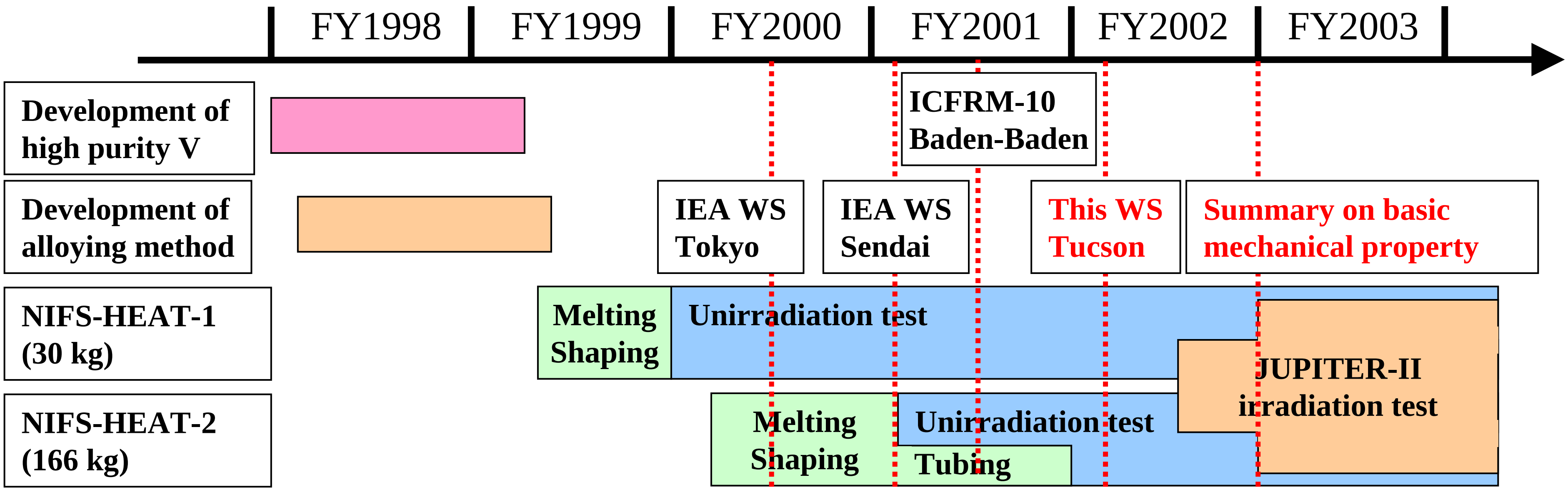
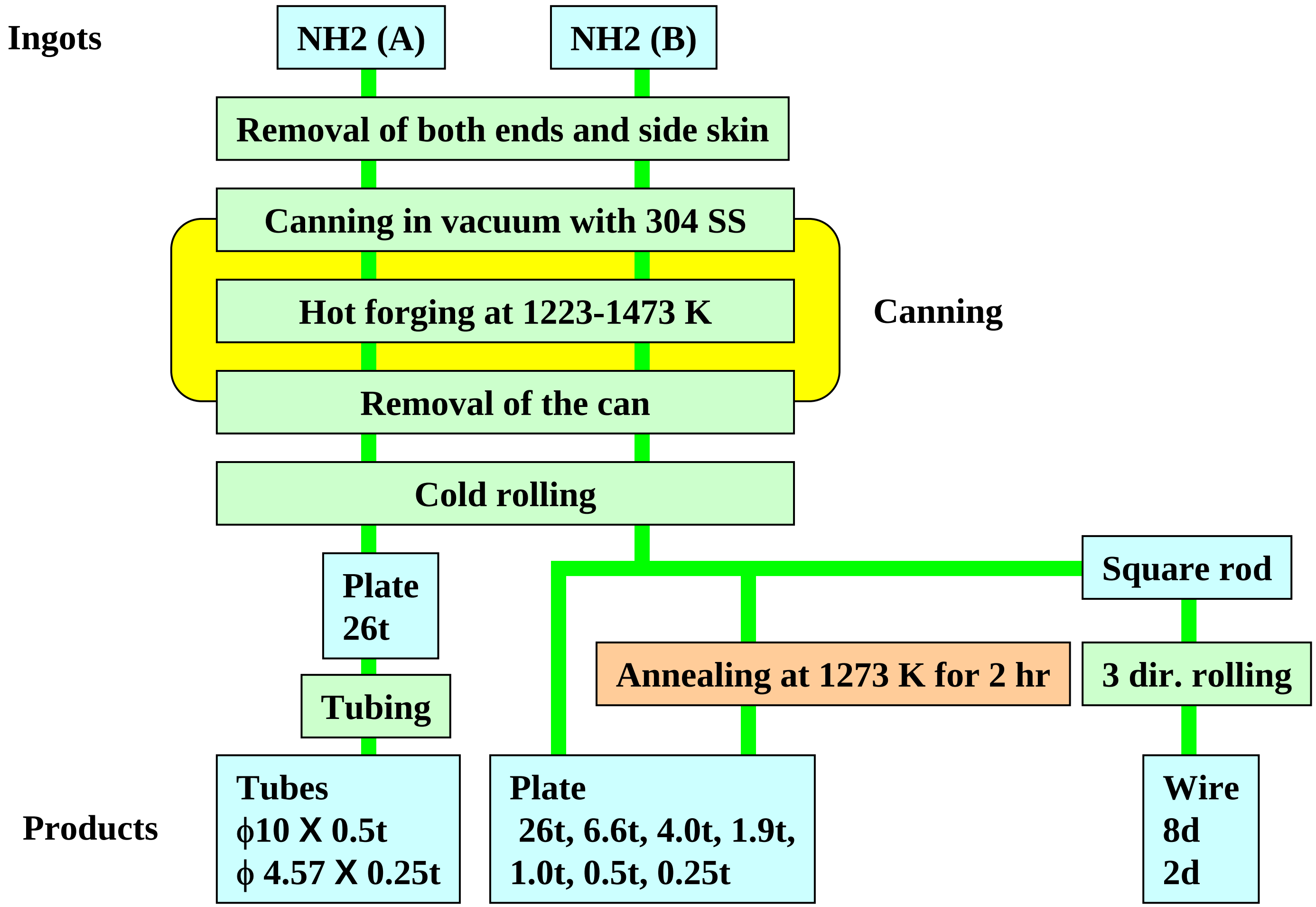
NIFS-HEAT production
Present status

6/21/2002, NH production #1, T. Nagasaka and T. Muroga, Fusion Reactor Engineering Center, NIFS, Japan



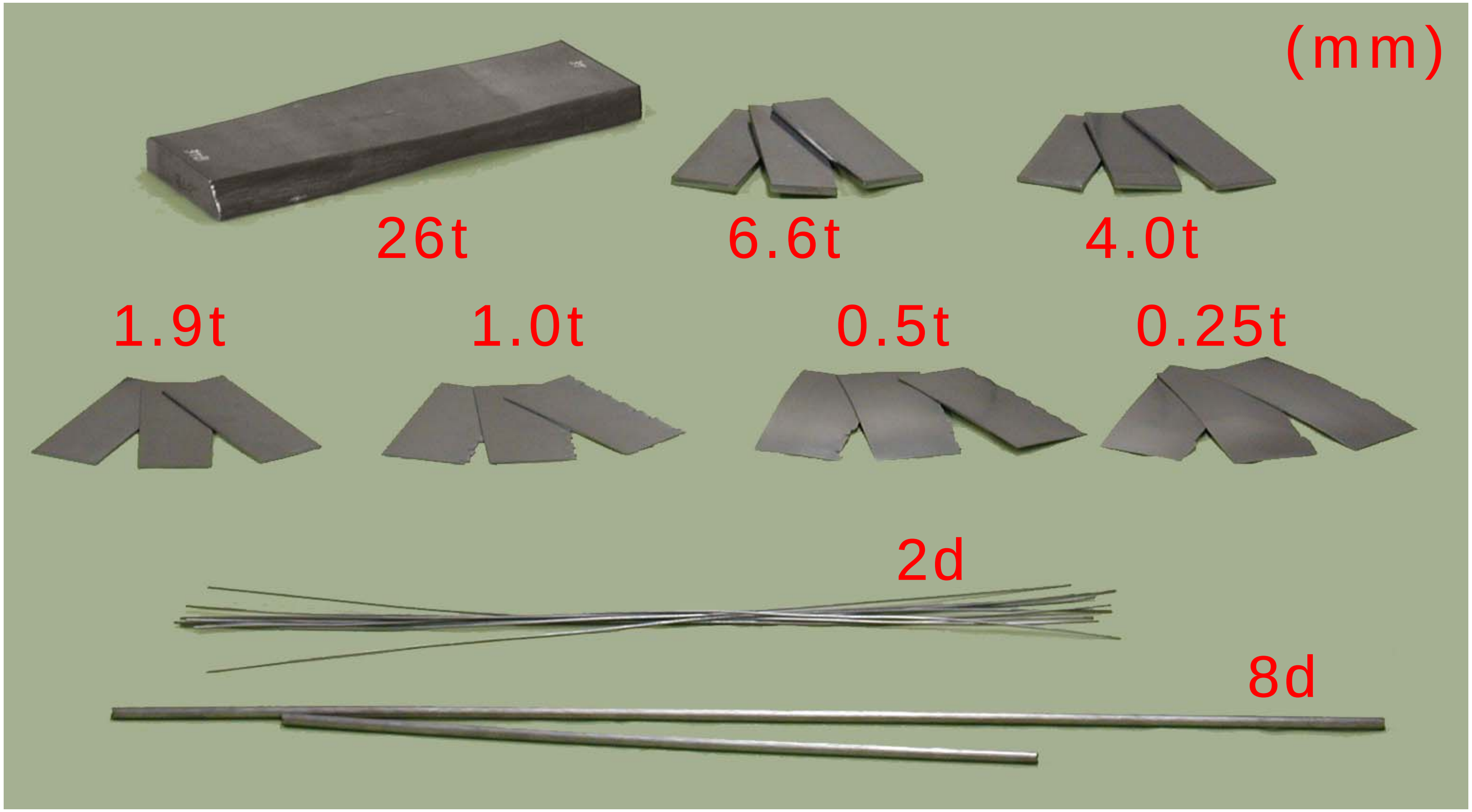
- Plates, wires and tubes has been fabricated and distributed to researchers
- New topics
  - Tube fabrication
  - Band structure development through fabrication process
  - Development of laser welding technique

