Boron: Type IV Cracking

Fujio Abe, M. Tabuchi,
S. Tsukamoto and Y. Liu

National Institute for Materials Science (NIMS)

ABE.Fujio@nims.go.jp

NIMS

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3. Suppression of Type IV cracking by boron
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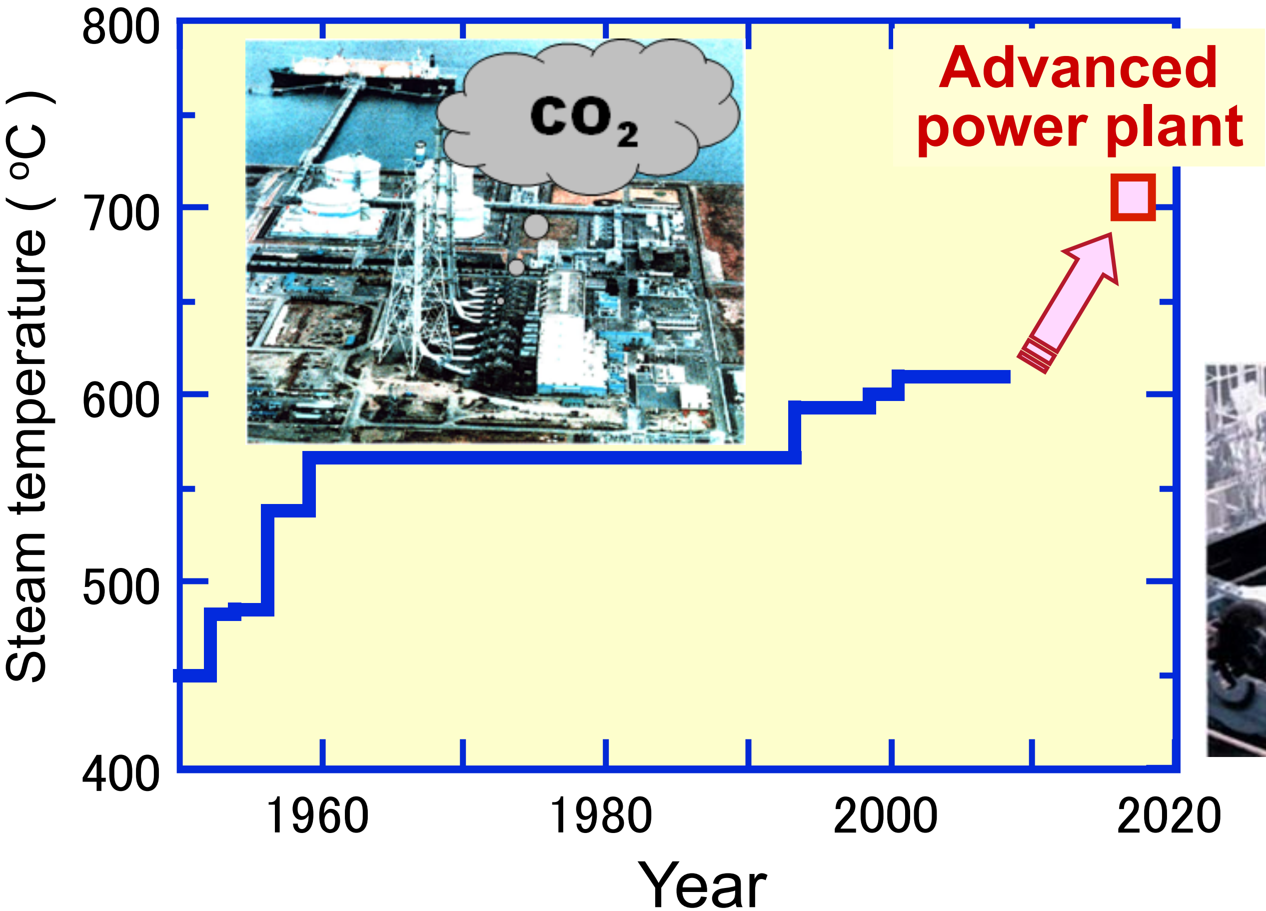
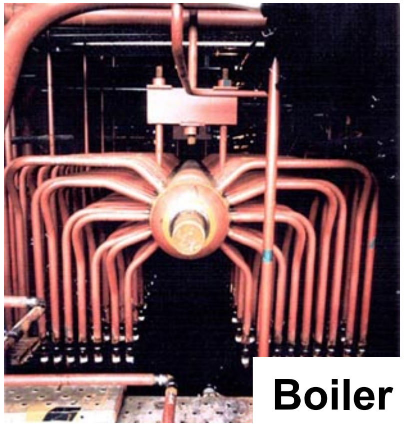
5. Summary

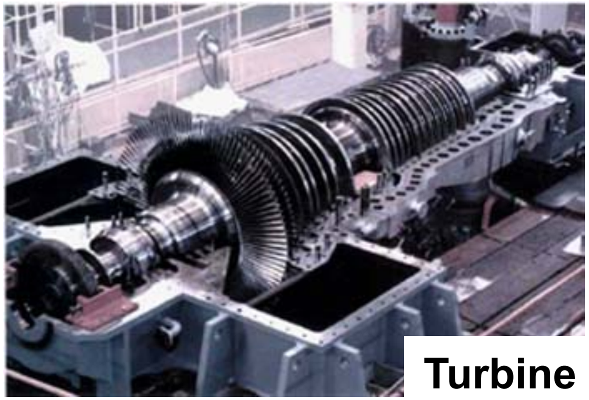
Higher steam temperature is strongly desired

