EFFECTS OF INITIAL MATERIALS INHOMOGENEITIES ON MICROSTRUCTURE AND MECHANICAL PROPERTIES AT IRRADIATED STATE

Hans-Werner Viehrig

SOTERIA Mid Term Workshop, Prague,

April 9 and 10, 2018

Main Objective

- Investigation of influence of the intrinsic inhomogeneity on the irradiation behavior of reactor vessel steels.

→ Task 3.3: Effects of initial materials inhomogeneities on microstructure and mechanical properties at irradiated state for LTO

SOTERIA Task 3.3: Specific objectives

Examination of selected materials used in Task 3.2 in the irradiated state in order to clarify the impact of the initial microstructure on the irradiation behaviour.

Correlation of initial and irradiation induced microstructural features with the mechanical property (fracture toughness) and fractographic observations including irradiation-induced changes.

Illustration of which kinds of inhomogeneity are most significant in producing the uncertainty in the post-irradiation conditions.

Input for the calibration of fracture toughness modelling tools (WP5) and handling of inhomogeneity in the RPV integrity assessment

Task 3.3: Outputs & interactions

Deliverable D3.2: Effects of initial materials inhomogeneities on microstructure and mechanical properties of RPV steels at irradiated state for LTO (M36)

Contributors: HZDR, AR-G, CIEMAT, CNRS, CVR,UJV, VTT

Input for WP5: local approach calibration with specific view on microstructure evolution models and modelling tools

This deliverable will be elaborated in Task 3.3 with inputs from the deliverable D3.1 (M24) to be elaborated in Task 3.2.

Materials to be investigated within Task 3.3

material ID	contributing partners	material description	applied technique
ANP-2	AR-G, HZDR	WM (S3NiMo1/OP41TT)	HV, FT (MC), OES
ANP-3	AR-G, CIEMAT, HZDR, VTT, CNRS	BM (22NiMoCr3-7) Kloeckner	TEM, and TEM with deformation, SEM, SPT, APT
ANP-4	AR-G, CIEMAT, VTT	BM (22NiMoCr3-7) reference material	OES, TEM, SEM
ANP-5	AR-G, HZDR	NiCrMo1/LW320, LW330 weld (high Cu)	HV, FT (MC)
ANP-6	AR-G, CIEMAT	S3NiMo/OP41TT weld (high Ni)	HV, FT (MC)
ANP-10	AR-G, HZDR, CIEMAT	22NiMoCr3-7 forging (P151 Kloeckner)	HV, SANS, PAS, TEM
FZD-4	HZDR, CIEMAT	BM (WWER-440/V-213 15Kh2MFAA) Greifswald unit 8	FT, SANS,TEM, SEM, TEM, and TEM with deformation, metallography

initial condition described deliverable 3.1

Materials to be investigated within WP-3.3 (continue)

material ID	contributing partners	material description	applied technique
JRQ	UJV	A 533-B BM (IAEA reference steel)	Micro-hardness tests
UJV-1	UJV	BM 15Kh2MFA WWER-440	Micro-hardness tests
UJV-2	UJV	WM 15Kh2NMFA WWER-1000	Micro-hardness tests
VTT-1	VTT	WWER-440 high Cu weld material	TEM, PAS, SEM, SANS, APT
VTT-MW1	VTT	WWER-440 mock-up weld	TEM, PAS, SEM, SANS, APT
EDF-4	CNRS	16MnD5	APT+TEM+PAS only for ion (CNRS); nano-indentation tests (EDF)
VFAB-1	AR-G, HZDR, CIEMAT	WM (WM S3NiMo/OP41TT) Uddcomb, high Ni	SANS, PAS

