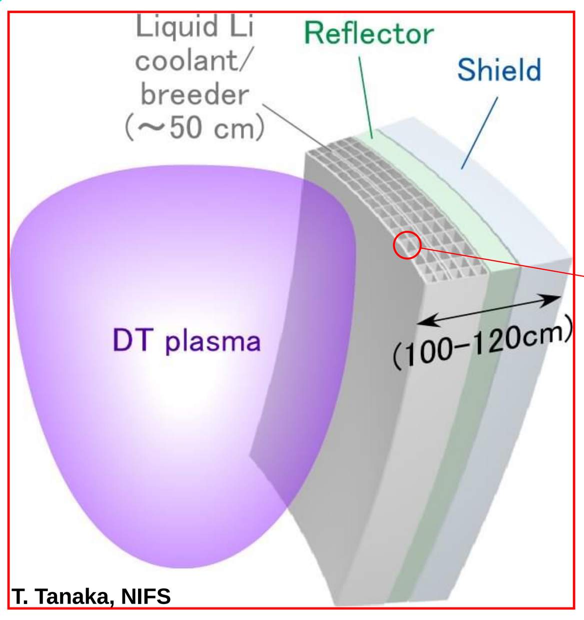
Impact Properties of Electron Beam Welds of V-4Ti-4Cr alloys NIFS-HEAT-2 and CEA-J57

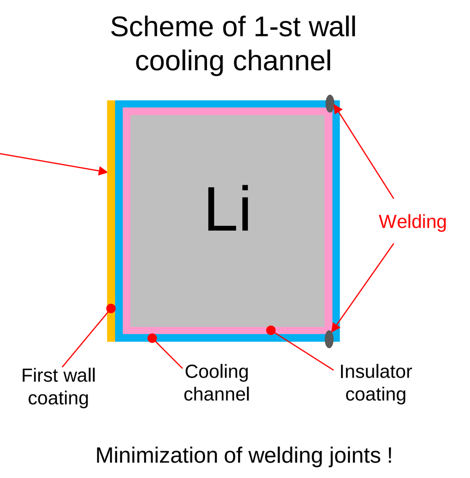
Valentyn Tsisar [1,3,4], Takuya Nagasaka [1], Marion Le Flem [2], Olga Yeliseyeva [3], Jürgen Konys [4], Takeo Muroga [1]

1. National Institute for Fusion Science (NIFS), 322-6 Oroshi, Toki, Gifu 509-5292, Japan;
2. CEA, DEN, DMN, SRMA, F-91191, Gif Sur Yvette, France;
3. Physical-Mechanical Institute of National Academy of Sciences of Ukraine (PhMI NASU), 5 Naukova St., 79601, Lviv, Ukraine;
4. Karlsruhe Institute of Technology (KIT) Hermann-von-Helmholtz-Platz, 1, 76344 Eggenstein-Leopoldshafen, Germany.

" V alloy – liquid Li " Blanket Concept



Development of joining techniques - challenging task for blanket fabrication technologies !



Joining techniques!

- ✓ Gas-tungsten-arc (GTA) and laser welding techniques have been investigated for welding of V-4Ti-4Cr alloys (ORNL, USA; NIFS, - Japan; Bochvar VNIINM, Russia Federation; and SWIP, China);

- ✓ Appropriate mechanical properties of welds could be ensured by means of using: high purity gas atmosphere during welding, in order to avoid contamination of V-alloys mainly by oxygen; high-purity filler metal and subsequent post weld heat treatment (PWHT) which controls the phase-structural state of weld metal (WM);
- ✓ **Electron Beam welding** can provide narrower zones of weld joints and as a results the mechanical properties can be improved in comparison with GTA and laser welding techniques.

V-4Ti-4Cr alloys: NIFS-HEAT-2 and CEA-J57

Chemical composition of V-alloys (wppm, *wt%)

grade	C	O	N	B	Na	Mg	Al	Si	V	Cr*	Mn	Fe	Ni	Cu
NH2	69	148	122	5	<1	<1	59	270	Bal.	4.02	<1	49	7	2
CEA-J57	70	290	110	7.5	40	5	190	280	Bal.	3.76	6.8	120	17	1

grade	As	Zr	Nb	P	S	Ca	Co	Ag	Sn	Sb	Ti*	W	Mo	Ta
NH2	<1	2.5	0.8	0.7	3	12	0.7	<0.05	<1	<1	3.98	<1	24	13
CEA-J57	-	-	<10	1.2	8	0.4	0.4	-	0.3	<10	3.93	35	75	<10