Coal-fired power plants in Japan



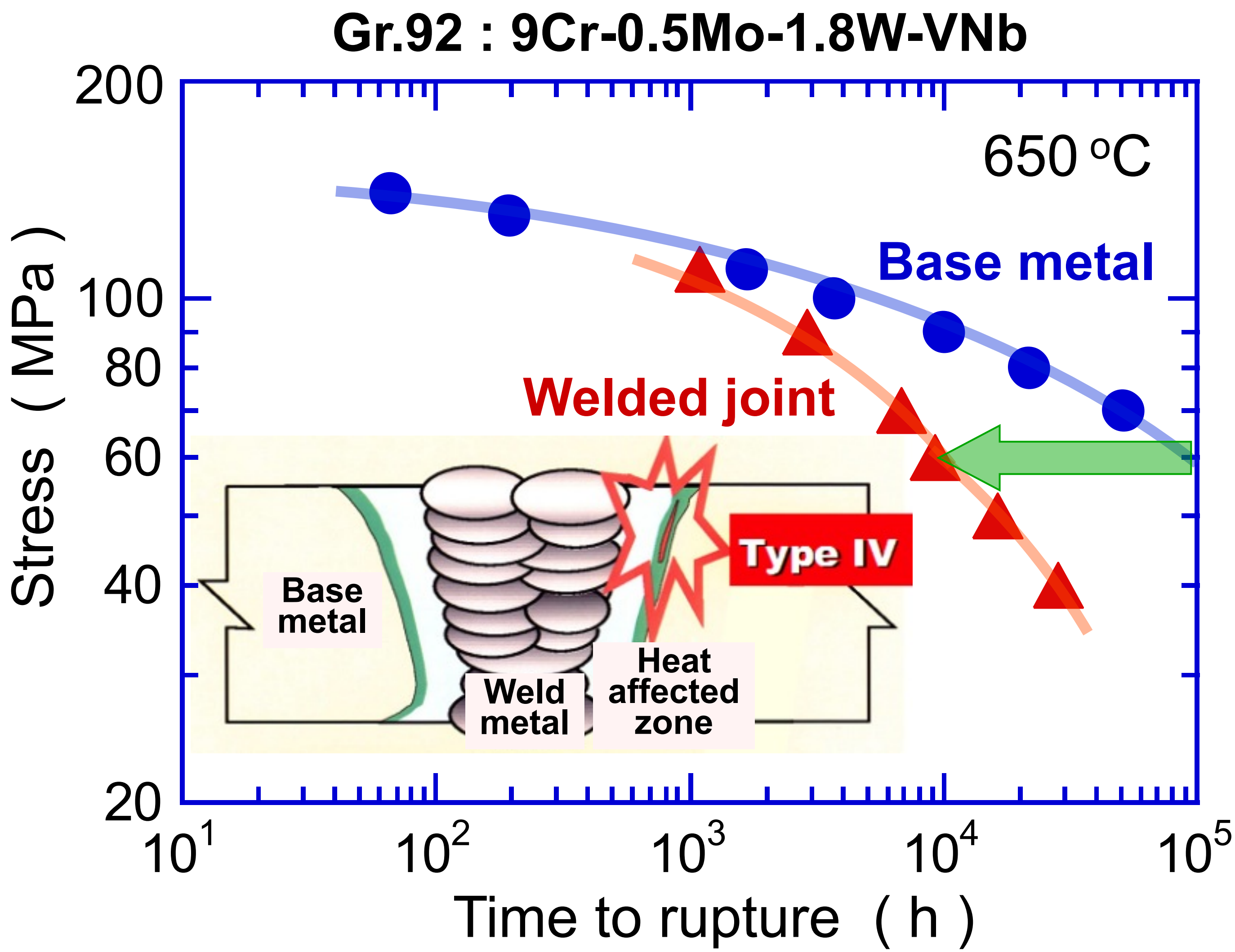


Boiler



Turbine

Conventional 9% Cr steel (Gr.92) shows significant degradation in welded joints



Objectives

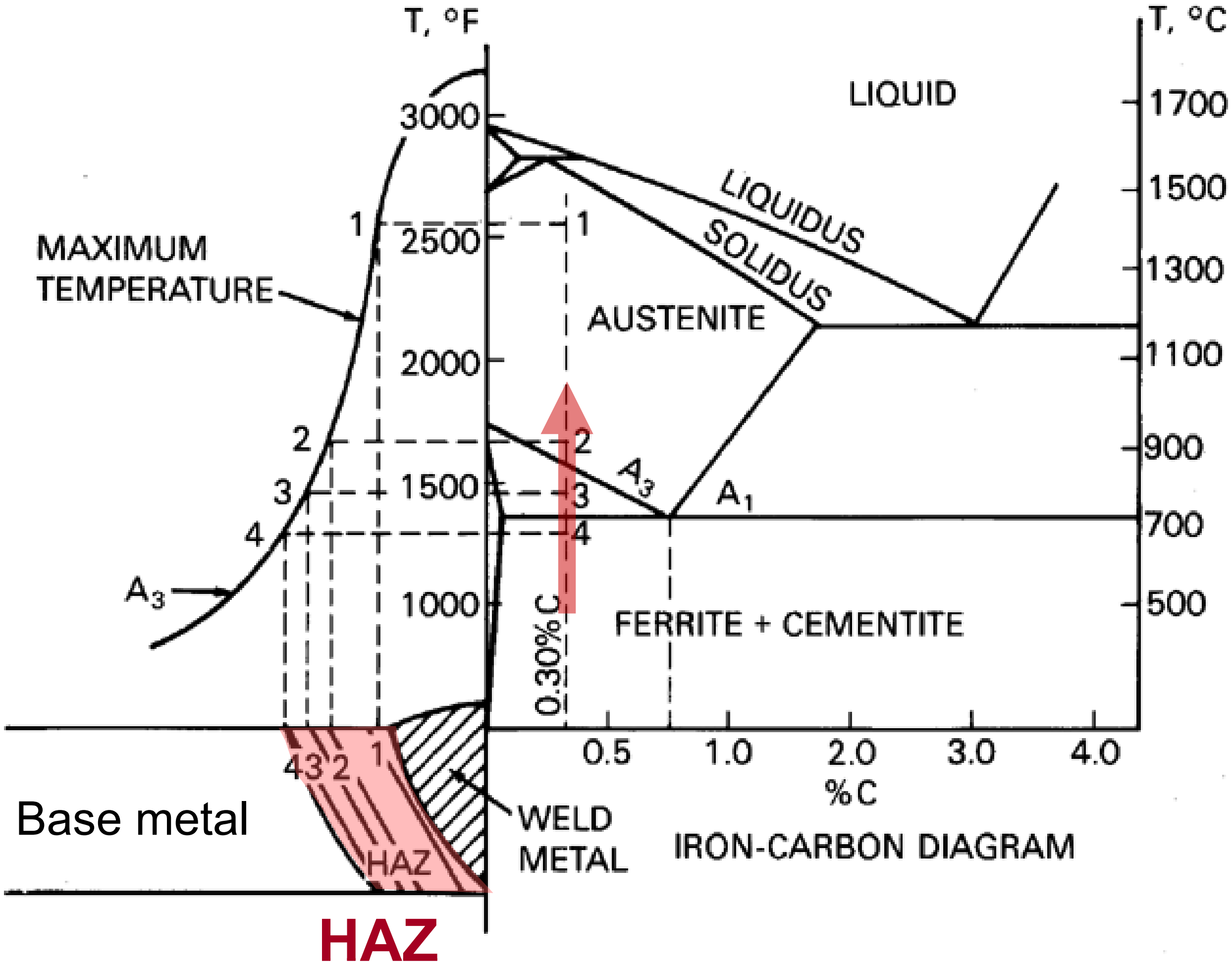