initial condition described deliverable 3.1

no information

Chemical composition in wt. % of the materials to be investigated within WP-3.3

material	reference	C	Mn	Si	Cr	Ni	Mo	V	P	Cu
ANP-2	D3.1 (mean)	0.06	1.05	0.08	0.04	1.02	0.63	<0.01	0.017	0.03
	Di3.2 (doc.)	0.07	1.08	0.12	<0.1	1.01	0.62	0.01	0.019	0.03
ANP-3	Di3.2	0.23	0.70	0.20	0.44	0.98	0.79	-	0.015	0.12
ANP-4	D3.1 (mean)	0.18	0.93	0.23	0.41	0.89	0.48	<0.01	0.005	0.06
	D3.2 (doc)	0.21	0.85	0.22	0.39	0.84	0.55	-	0.006	0.05
ANP-5	Di3.2	0.08	1.10	0.15	0.74	1.11	0.60	-	0.015	0.22
ANP-6	Di3.2	0.05	1.41	0.15	0.07	1.69	0.46	0.004	0.012	0.08
ANP-10	Di3.2	0.18	0.81	0.15	0.40	0.96	0.53	<0.01	0.006	0.09
VFAB-1	Di2.2	0.06	1.66	0.21	0.14	0.9-1.47	0.38	0.01	0.016	0.06
FZD-4	Di3.2	0.15	0.45	0.30	2.86	0.10	0.79	0.31	0.008	0.05
VTT-1	Di3.2	0.04	1.06	0.60	1.57	0.13	0.46	0.20	0.020	0.19
VTT-WM1	Di3.2	0.05	1.20	0.40	1.40	0.14	0.49	0.19	0.038	0.17
EDF-4	Di3.2	0.16	1.31	0.24	0.18	0.70	0.50	0.006	0.011	0.08

AR-G materials: broken halves of Charpy size SE(B) and 1T-C(T) specimens

material	task	$\Phi^{E>1MeV}$ 10^{19} n/cm^2	0.16T-C(T)	discs* thickness:		APT needles	investigation/testing	recipient
				1 mm	0.4 mm			
ANP-2	2, 3, 4	0	8				HV, MC	HZDR
	3, 4	4.17	8				HV, MC	HZDR
ANP-3	2, 4	0		2	2	4	HV, SANS, PAS, TEM, APT	HZDR, CIEMAT, CNRS
	3, 4	3.89		2	2	4	HV, SANS, PAS, TEM, APT	HZDR, CIEMAT,CNRS
ANP-5	2, 3, 4	0	8				HV, MC	HZDR
	3,4	2.21	8				HV, MC	HZDR
ANP-6	2, 3, 4	0	8	2	2	4	HV, MC, SANS, PAS, TEM, APT	HZDR, CIEMAT,CNRS
	3, 4	5.63	8	2	2	4	HV, MC, SANS, PAS, TEM, APT	HZDR, CIEMAT, CNRS
ANP-10	2, 4	0		2	2	4	HV, SANS, PAS, TEM, APT	HZDR, CIEMAT, CNRS
	3, 4	3.38		2	2	4	HV, SANS, PAS, TEM, APT	HZDR, CIEMAT, CNRS
ANP-15	4	0	FT testing of reconstituted Charpy size SE(B) specimens by CIEMAT					
VFAB-1	2, 4	0		2	2		HV, SANS, PAS, TEM	HZDR, CIEMAT
	3, 4	5.87		2	2		HV, SANS, PAS, TEM	HZDR, CIEMAT