Initial structure of V-4Ti-4Cr alloys

CEA-J57

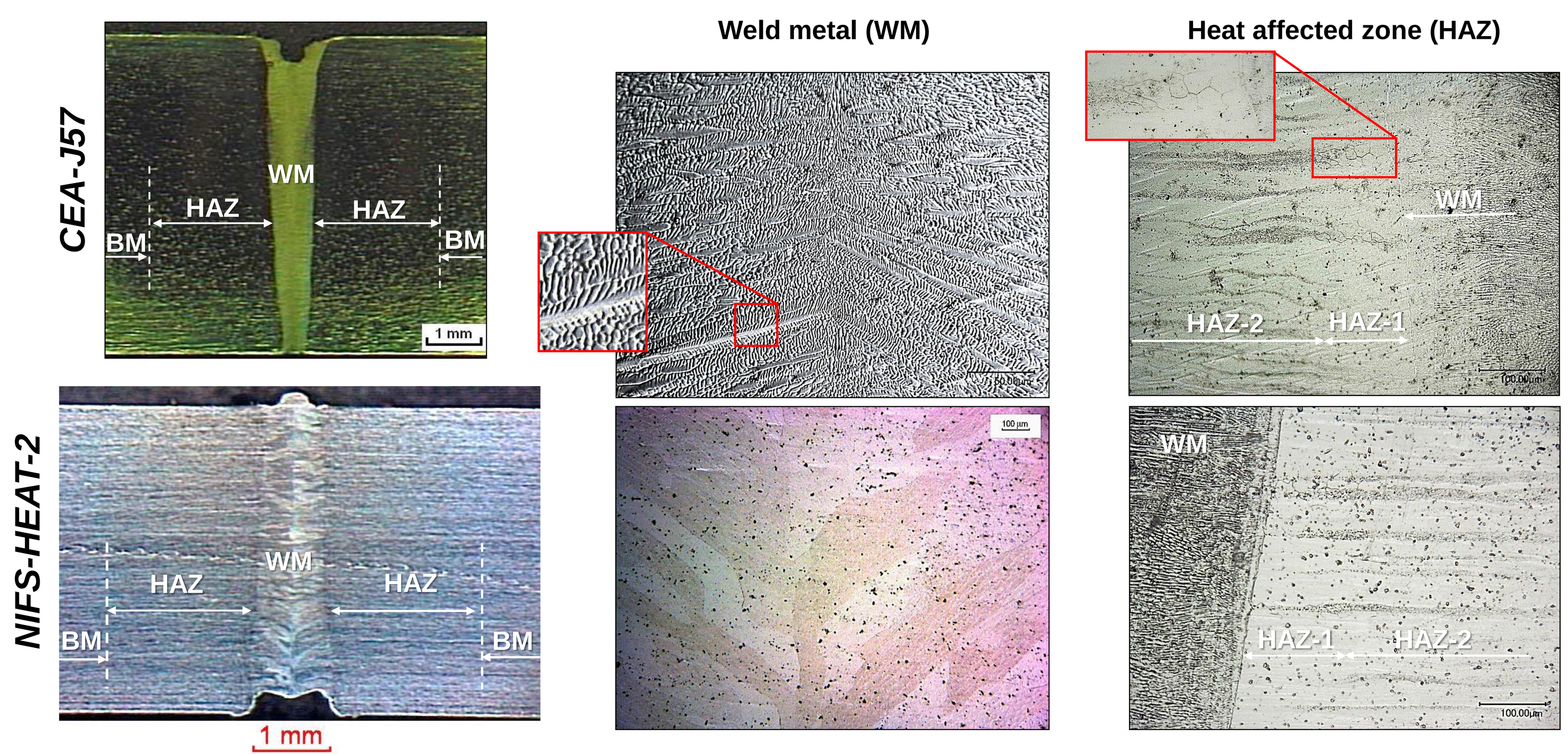
54 % reduction in thickness followed by VA at 1000°C for 2h - 7 mm thick plate.

NIFS-HEAT-2

96 % reduction in thickness followed by VA at 1000°C for 2h - 4 mm thick plate.

Precipitation bands (Ti-C,O and Ti-C,O,N) aligned along rolling direction (arrows).