NIFS-HEAT production
Fabrication process



- NIFS-HEAT-2(A): Plates and wires
- NIFS-HEAT-2(B): Tubes (including made-in-US tubes)

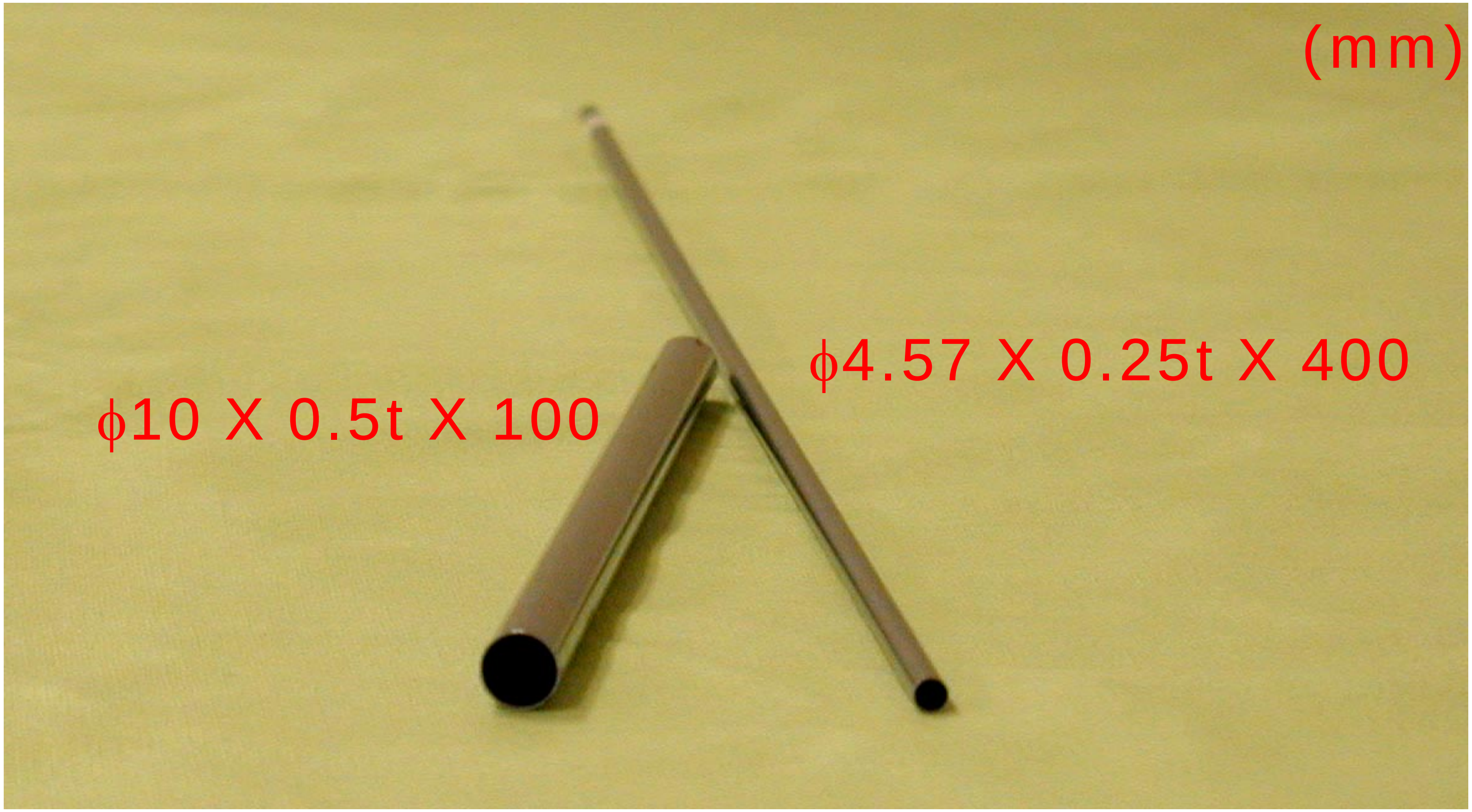
NIFS-HEAT production
Plates and wires



- Plates: Tensile, Impact, Toughness, Fatigue etc.
- 2d wires: Welding wire
- 8d rods: Ceramics bonding

NIFS-HEAT production
Tubes

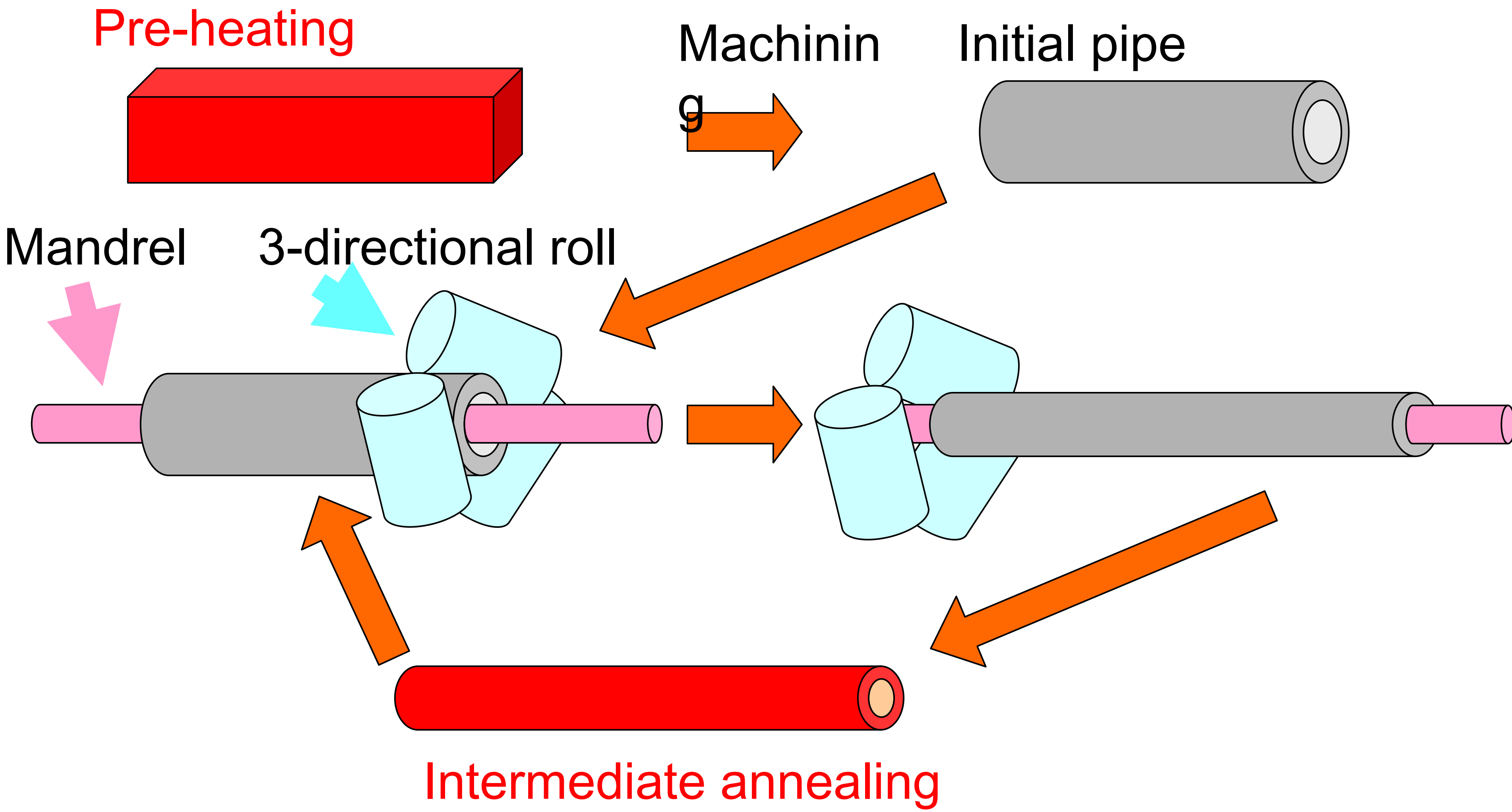
6/21/2002, NH production #4, T. Nagasaka and T. Muroga, Fusion Reactor Engineering Center, NIFS, Japan



- ϕ10 tubes: Tritium permeation
- ϕ4.57 tubes: Creep tube

Tubing
Scheme for tubing

NH2 26×26×140 mm,



Tubing
Failed case and successful case

OD: Outer diameter, ID: Inner diameter, RA: Reduction of area for 1 pass
RAA: RA accumulated from the last annealing