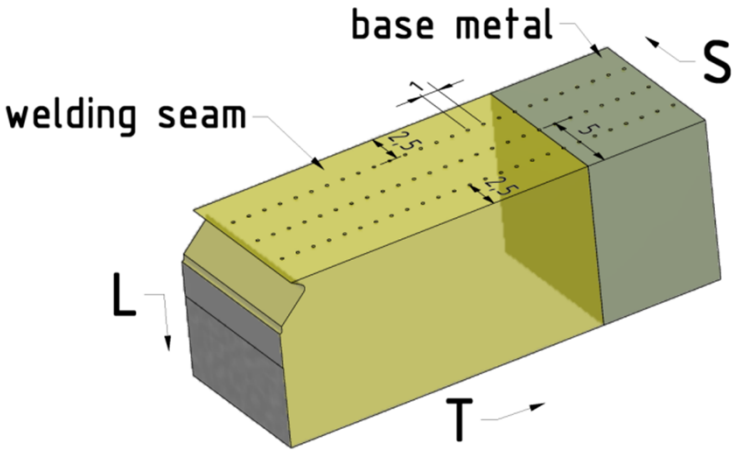
* discs 10 mm x 10mm

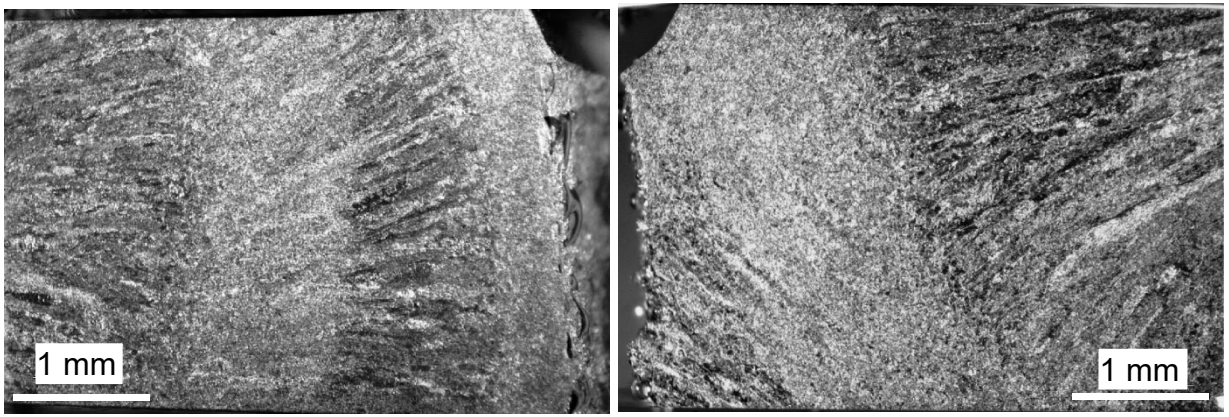
WWER materials: broken halves of Charpy size SE(B) specimens

material	task	$\Phi^{E > 1MeV}$ 10^{19} n/cm^2	0.16T-C(T)	discs* thickness: 1 mm	discs* thickness: 0.4 mm	APT needles	investigation/testing	recipient
FZD-4	2, 3, 4	0	24	2	4		HV, MC, TEM, PAS	HZDR, Ciemat
	3, 4	2.07	8				HV, MC, PAS	HZDR
	3,4	25.3	8	2	4		HV, MC, TEM, PAS	HZDR, Ciemat
VTT	2	0					TEM, SEM	VTT
	3	up to 4					TEM, SEM	VTT
VTT-MW1		0					TEM, SEM	VTT
		up to 4					TEM, SEM	VTT

* discs 10 mm x 10 mm

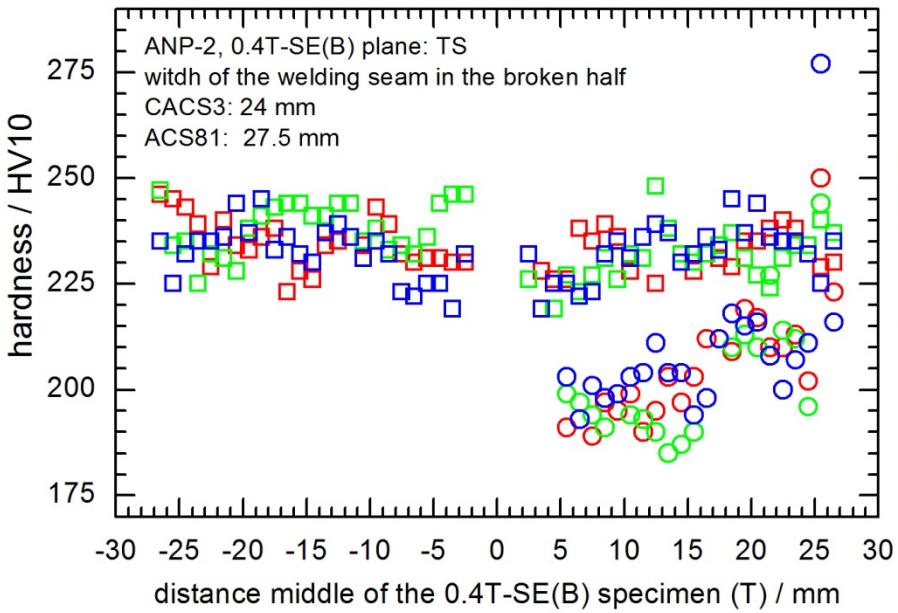
Hardness measurements HV10:
ANP weld metals: on plane TS