- to make clear mechanisms for lower creep strength of HAZ than base metal

  Fine grains?

- to make clear boron effect on suppression of Type IV cracking in HAZ

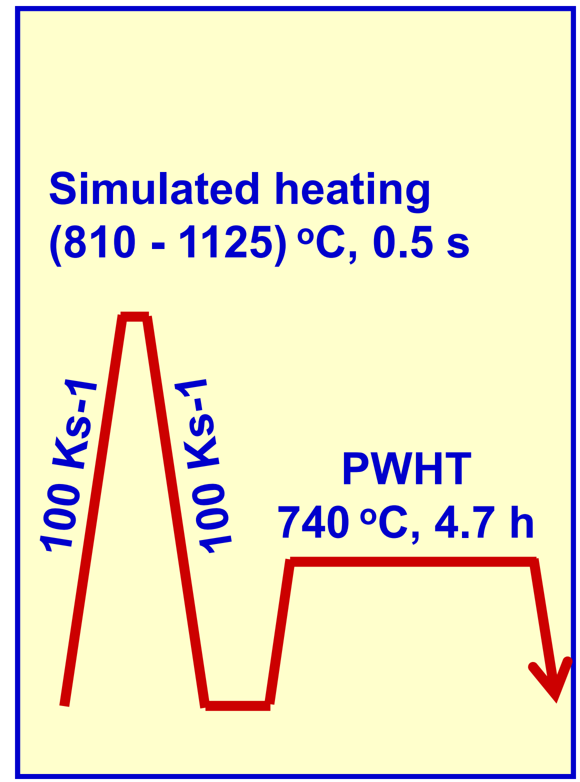
- to establish alloy-design of 9Cr steel with high strength and no Type IV cracking

