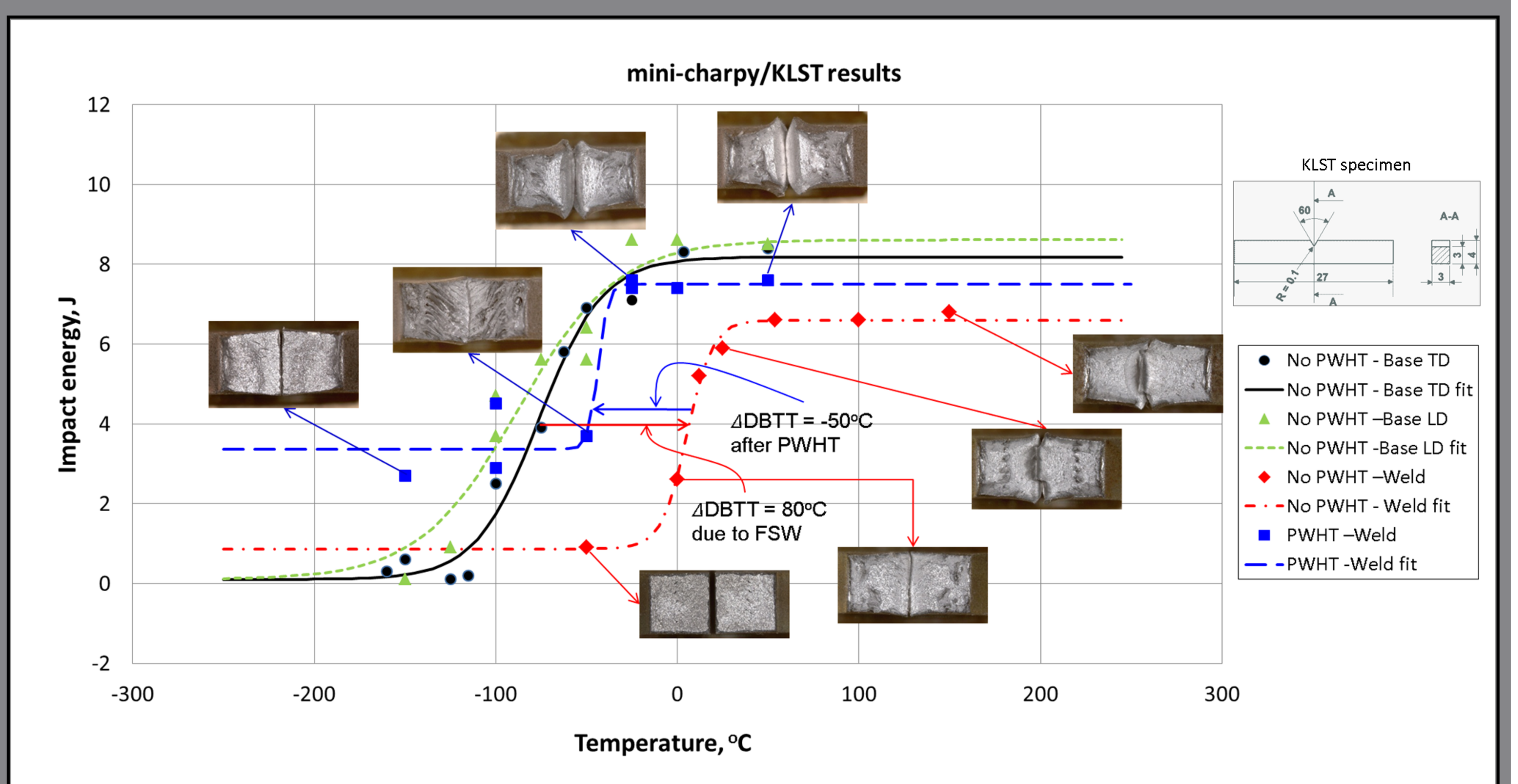
Test matrix and heat treatment cycle

Mechanical testing



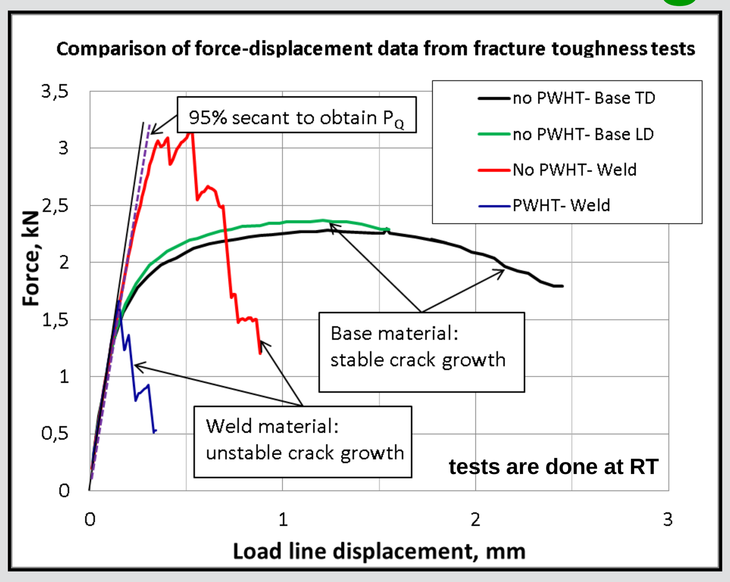


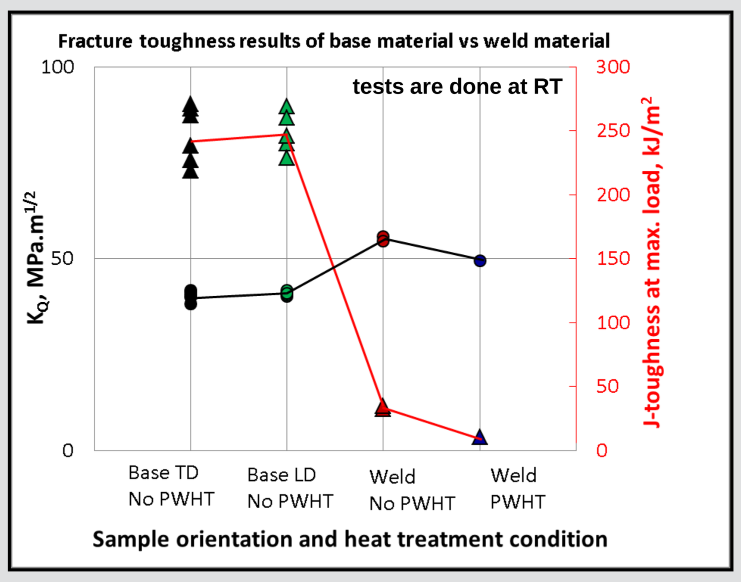
Tensile and notch tensile test results

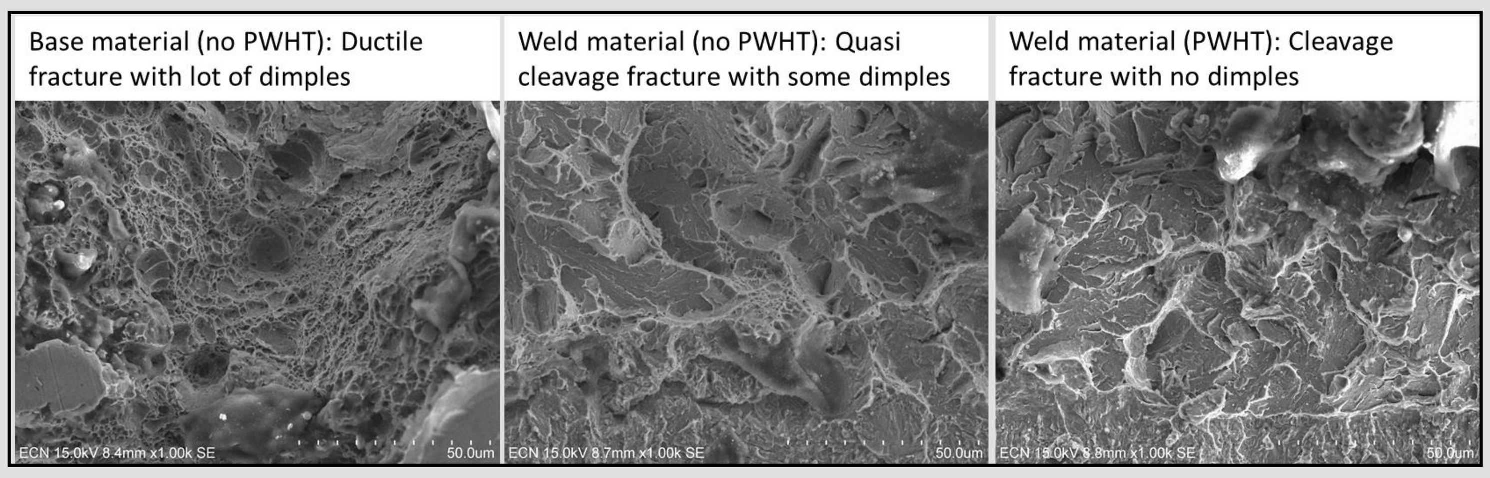


Min-charpy impact test results

Mechanical testing

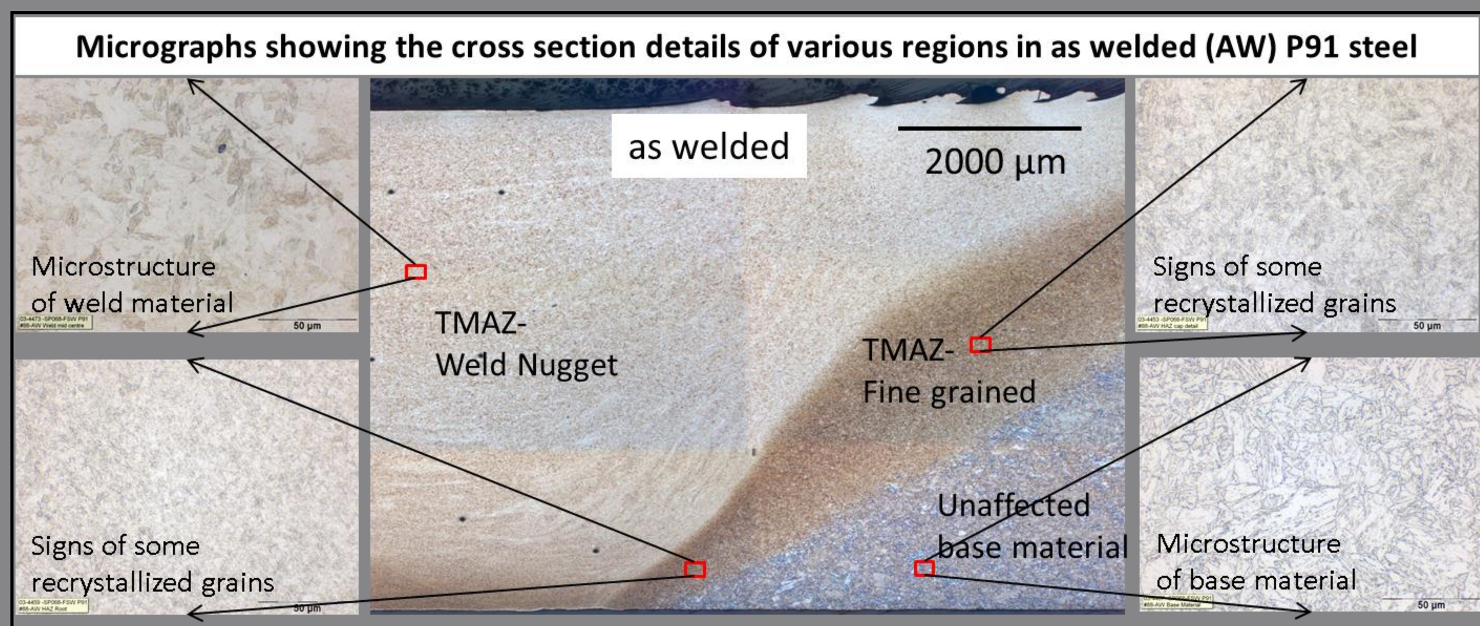


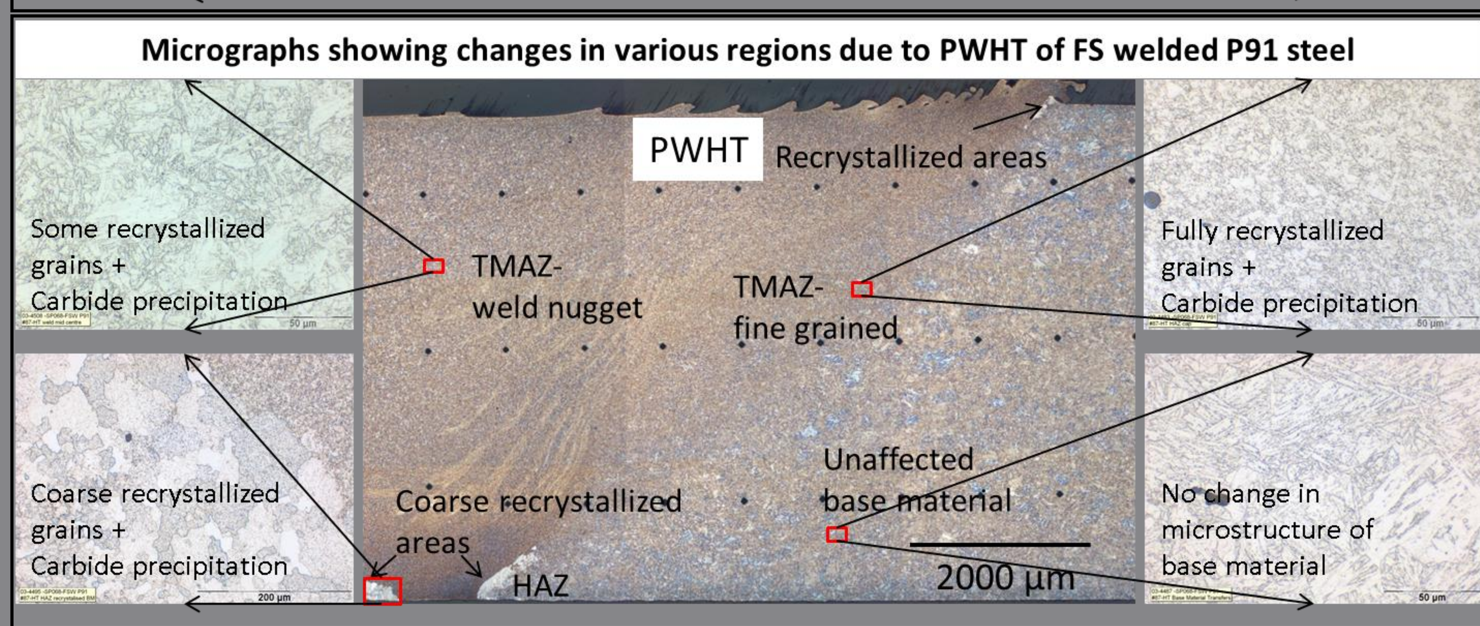




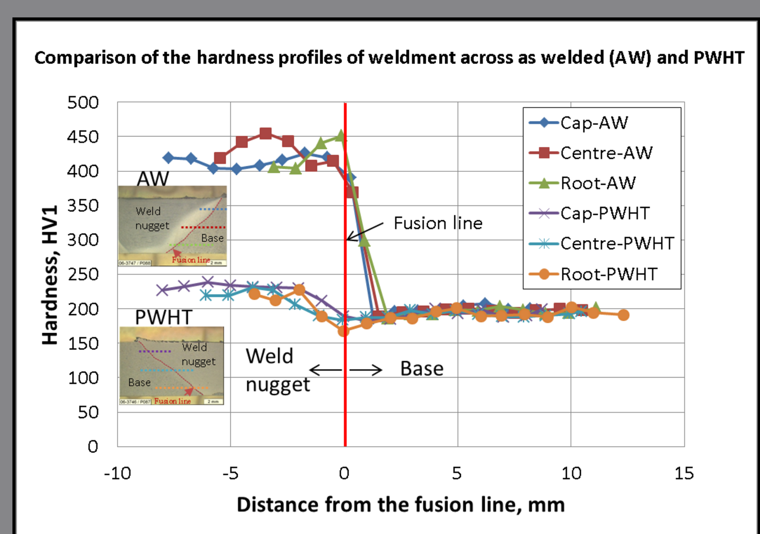
Fracture toughness test results

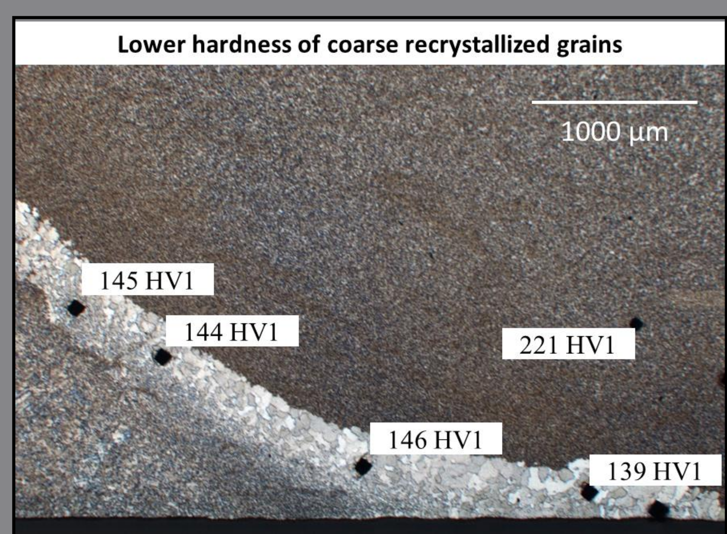