Hardness measurements HV10: ANP weld metals

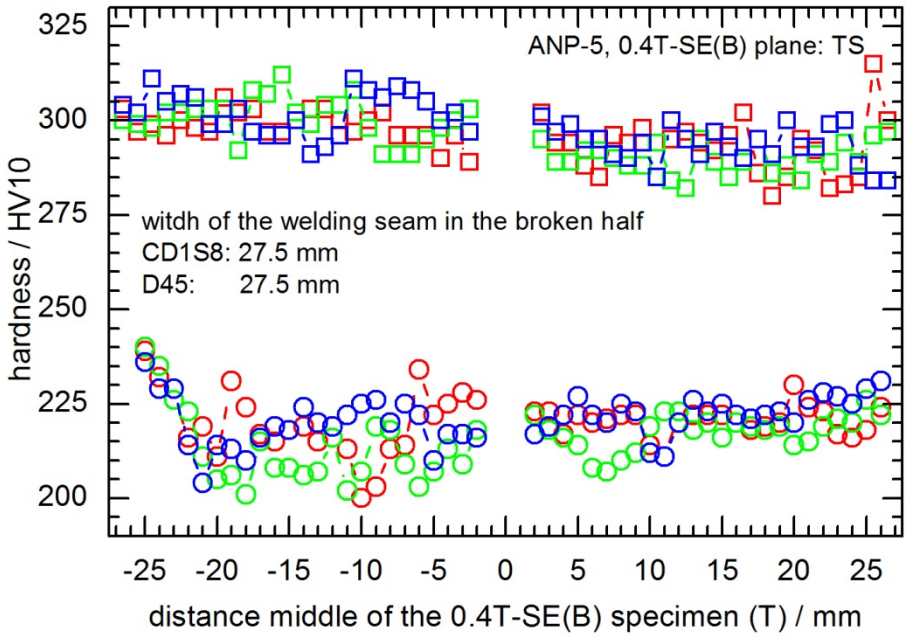
ANP-2



	initial (CACS3)	irradiated (ACS81)
line (S) 2.5 mm:	○	□
line (S) 5 mm:	○	□
line (S) 7.5 mm:	○	□
mean:	203 HV10	232 HV10
SD:	9 HV10	6 HV10
span (min- max):	42 HV10	31 HV10

irradiation: $4.17 \cdot 10^{19}$ n/cm^2 (E > 1MeV)

ANP-5

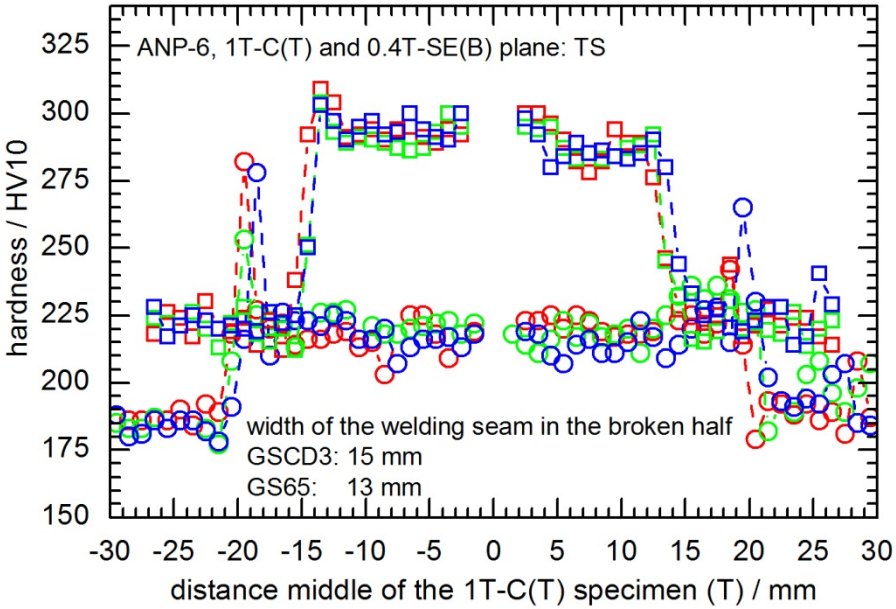


	initial (CD1S8)	irradiated (D45)
line (S) 2.5 mm:	-○-	-□-
line (S) 5.0 mm:	-○-	-□-
line (S) 7.5 mm:	-○-	-□-
mean:	218 HV10	297 HV10
SD:	7 HV10	7 HV10
span (min - max):	34 HV10	32 HV10

irradiation: $2.21 \cdot 10^{19}$ n/cm^2 (E > 1MeV)