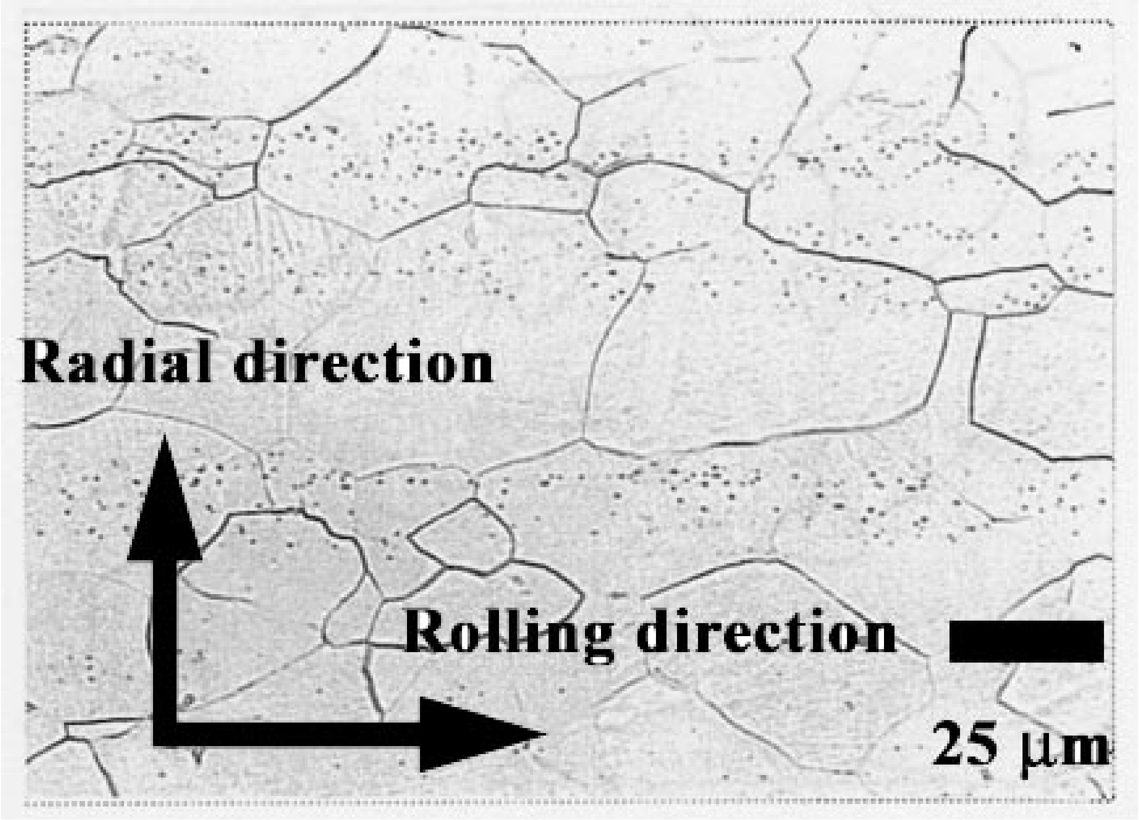
	Alloy	Initial pipe OD / ID / mm	Pre-heating / K	RA / %	Pass, RA, RAA @ cracking	Intermediate annealing	Final tube OD / ID / mm
Failed	0.87Cr-5.56Ti	25 / 19	1373	20.6-25.9	3rd pass RA = 20.6 RAA = 54.3	None	17 / 14
Failed	NH2 (A)	25 / 19	1273	20.6-41.1	8th pass RA = 41.1 RAA = 60.1	1123 K X 1 h 4 heats	10 / 9
Successful	NH2 (A)	25 / 19	1273	20.6-32.3	No crack for 9 pass (Max. RAA = 60.3)	1123 K X 1 h 4 or 5 heats	10 / 9
Successful	NH2 (A)	10 / 7	1273	21.7-36.1	No crack for 7 pass (Max. RAA = 57.2)	1123 K X 1 h 4 heats	4.57 / 4.07

- Condition to induce cracking
  - Pre-heating at 1373 K and no intermediate annealing
  - RA > 40 %

Tubing
Microstructure after recrystallization

ϕ4.57 X 0.25 t

1273 K X 2 hr



- Band structure similar to plate product was observed
- Grain size was 29 mm after annealing at 1273 K for 2 hr

Tubing
Impurity pickup

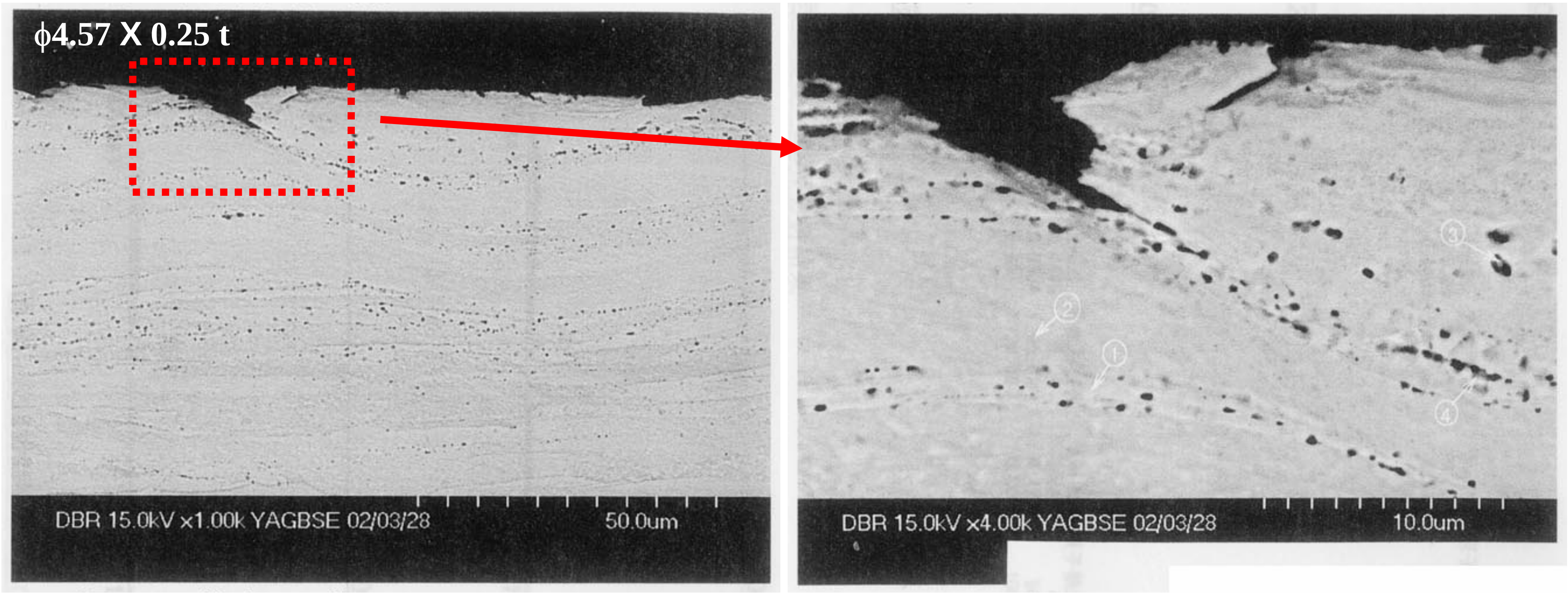
ϕ4.57 X 0.25 t

	H	C	N	O
Starting rod	146	80	108	124
After working	10	130 150	100	270 340
After final annealing	NA	NA	NA	NA

Wppm, NA: Not available, they will be analyzed soon

- C and O pickup occurred during working process
- Possible contamination source
  - Atmosphere at initial and intermediate annealing
  - Lubricant (mineral oil+animal oil+sulfide+phosphide)
- S and P should be analyzed

Tubing
Defect on the wall surface



- Scratch-like defects were observed on the both outer and inner surface
- The size of the defects was mostly 3-13 μm, and 20 μm at the maximum
- The defects seems to propagate along the band
- Top of the band wave can be initiation point of the defects

Tubing
Future plan

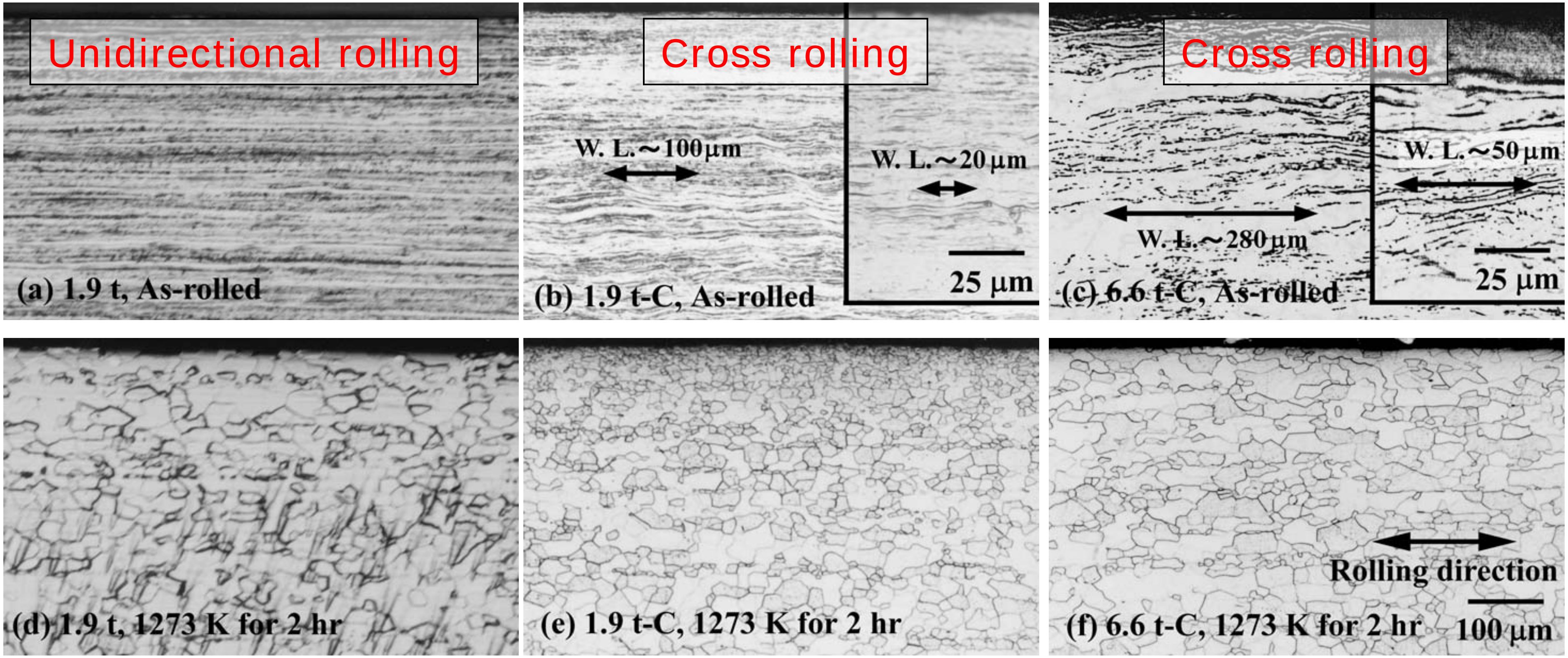
- Creep test
- Irradiation test
- Effect of final annealing condition on grain structure
- Impurity tracing

Tubing Recommendation

- Pre-heating before working: 1273 K
- RA limit per pass: 30-40 %
- RAA limit before intermediate annealing: 60 %
- Intermediate annealing condition: 1123 K X 1 h, 1 X 10^{-6} Torr
- Smooth inner surface should be made by the initial machining
- Zr wrapping with Ta spacer would reduce further the contamination from atmosphere