Microscopy and Hardness results





Microscopy results





Hardness test results

Discussion and Conclusions

- Comprehensive mechanical and microscopic characterization of P91 steel plate, welded with friction stir welding (FSW), was performed to assess the suitability of FSW for joining of steels for nuclear applications.
- FS welded specimens has shown superior tensile strength properties than the base material, though, there was a considerable reduction in the ductility due to FSW. Application of PWHT helped to partially recover the ductility.
- A substantial increase in DBTT was observed due to FSW. This can be attributed to hardening of weldment (or thermo-mechanical affected zone,TMAZ) as a result of formation of fresh martensite and very fine grained micro-structure. However, application of PWHT reduced hardness of the weldment and, hence, recovered the impact properties.
- A slight increase in initiation fracture toughness (K_Q) was observed in weld specimens. Upon PWHT, K_Q was lowered to the base material level.
- Stable crack growth was observed during J-toughness/crack growth resistance test of base material, featured with dimpled fracture surface. Conversely, unstable crack growth was observed in as welded (featured with quasi-cleavage fracture) as well as PWHT (featured with full cleavage fracture) specimens. The decrease in J-toughness could be due to the formation of fresh martensite in TMAZ weld nugget during FSW in as welded specimens. The reasons for low J-toughness in PWHT samples was not clear. Hence, further investigation, including more J-toughness tests, is needed to clarify this point.
- Formation of recrystallized regions of soft ferrite observed in the cap and root regions of TMAZ of the weld could be due to over tempering of the fresh martensite formed during FSW.
- Proper control of maximum attained temperature (to be below A_1) during FSW, in order to avoid PWHT, is key for the application this method for joining of the selected steels for nuclear applications.

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