Simulated heat-affected-zone (HAZ) specimens



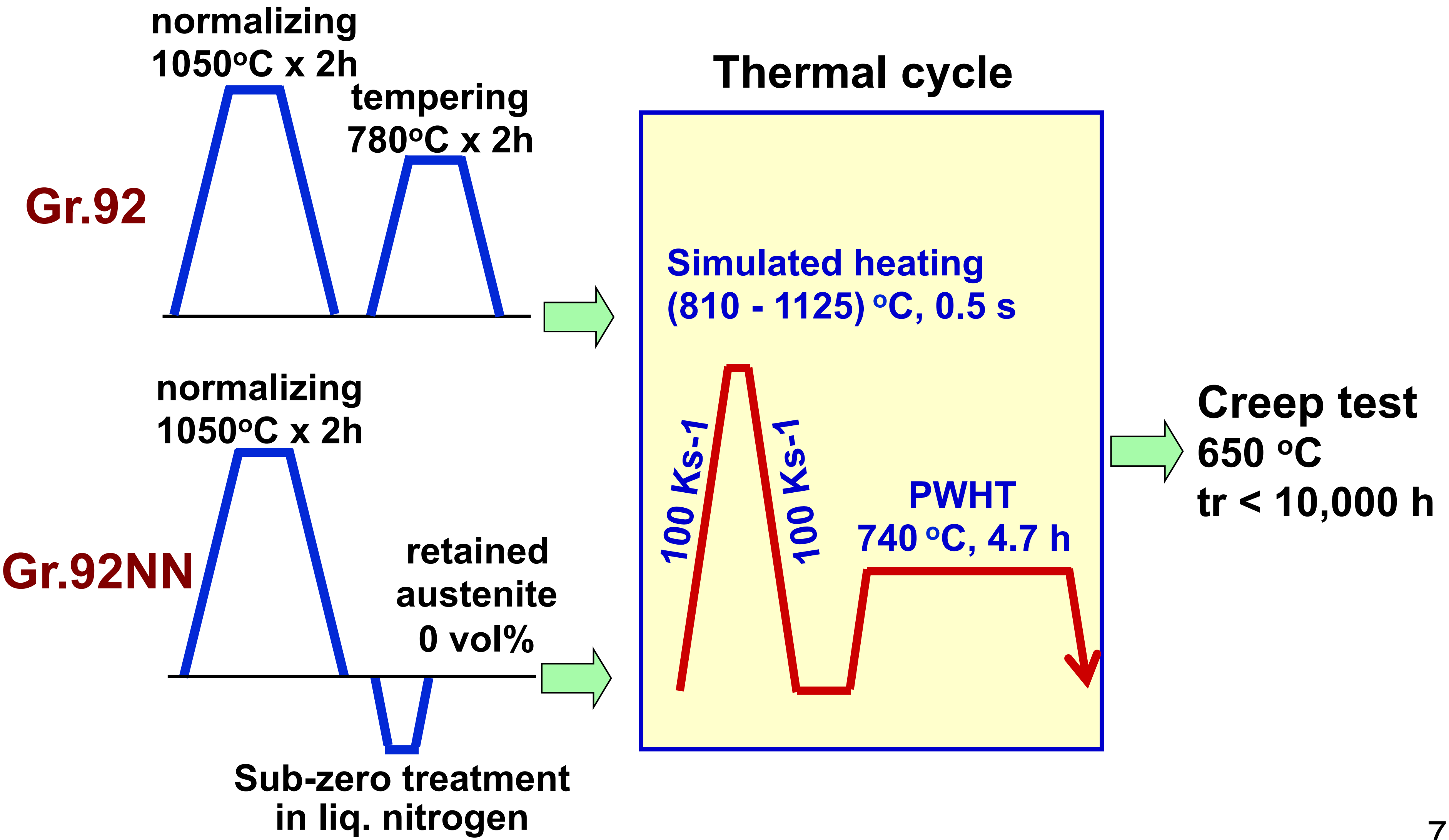
M. Santella et al. (2006)