Hardness measurements HV10: ANP weld metal

ANP-6

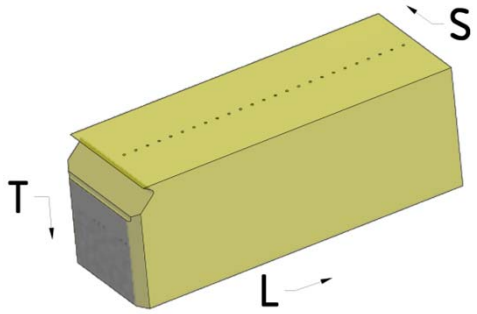


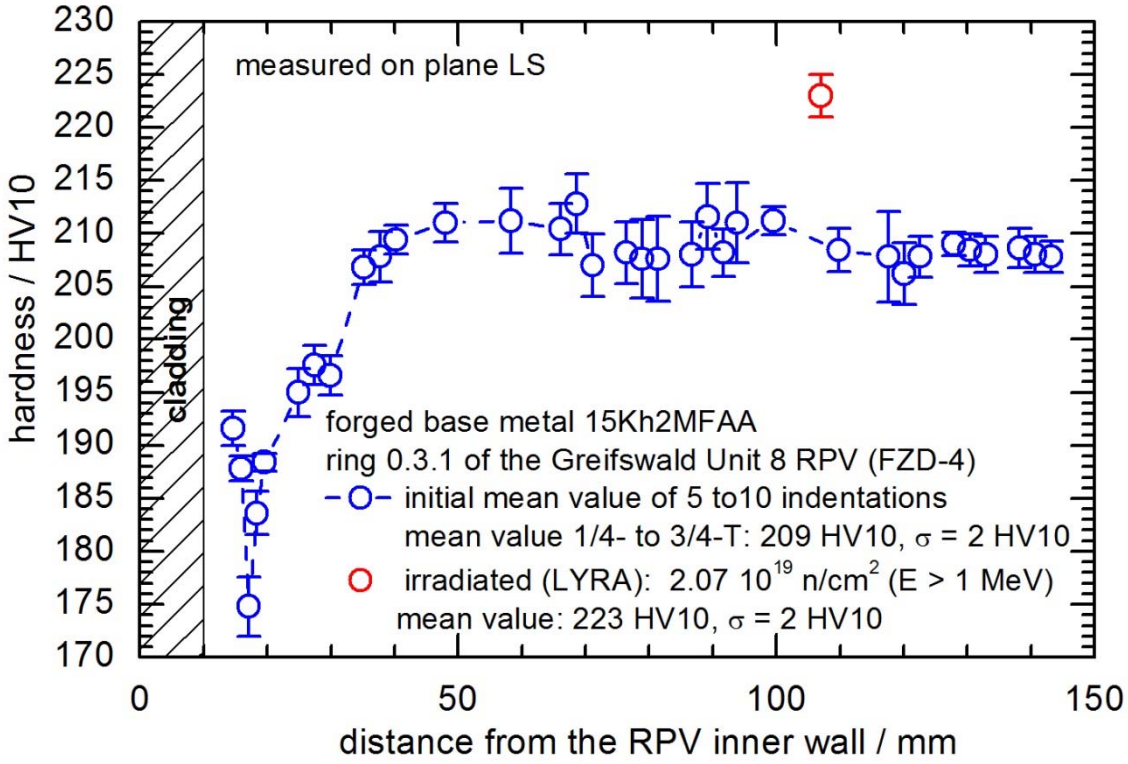
	initial (1T-C(T): GSCD3		irradiated (0.4T-SE(B): GS65
line (S): 2.5 mm	–O–	line (S) 2.5 mm:	–□–
line (S): 12.5 mm	–O–	line (S) 5.0 mm:	–□–
line (S): 22.5 mm	–O–	line (S): 7.5 mm	–□–
mean:	219 HV10		290 HV10
SD:	6 HV10		6 HV10
span (min - max):	33 HV10		28 HV10

irradiation: $5.63 \cdot 10^{19}$ n/cm^2 (E > 1MeV)

Hardness measurements HV10: FZD-4 base metal

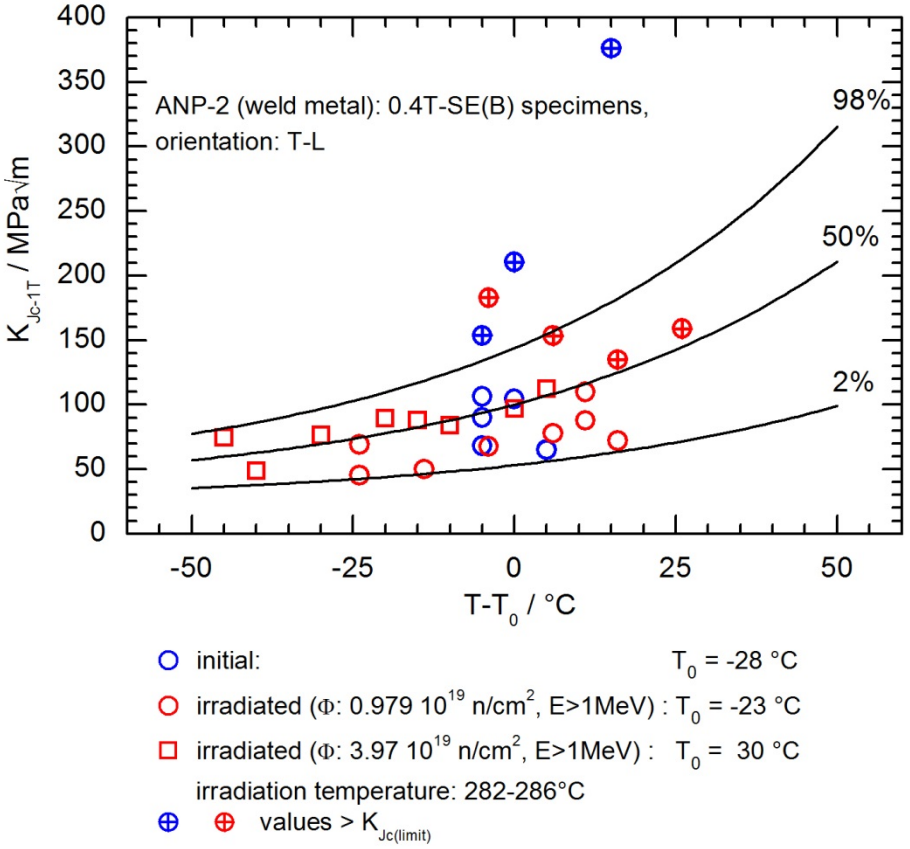
forged base metal ring 0.3.1. of the Greifswald Unit 8 RPV: plane LS