Tubing

Wavy bands produced by cross rolling



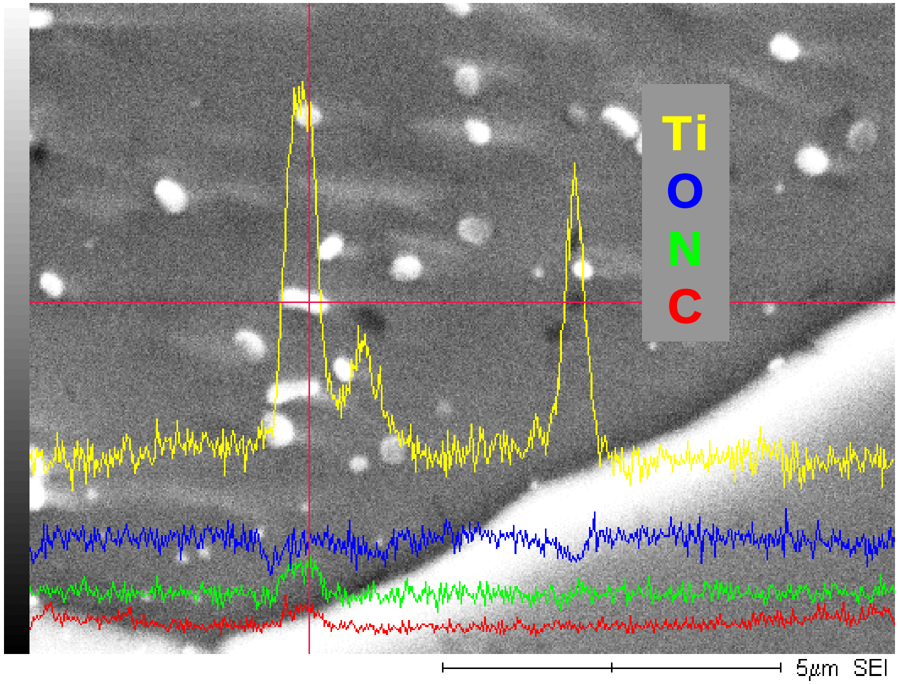
W. L.: Wave length

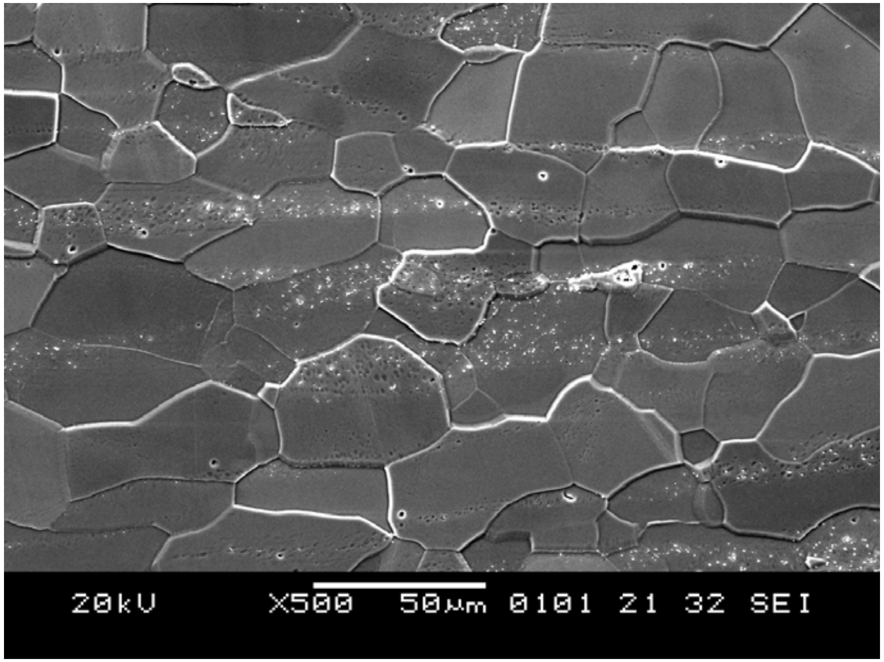
- Wavy bands were observed after cross rolling

Band structure
Ti-rich precipitates

6/21/2002, NH production #13, T. Nagasaka and T. Muroga, Fusion Reactor Engineering Center, NIFS, Japan

NIFS-HEAT-1, 6.6t, 1273 K, 1 hr

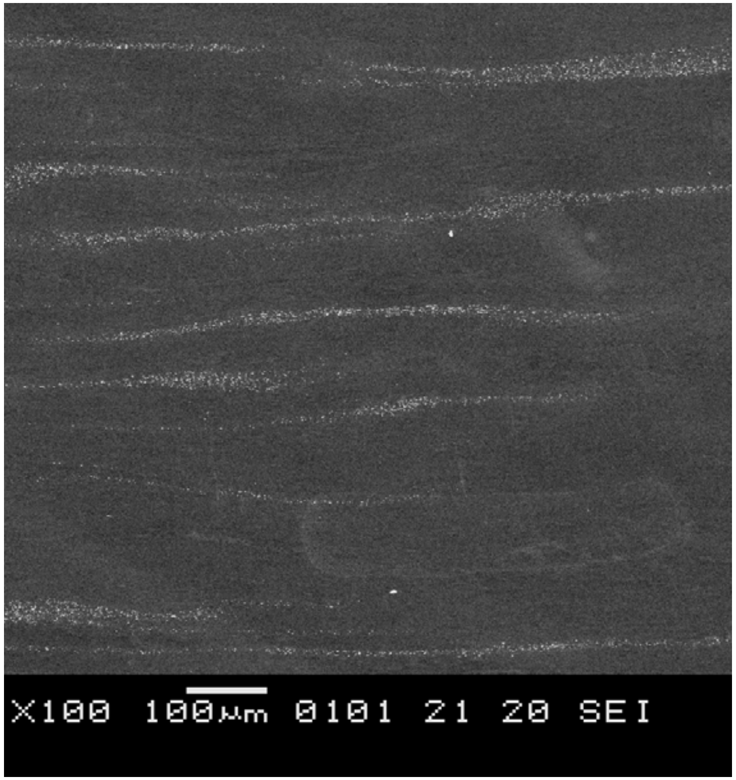




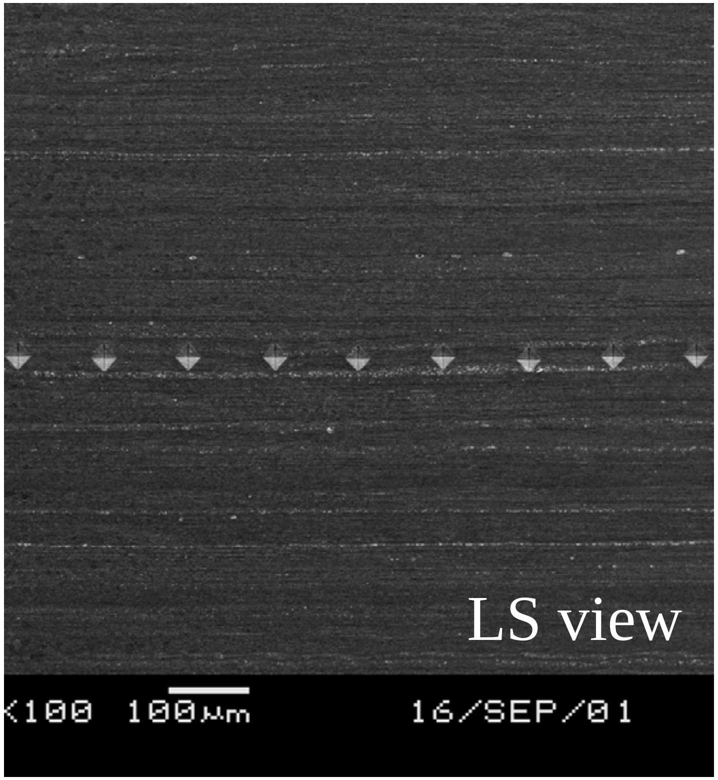
- Bands consist of precipitates containing Ti, C, N and O
- They are called “Ti-rich” precipitates in this presentation

Band structure
After hot working

After hot rolling (NIFS-HEAT-1)



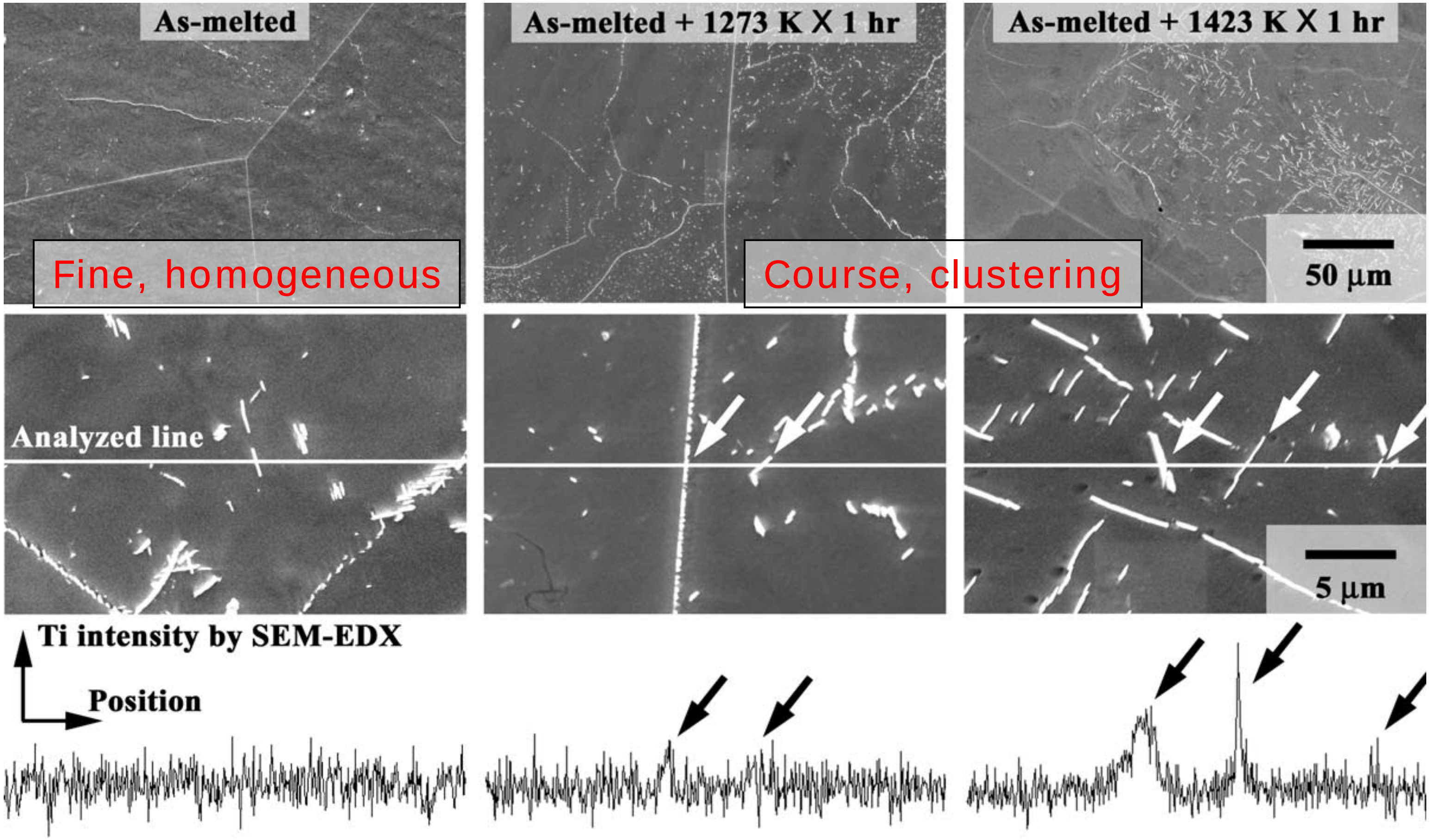
After cold rolling
(NIFS-HEAT-2 (B), 4.0t)