Thermal cycle

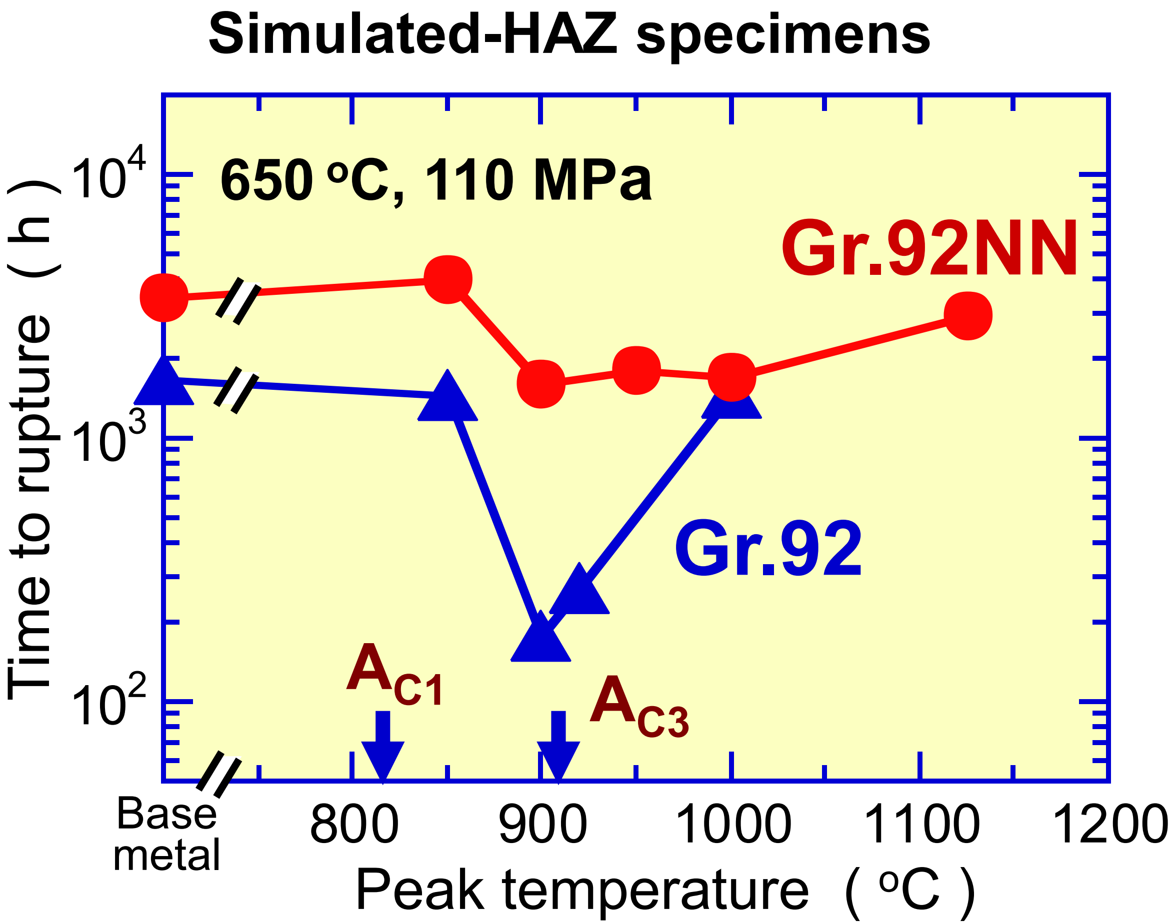


Same grain size, Different amount of GB $M_{23}C_6$ carbides

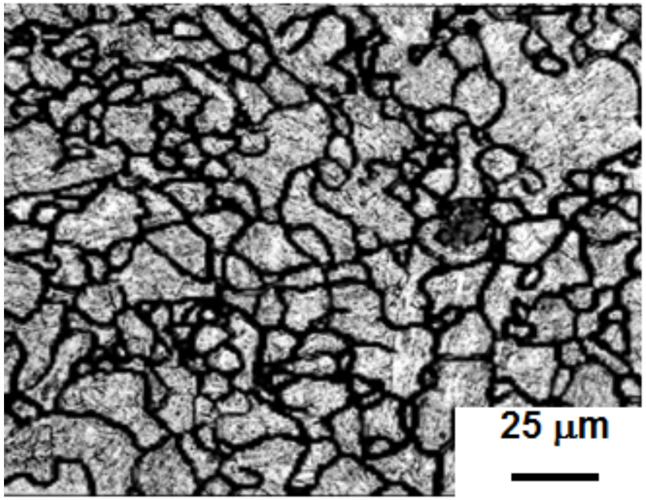
Gr.92 : 9Cr-0.5Mo-1.8W-0.2V-0.05Nb



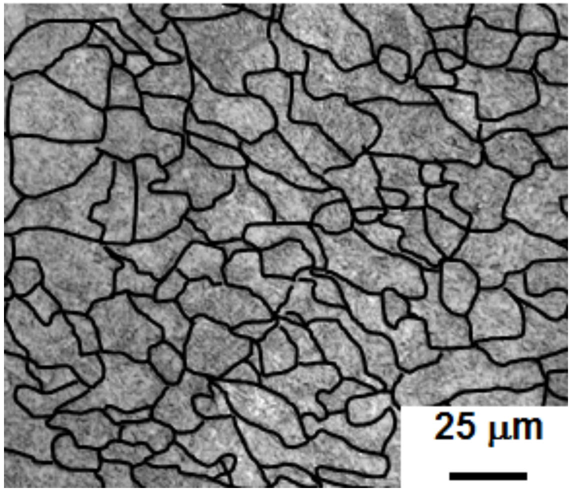
Grain refinement is not a main reason for degradation



Gr.92
after A_{C3} thermal cycle



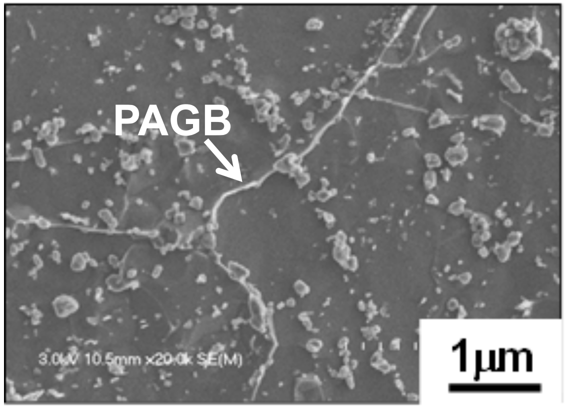
Gr.92NN
after A_{C3} thermal cycle



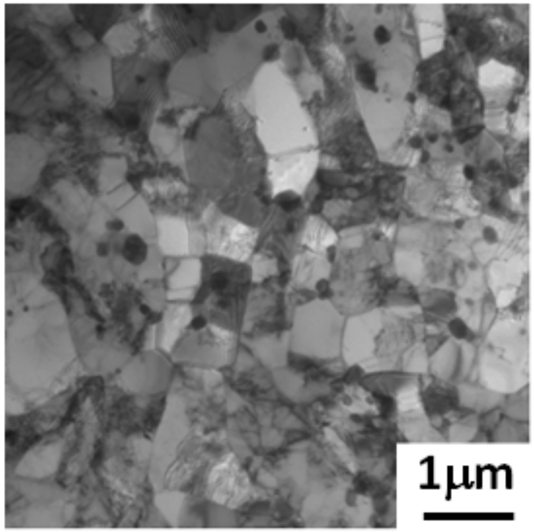
Microstructure after A_{C3} thermal cycle