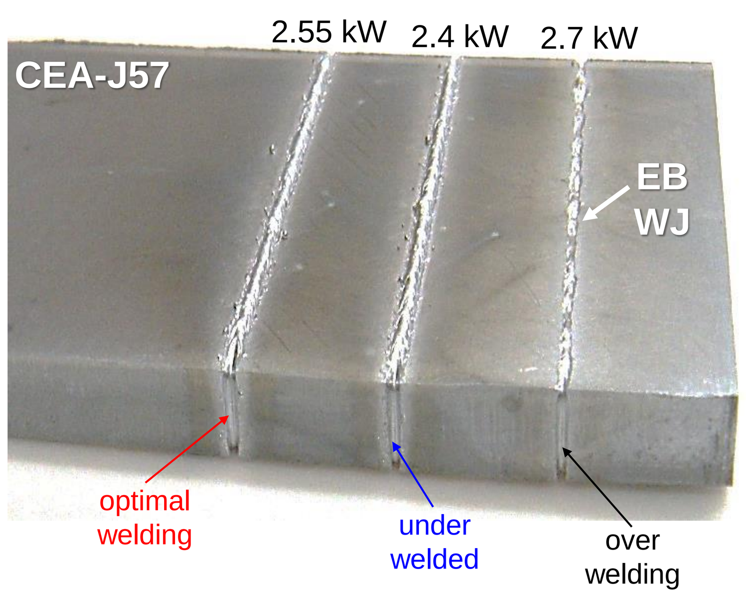
Morphology of Zones of Weld Joints



- ✓ Cross-sections of both grades do not revealed any discontinues in the structure of weld joint;
- ✓ Columnar crystallites (grains) with dendritic structure elongated from the center of the weld join in the direction of heat removal (solidification front) are observed in weld metal (WM) of both grades;
- ✓ Precipitation bands, observed initially in the structure of v-alloys, are completely disappeared in WM and partially in HAZ-1 directly adjoining WM due to temperature-induced decomposition of Ti-C,O,N precipitates during melting of fusion zone;
- ✓ Thickness of WM does not exceed 1 mm while HAZ is about 3 mm thick.

Electron Beam Bead-on-plate Welding Conditions

EB welding was carried out at SFC Co., Ltd. (Yokohama)

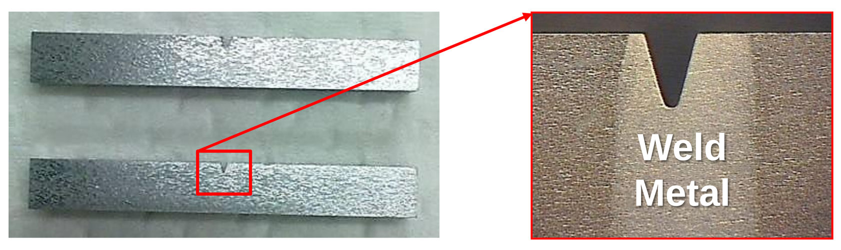


Welding parameters:

- ➢ High-vacuum atmosphere;
- ➢ Welding power:
  - ✓ 1.5 kW for 4 mm thick plate (NH2);
  - ✓ 2.55 kW (150kV, 15mA) for 7 mm thick plate (CEA-J57-1A);
- ➢ Rate of electron beam – 1m/min.

Sub-size (1/3) Charpy-impact specimens:

- ✓ 3.3 mm thick x 3.3 mm wide x 25.4 mm long, with a 30°, 0.66-mm-deep, 0.08-mm root radius;
- ✓ V notch is oriented perpendicularly to the rolling direction;