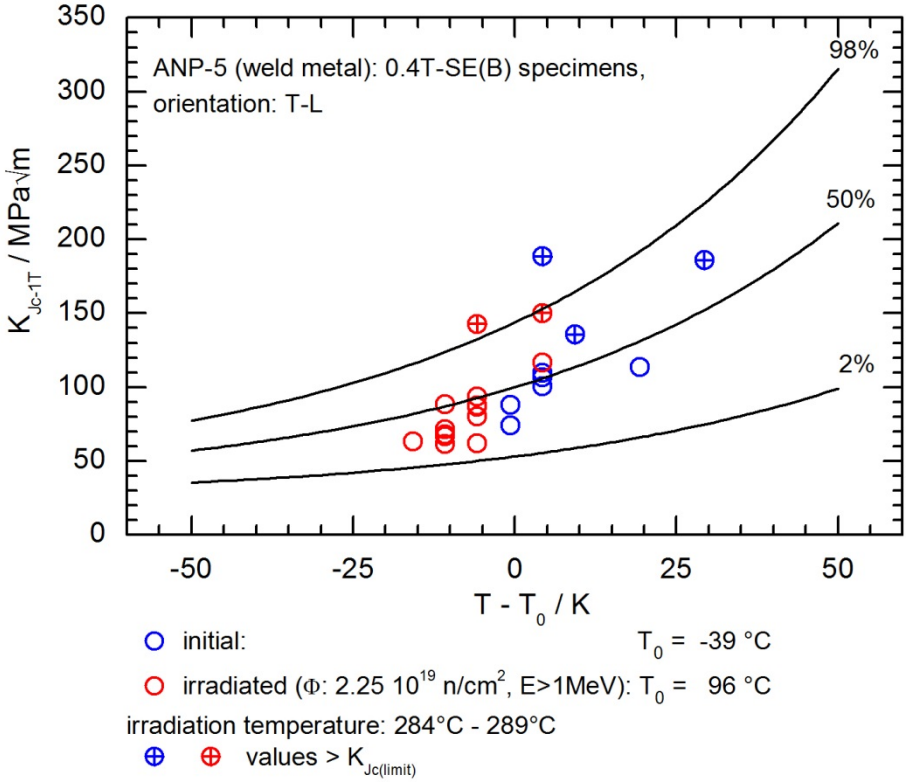




Fracture toughness testing according to ASTM E1921 (Master Curve approach)