- Bands were already observed after hot working
- Band spacing decreased with increasing working degree

Band structure
As-melted structure

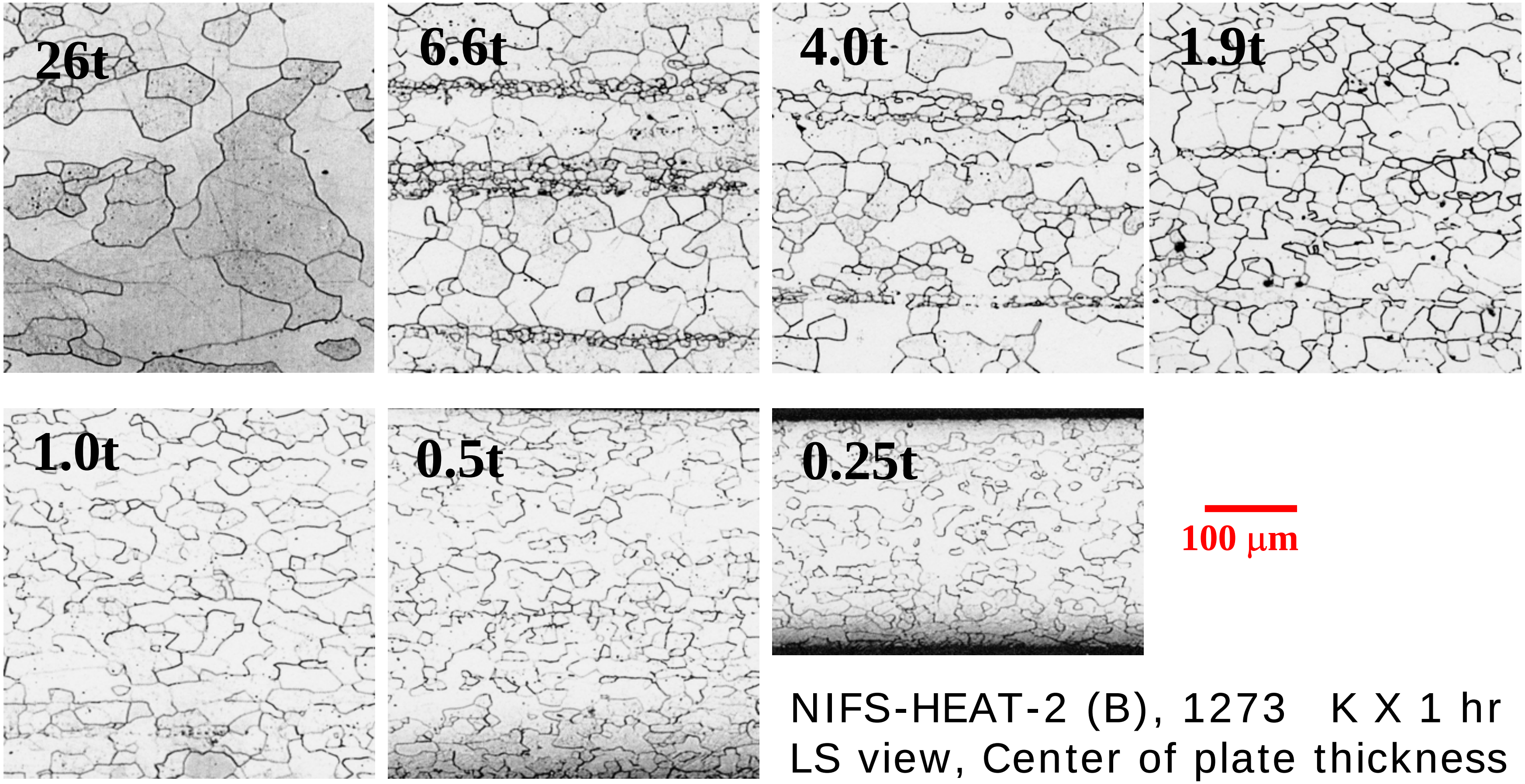
NH2 (B)



- Homogeneous precipitates observed in as-melted structure did not contain Ti
- Annealing at 1273 K and 1423 K produced Ti-rich precipitate cluster
- Ti-rich precipitates are considered to be formed and distributed as band during hot working process

Band structure
Effect on grain structure

6/21/2002, NH production #16, T. Nagasaka and T. Muroga, Fusion Reactor Engineering Center, NIFS, Japan



NIFS-HEAT-2 (B), 1273 K X 1 hr
LS view, Center of plate thickness

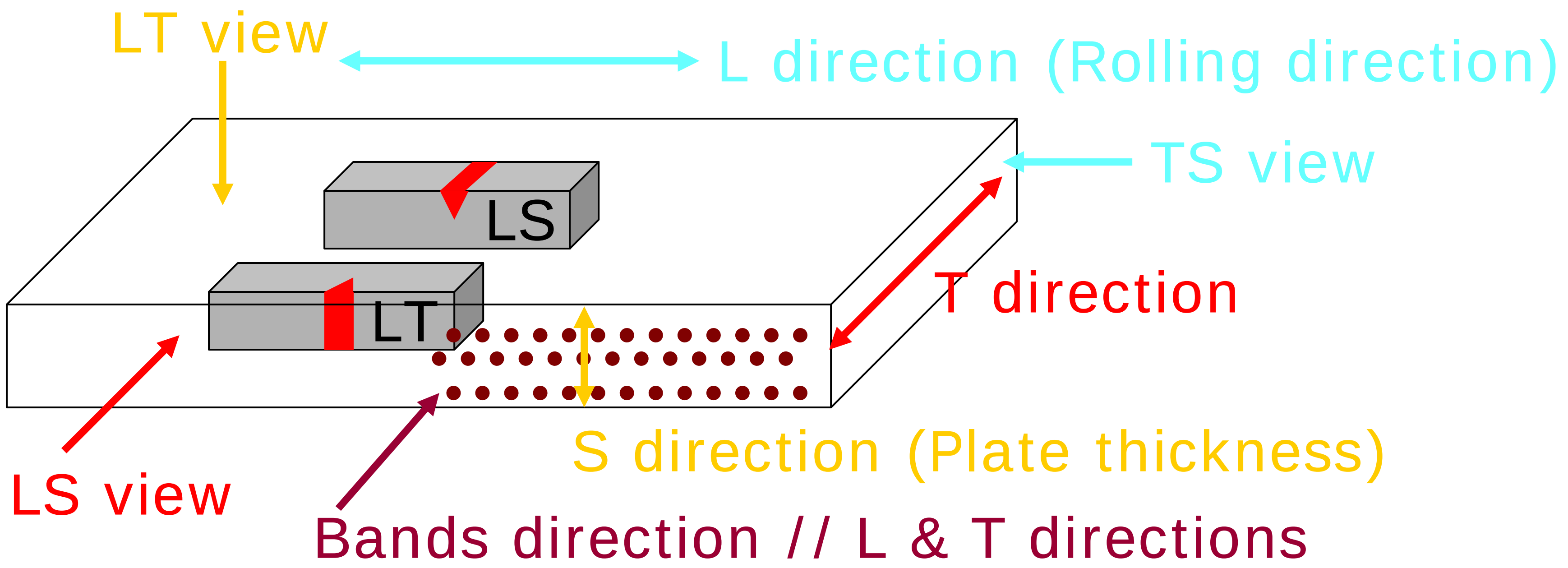
- Fine grain bands were observed in the 1.9 mm-thick or thicker plate. Distribution of Ti-rich precipitates can be homogenized by large working degree.