Gr.92

normalizing
→ tempering
→ A_{C3} thermal cycle

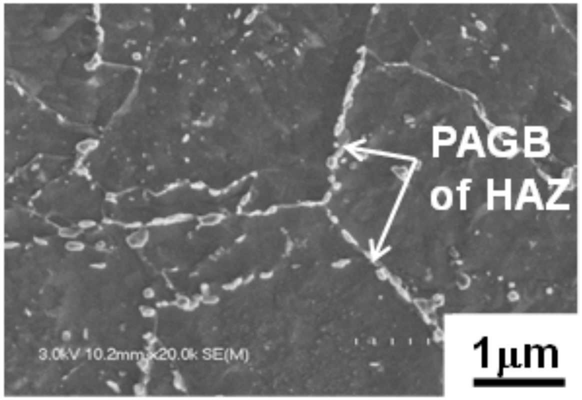


Poor $M_{23}C_6$ along GB and Sub-GB

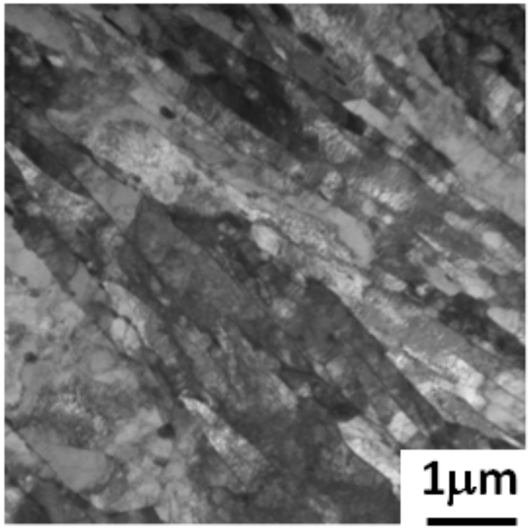


Gr.92NN

normalizing
→ sub-zero in liq. N
→ A_{C3} thermal cycle