ANP-2 and ANP-5: 0.4T-SE(B) specimens



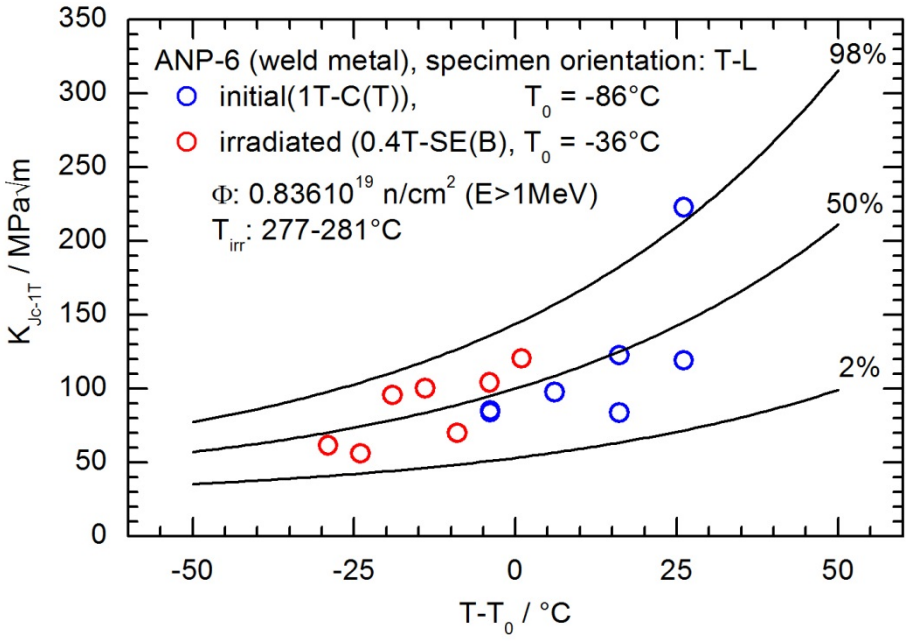


K_{Jc-1T} values outside 2 % and 98 % :

	initial	irradiated 1	irradiated 2
• ANP-2:	3 out of 9 (33 %)	2 out of 12 (17 %)	0 out of 8 (0 %)
• ANP-5:	1 out of 9 (11 %)	12 out of 14 (7 %)	

Fracture toughness testing according to ASTM E1921 (Master Curve approach)

ANP-6: 1T-C(T)- and 0.4T-SE(B) specimens

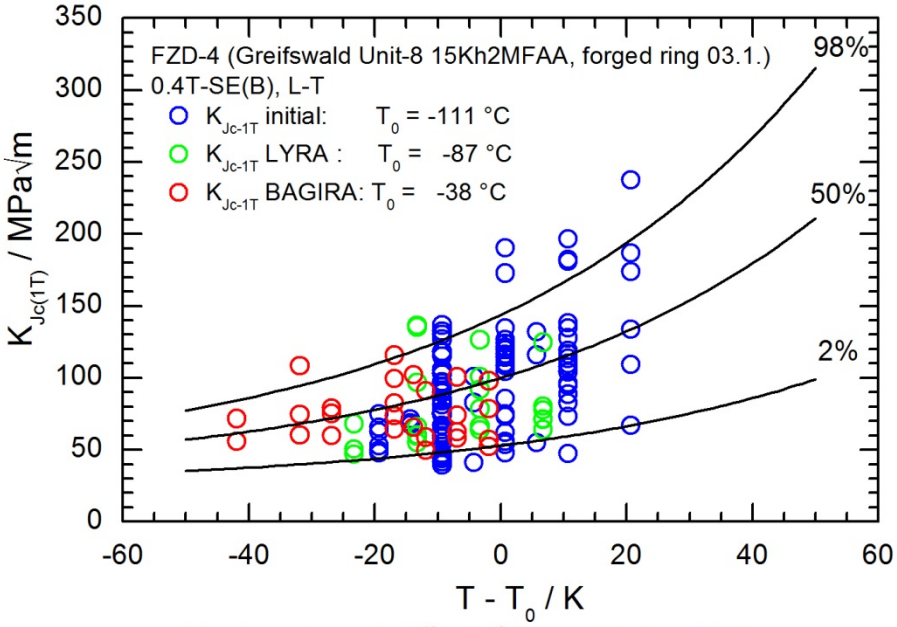


$K_{Jc\text{-}1T}$ values outside 2 % and 98 %:

	initial	irradiated
• ANP-6:	1 out of 6 (16 %)	0 out of 7 (0 %)

Fracture toughness testing according to ASTM E1921 (Master Curve approach)