Band structure
Working degree

	Reduction of area at hot working / %	Draft (reduction of thickness) at cold rolling / %						
		26t	6.6t	4.0t	1.9t	1.0t	0.5t	0.25t
NH1	88		55	73	87	93	97	98
NH2 (A)	52	68						
NH2 (B)	55	74	93	96	98	99	99.5	99.8

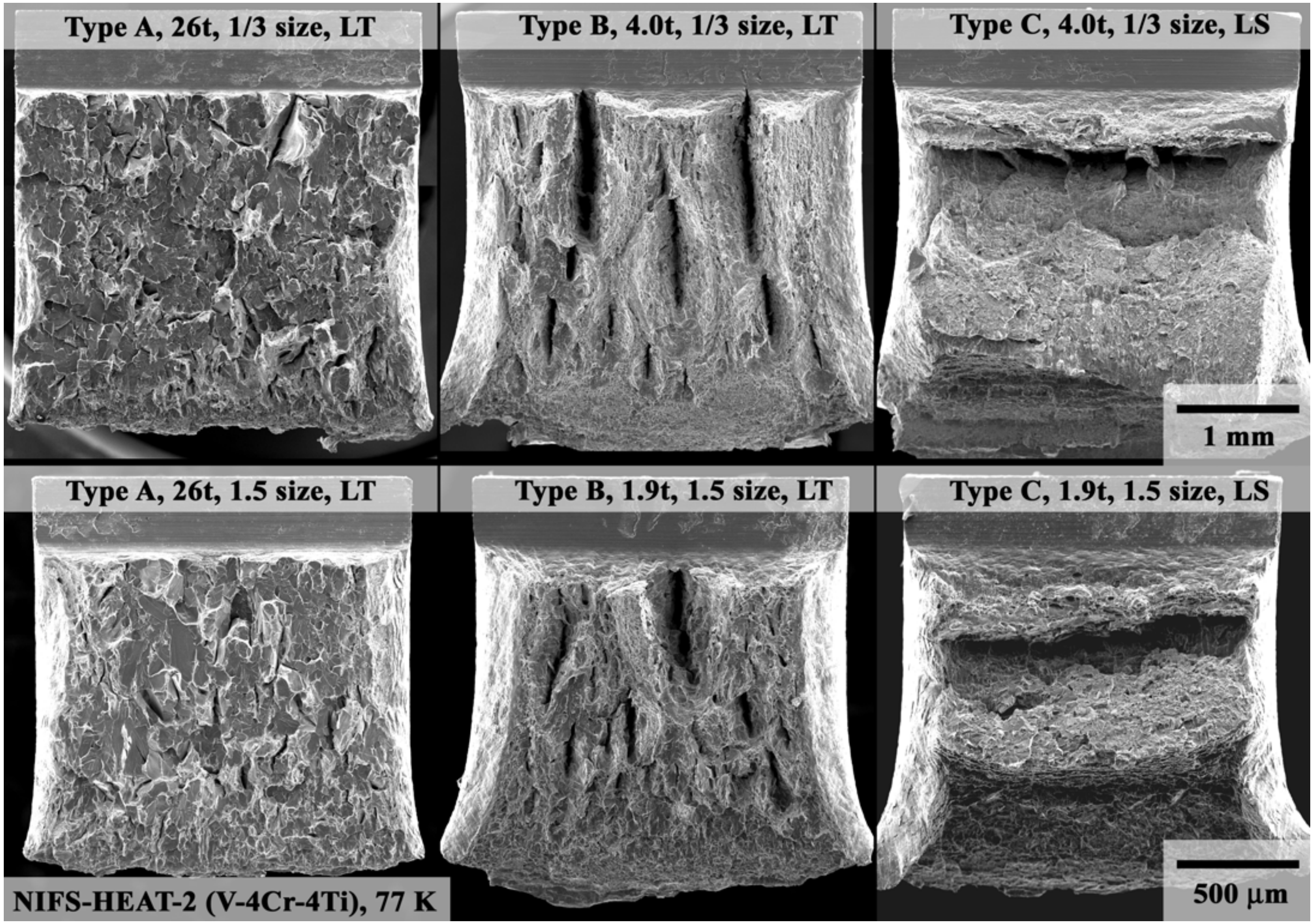
- Homogeneous recrystallization requires 99 % or more working degree

Band structure
CVN specimen orientation



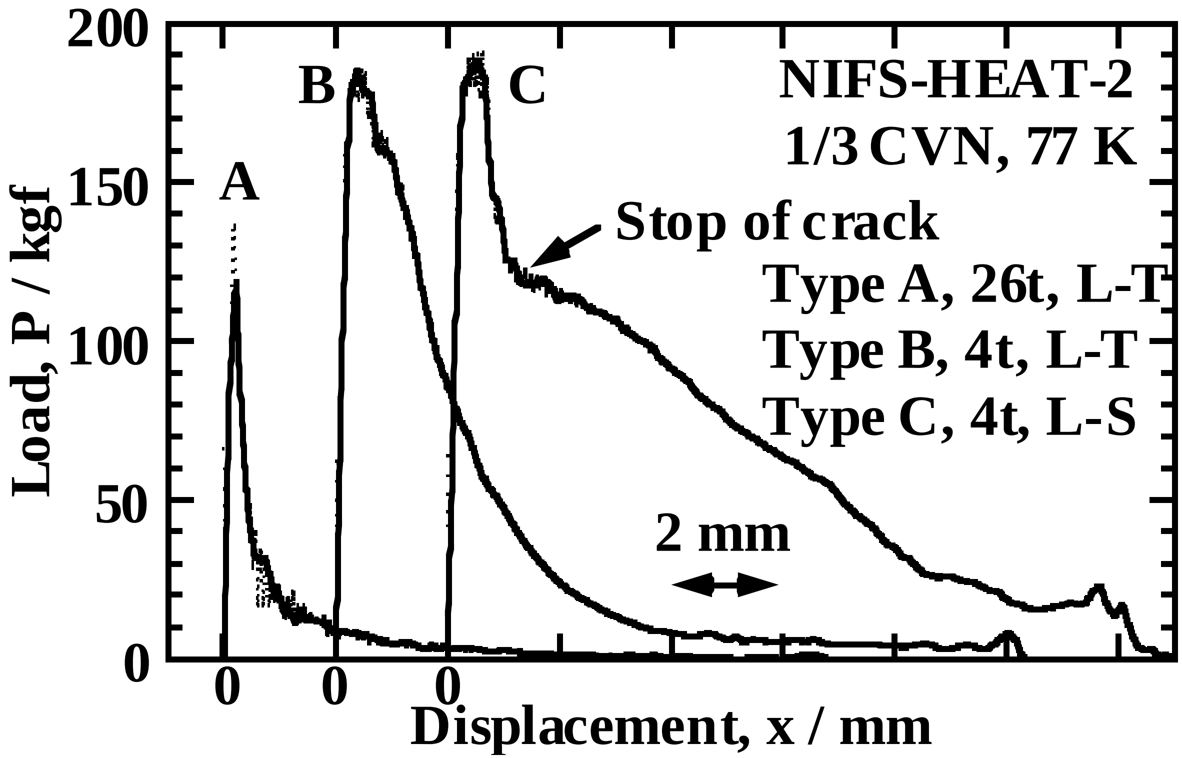
Band structure
Effect on fracture surface

6/21/2002, NH production #19, T. Nagasaka and T. Muroga, Fusion Reactor Engineering Center, NIFS, Japan



- Secondary cracking occurred parallel to the band plane
- 26t plate showed brittle fracture

Band structure
Charpy impact curves (1/3 size)

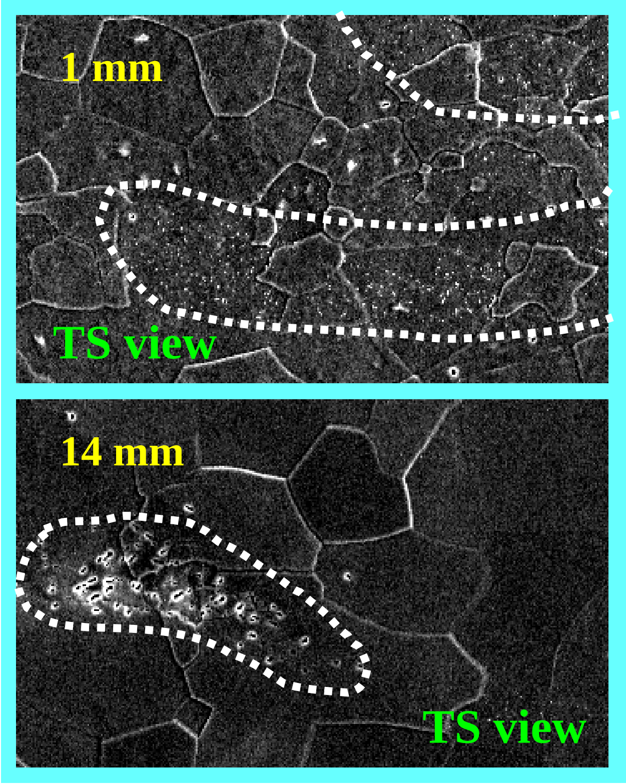


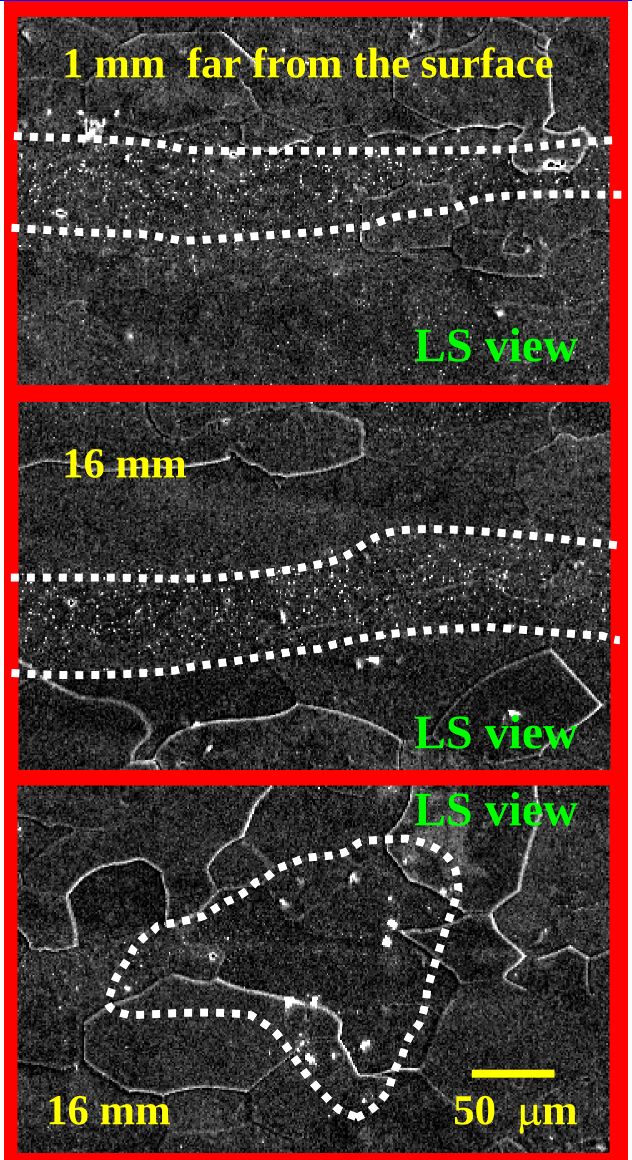
- Stop of crack propagation at secondary crack was indicated at type C fracture
- Bands are considered to increase absorbed energy, because a new crack beyond the secondary crack have to be formed without a notch

Band structure
Embrittlement of 26t plate

6/21/2002, NH production #21, T. Nagasaka and T. Muroga, Fusion Reactor Engineering Center, NIFS, Japan

- 26t plate showed brittle fracture at all the orientation and size
- CVN Specimens were taken from the center of the thickness
- Cluster of Ti-rich precipitates, which were observed in the region 2 mm or farther from the surface, seems to be responsible for the brittleness
- Local working degree around the clusters is considered to be low





Band structure Summary

- Ti-rich precipitates are considered to be formed and distributed as band during hot working process.