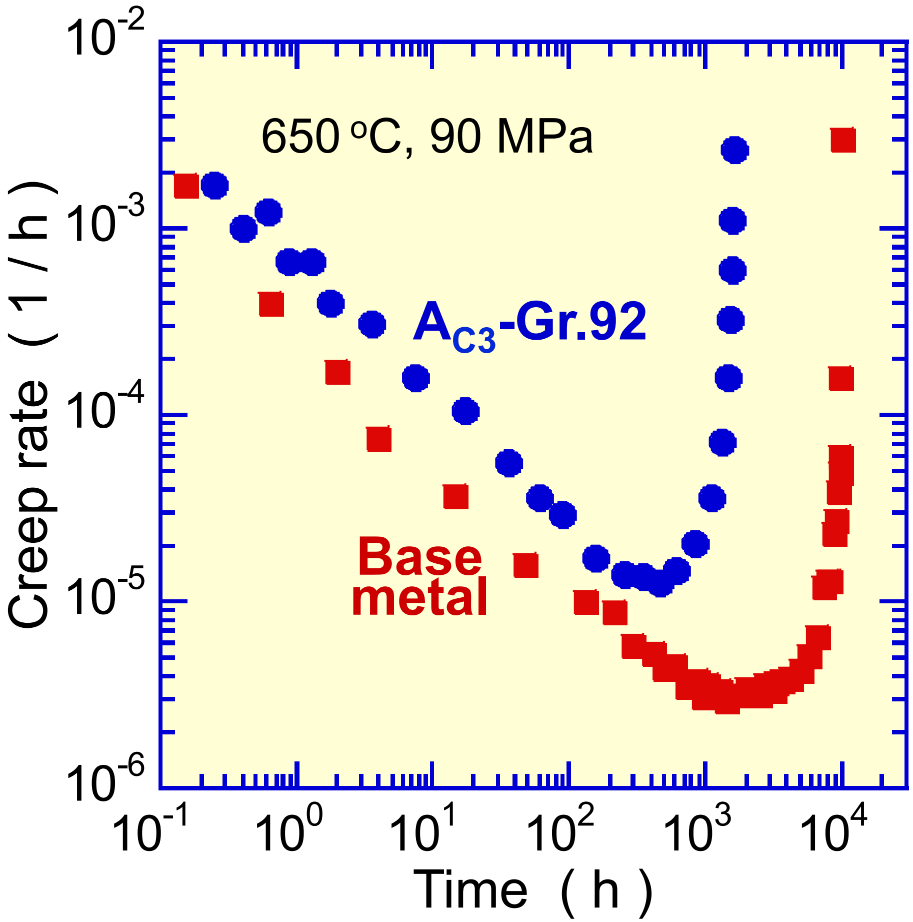


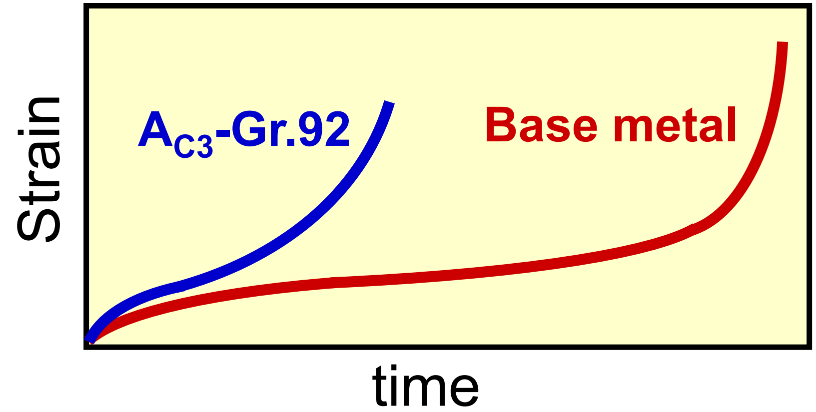
Enough $M_{23}C_6$ along GB and LB

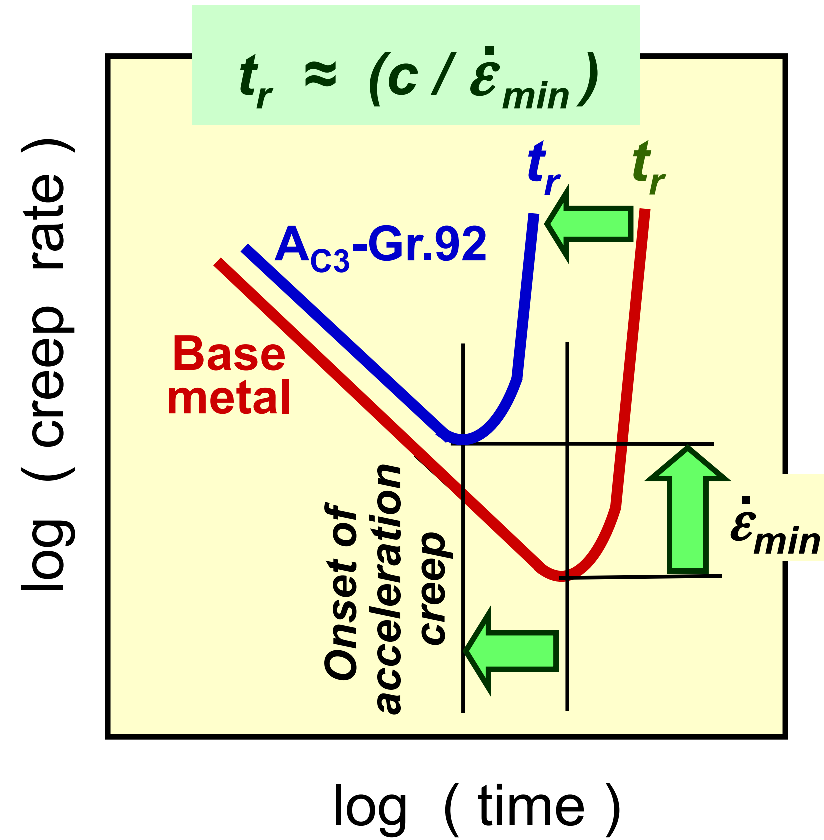


LB :
lath boundary

Poor GB $M_{23}C_6$ promotes microstructure recovery