FZD-4: 0.4T-SE(B) specimens, L-T

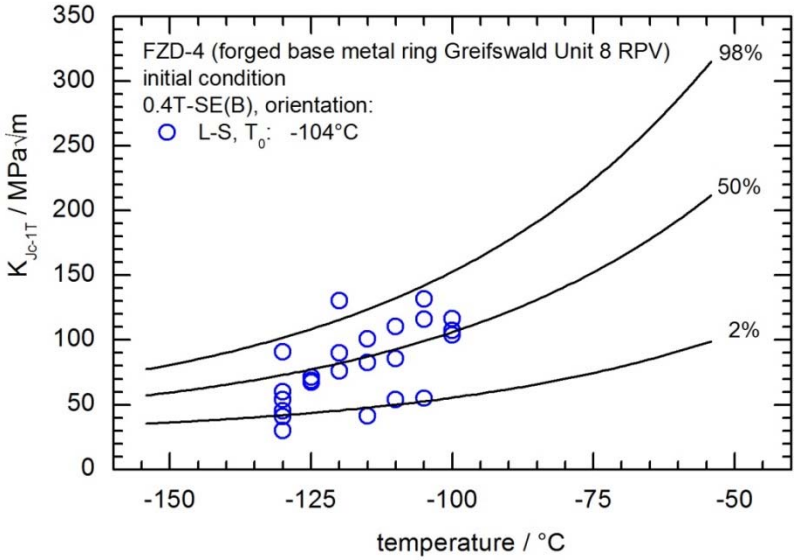


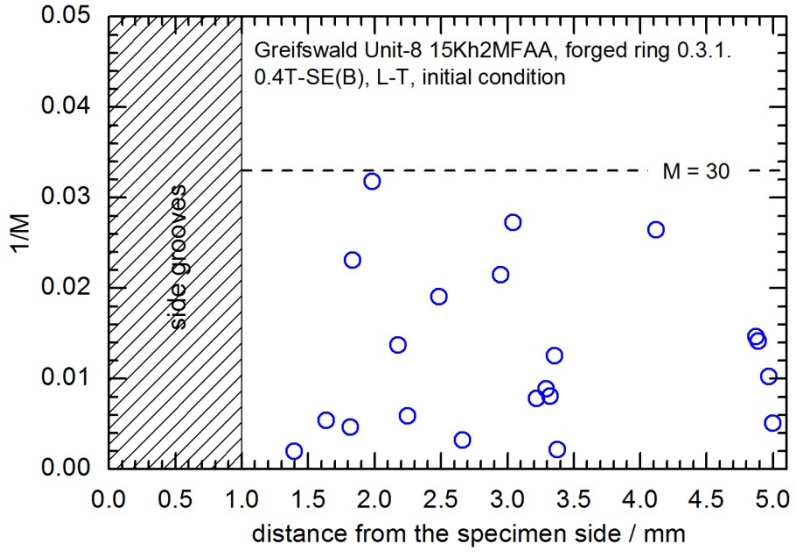
$K_{Jc\text{-}1T}$ values outside 2 % and 98 %:

- initial condition: 19 out of 98 (19 %)
- LYRA irradiation: 2 out of 22 (9 %)
- BAGIRA irradiation: 2 out of 26 (8 %)

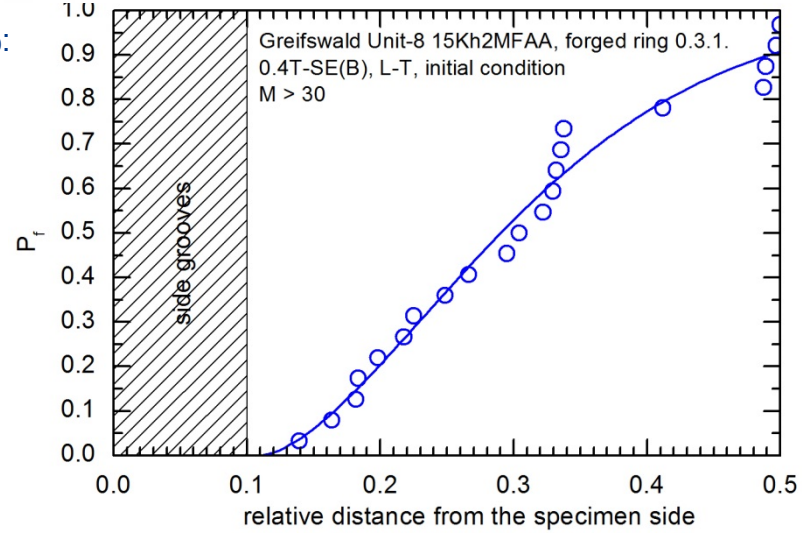
Fracture toughness testing according to ASTM E1921 (Master Curve approach)

FZD-4: 0.4T-SE(B), L-S specimens





$K_{Jc\text{-}1T}$ values outside 2 % and 98 %:
- 8 out of 28 (29 %)



$$K_{Jclimit} = \sqrt{\frac{E \cdot b_0 \cdot \sigma_{YS}}{M \cdot (1-\nu^2)}}$$

$$M = \frac{E \cdot b_0 \cdot \sigma_{YS}}{K_{Jc}^2 \cdot (1-\nu^2)}$$

Fracture toughness testing according to ASTM E1921 (Master Curve approach)

FZD-4: 0.4T-SE(B) specimen, L-S, tested at -130°C, K_{Jc} = 63 MPa√m