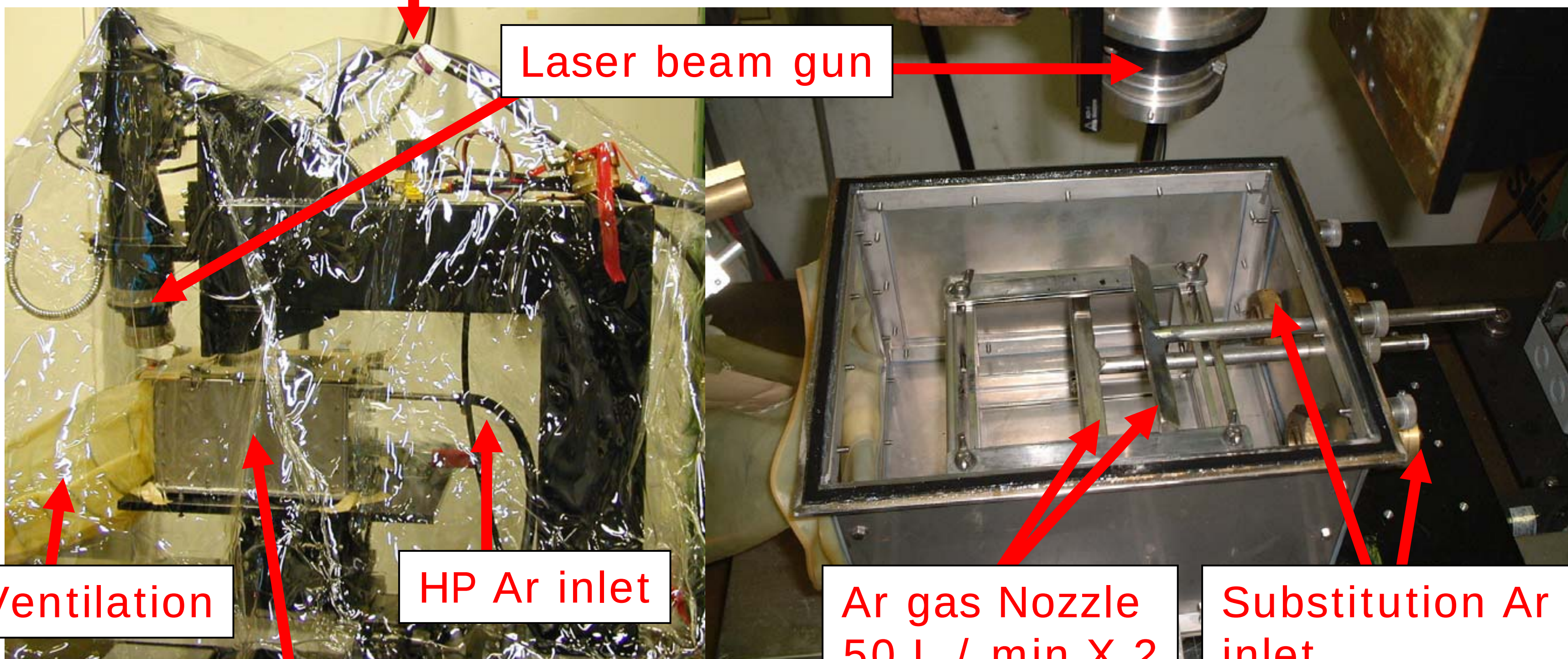
- Bands induced anisotoropic fracture mode.

- To avoid the anisotoropy of fracture mode, homogenization of the precipitate distribution may be effective. One of methods for this might be to increase the working degree.

- Future plan
  - Effect on tensile property and fracture toughness

Laser welding
Welding box

6/21/2002, NH production #23, T. Nagasaka and T. Muroga, Fusion Reactor Engineering Center, NIFS, Japan



- Welding box has been installed into 2.0 kW YAG laser welding system in Hiroshima University

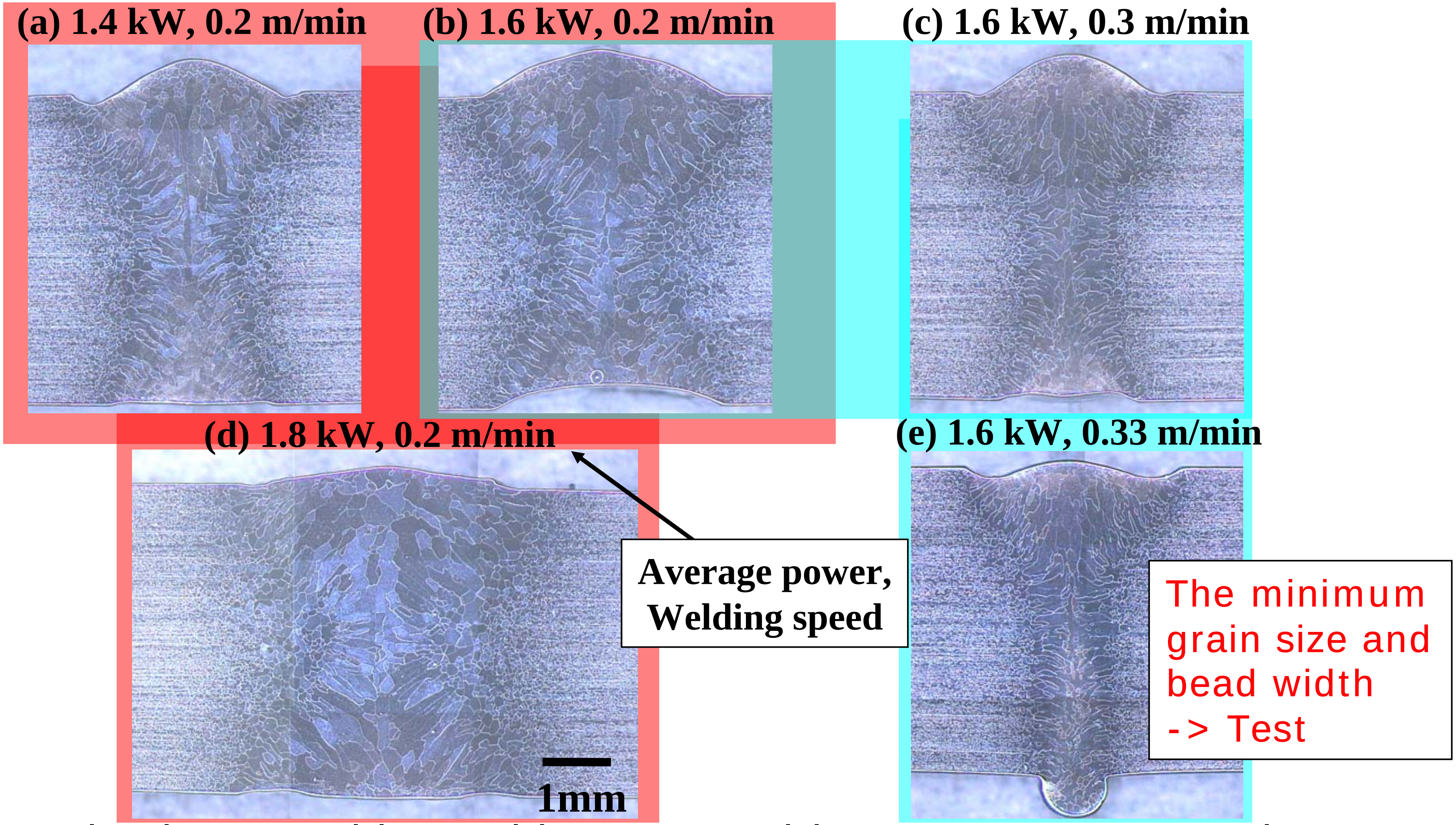
Laser welding
Impurity pickup during welding

	H	C	N	O
Before welding (NH2 (B))	29	51	123	139
After welding at weld metal	35	49	129	158

wppm

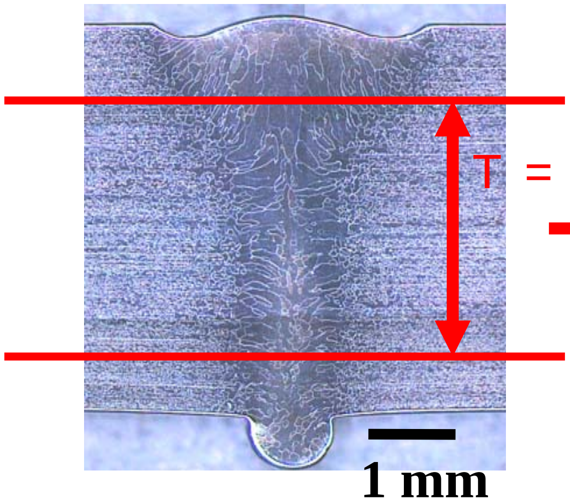
- Only 20 wppm oxygen pickup was observed