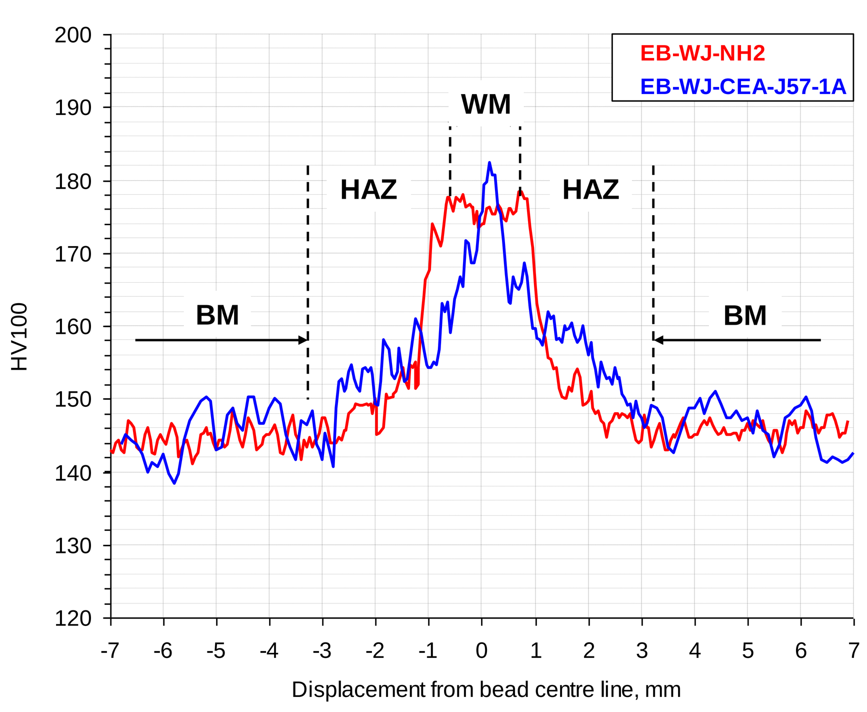


Notch in the Weld Metal (LT)

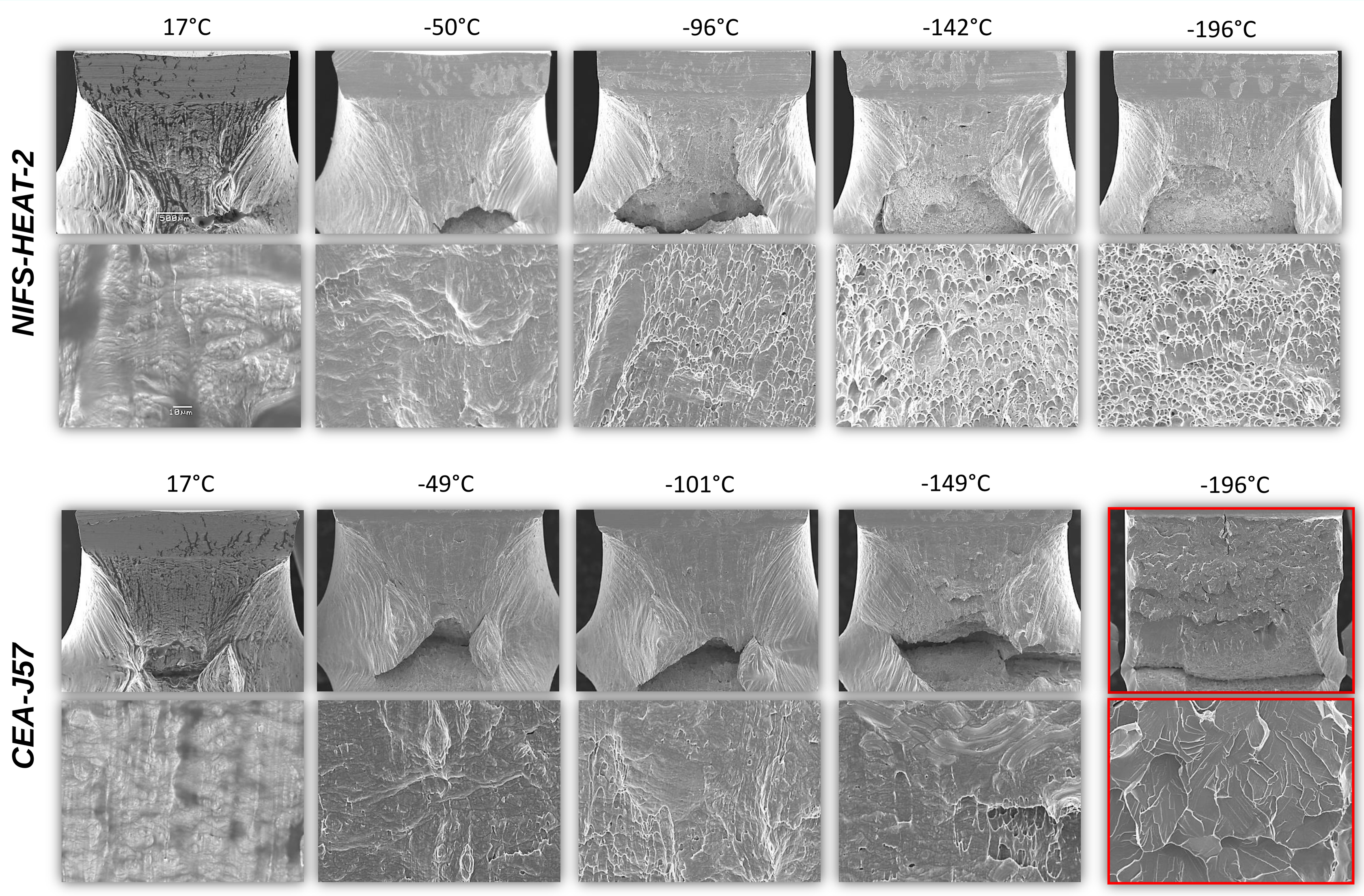
- ✓ Post-machining vacuum annealing at 400°C for 1h was applied to remove hydrogen.