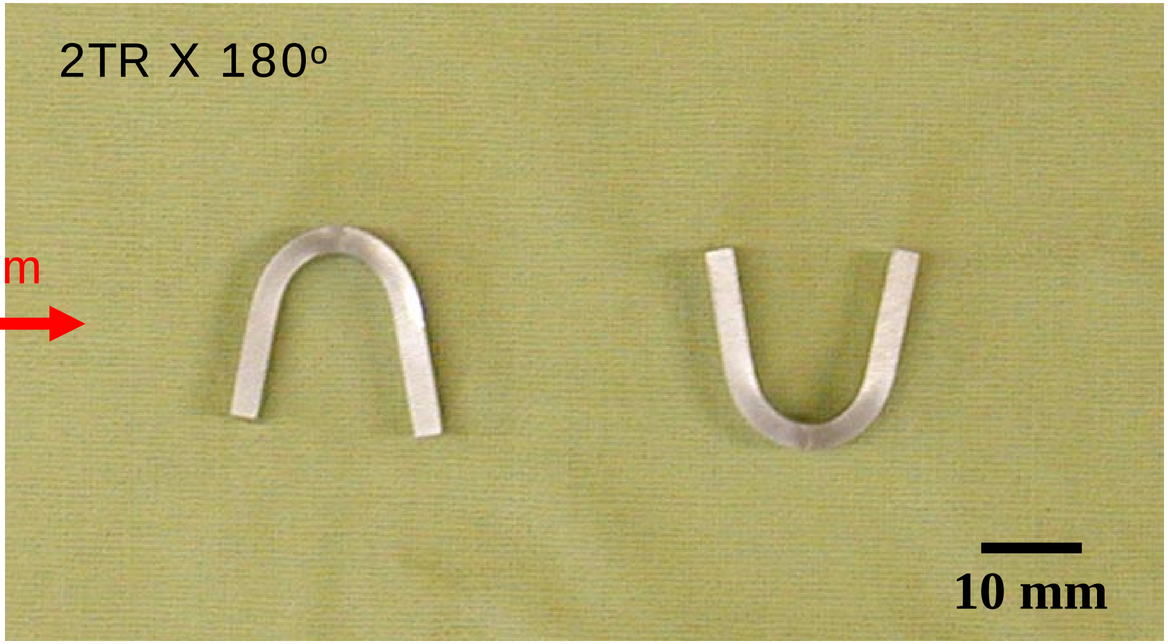
Laser welding
Effect of welding parameter



- Grain size at weld metal increases with average power, and decreases with welding speed

Laser welding
U bend test





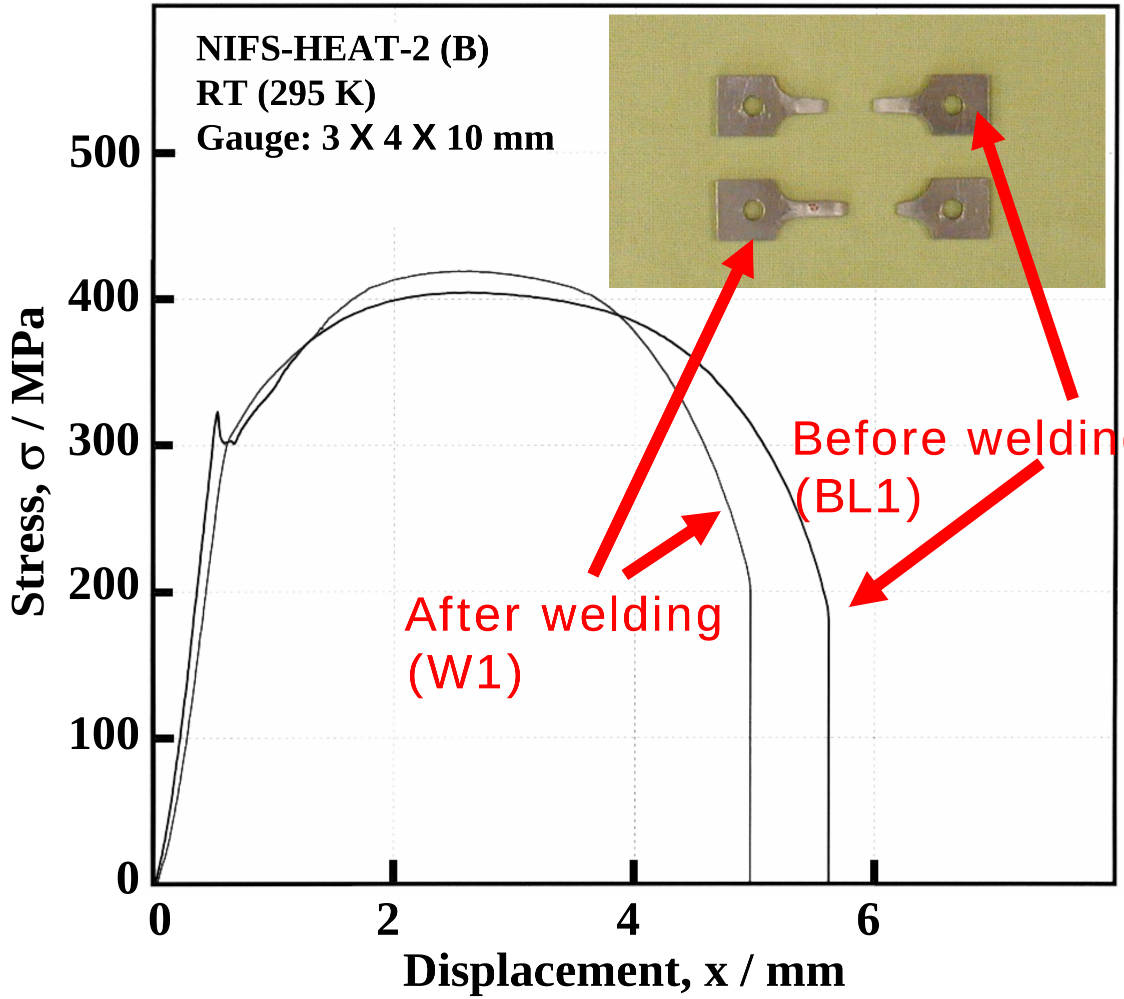
Specimen: 50 X 8 X 3 mm

- No defect was observed after U bend test

Laser welding
Tensile test

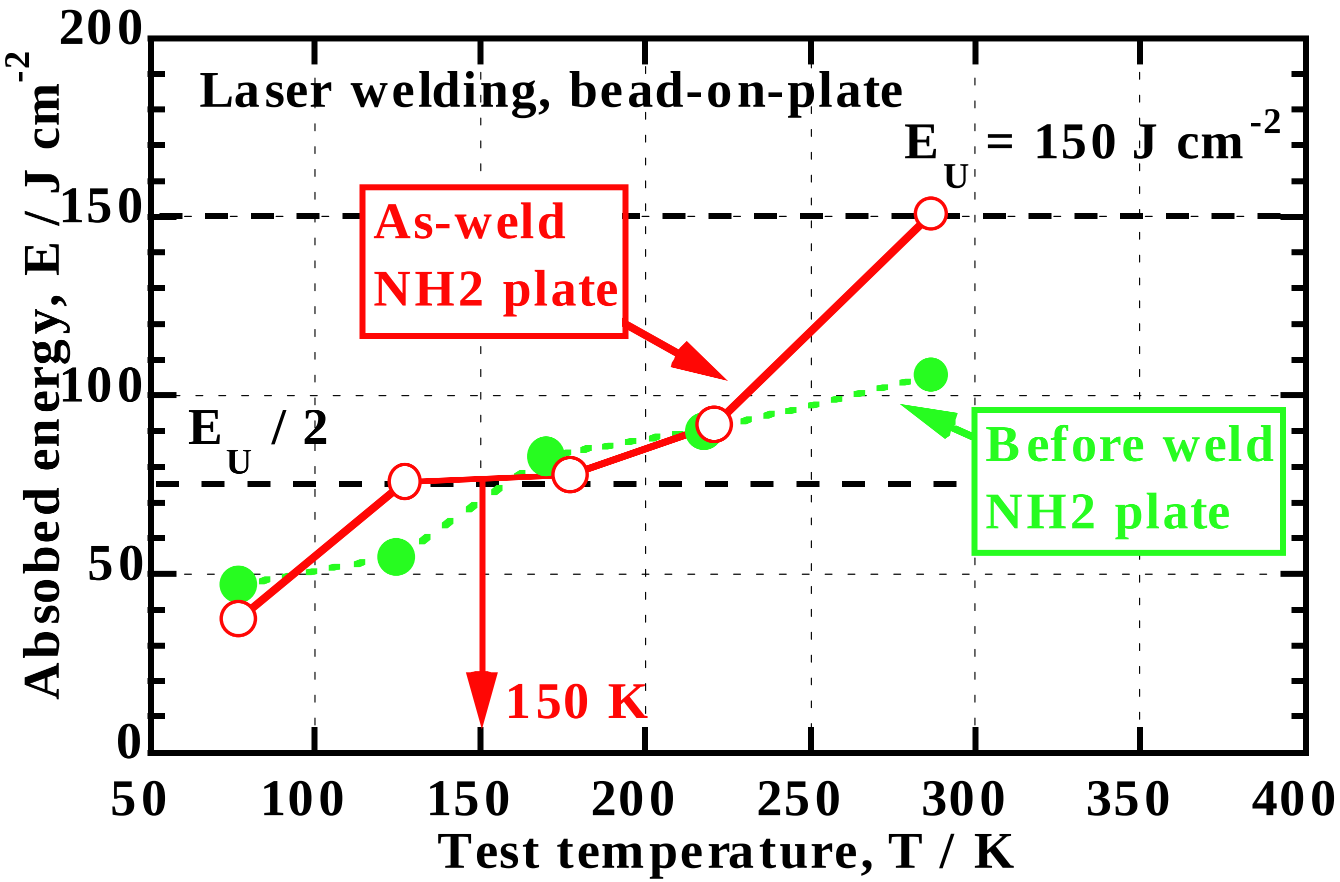
Tensile property
BL: Before welding
W: After welding

ID	YS / MPa	UTS / MPa	Tot. Elo. / %	Fracture position
BL1	323	404	50	A
BL2	313	400	48	A
BL3	310	402	50	A
W1		419	41	Base metal
W2		419	39	Base metal
W3		417	41	Base metal



- UTS after welding was comparable to that before welding
- Weld specimens were fractured at the base metal

Laser welding
Charpy impact test



- Impact property of weld metal at as-welded condition is comparable to that before welding

Laser welding
Summary

- Welding box has been developed. No pickup of H, C, N was detected. Oxygen contamination was observed, and was only 20 wppm.
- U bend, tensile and Charpy impact test showed good results at as-welded condition.
- Future plan
  - Characterization of HAZ
  - Effect of aging
  - Effect of oxygen
  - Bonding to other low-activation material