Mechanical and Fractographical Properties of Weld Metal of Electron Beam Welds of V-alloys

Hardness of electron beam weld joints versus zones of welding

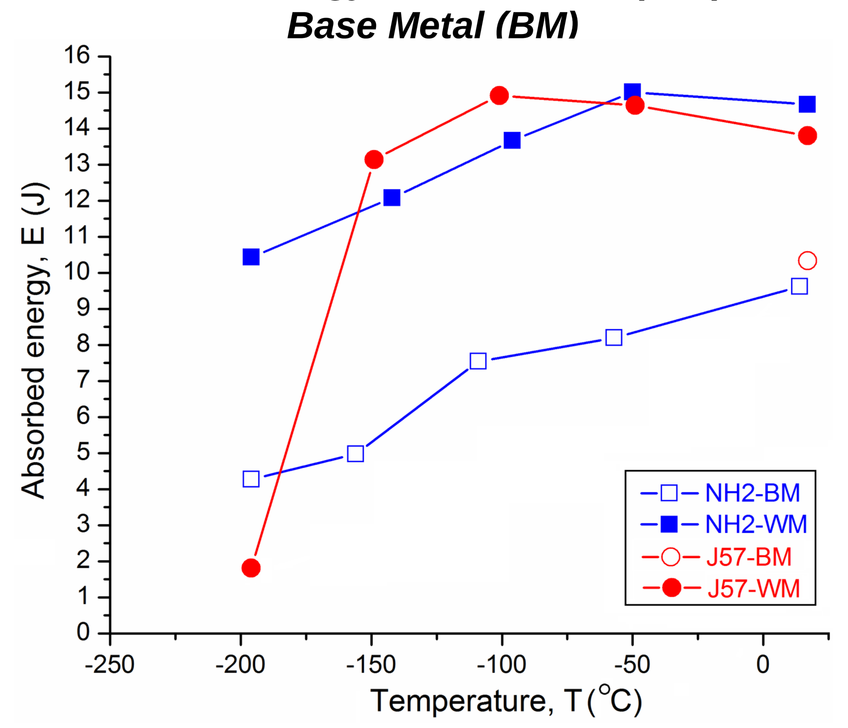


- ➢ Increase in hardness up to HV_{100} ~ 180 is observed in weld metal (WM) in comparison with that of base metal (BM) (HV_{100} ~ 145). Hardness decreases gradually from WM through the heat affected zone (HAZ) towards the BM.
- ➢ Increase in hardness in WM and HAZ in comparison with BM is caused by temperature-induced decomposition of Ti-C,O,N precipitates during welding.



- ➢ Weld metal of both alloys demonstrating mostly ductile mode of fracture accompanied by significant lateral expansion of samples;
- ➢ At -196°C the brittle fracture mode (river-like pattern) is observed for weld metal of J57.

Absorbed energy of Weld Metal (WM) and Base Metal (BM)



- ➢ Values of absorbed energies of weld metal (WM) are superior in comparison with those of base metal (BM) for both grades of V-alloys (-196°C for J57 - exception);
- ➢ The expected shift of ductile-brittle transition temperature to higher temperatures does not take place most probably due to narrow fusion zone (~1mm) and/or thermal stresses remained in weld metal because of fast cooling rate during electron beam welding;

Conclusions

- ❑ Weld metal of V-4Ti-4Cr alloys NIFS-HEAT-2 and CEA-J57-1A obtained by electron beam bade-on-plate welding showed superior impact properties in comparison with base metal;
- ❑ Weld metal of both grades demonstrated mainly ductile mode of fracture accompanied by significant lateral expansion of samples;
- ❑ In spite of the temperature-induced dissolution of Ti-C,O,N precipitations in weld metal during melting of fusion zone and subsequent solid-solution hardening of V-matrix with oxygen the expected shift of ductile-brittle transition temperature to higher temperatures does not take place;
- ❑ The obtained results testify that post weld heat treatment is not necessary to be performed after electron beam welding.