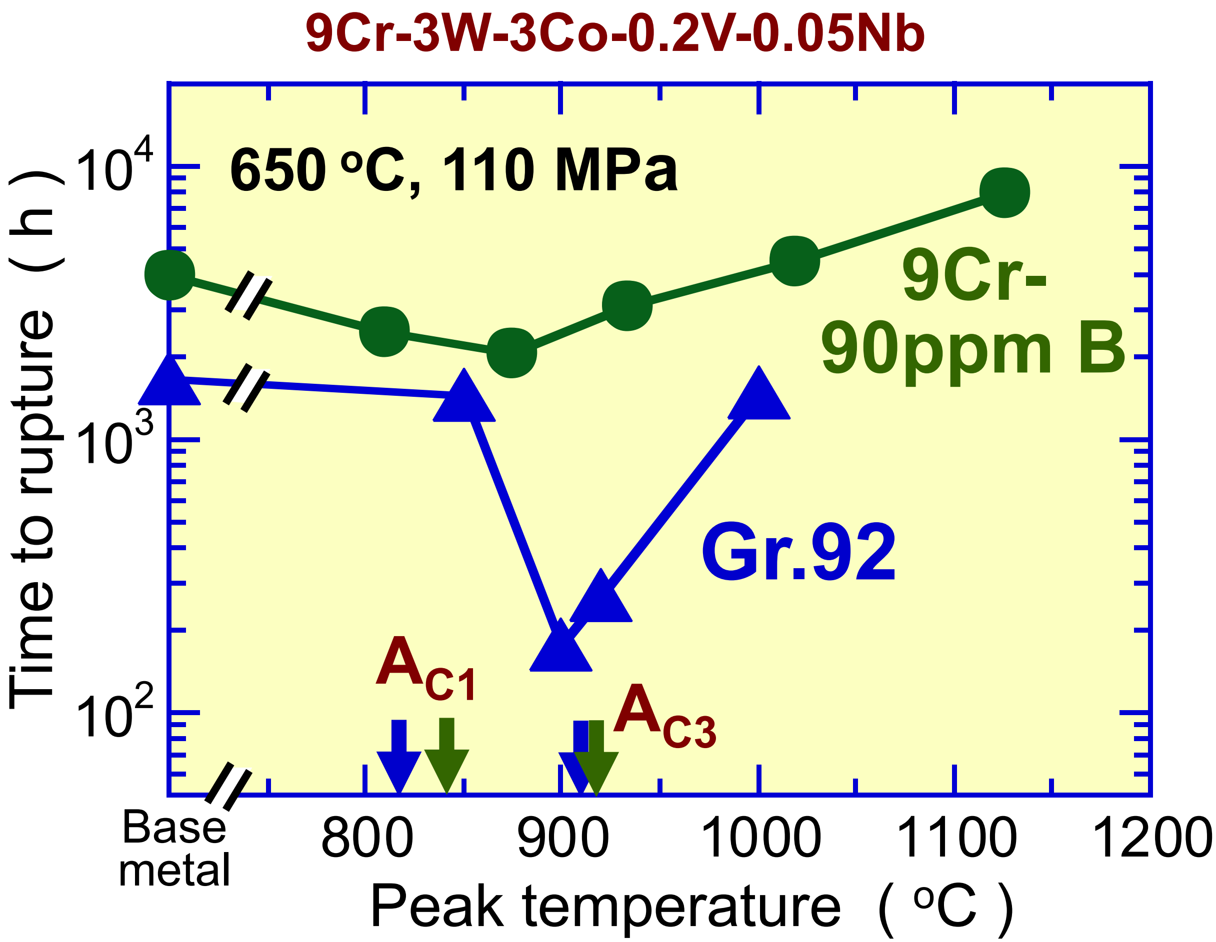






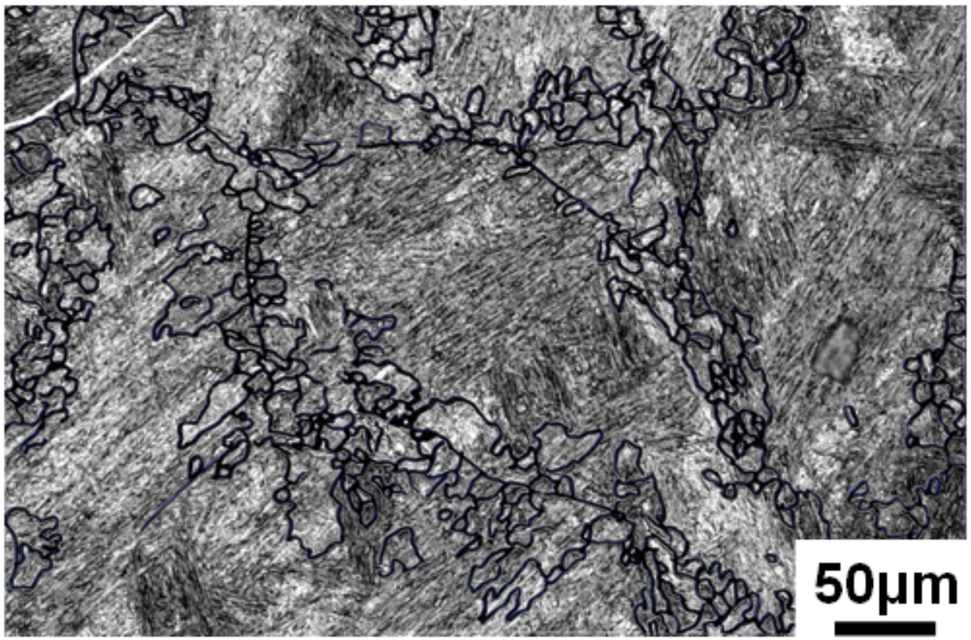
9Cr-90ppm boron steel

No degradation even after A_{C3} thermal cycle

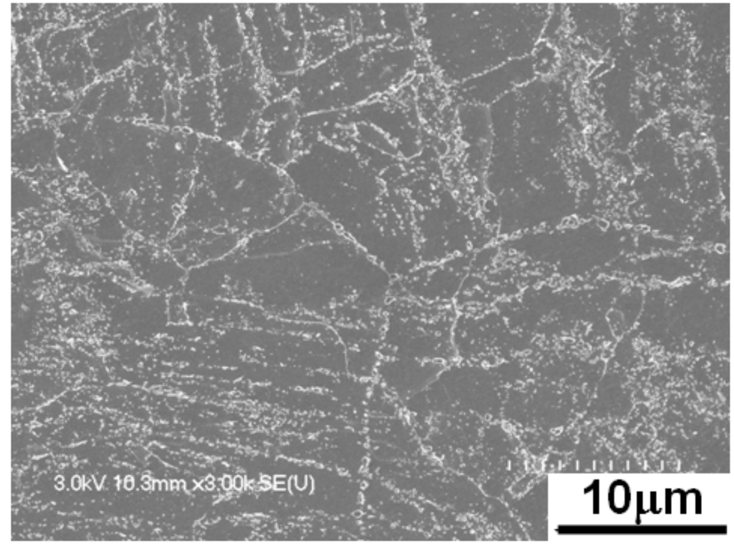


9Cr-90ppm B
after A_{C3} thermal cycle

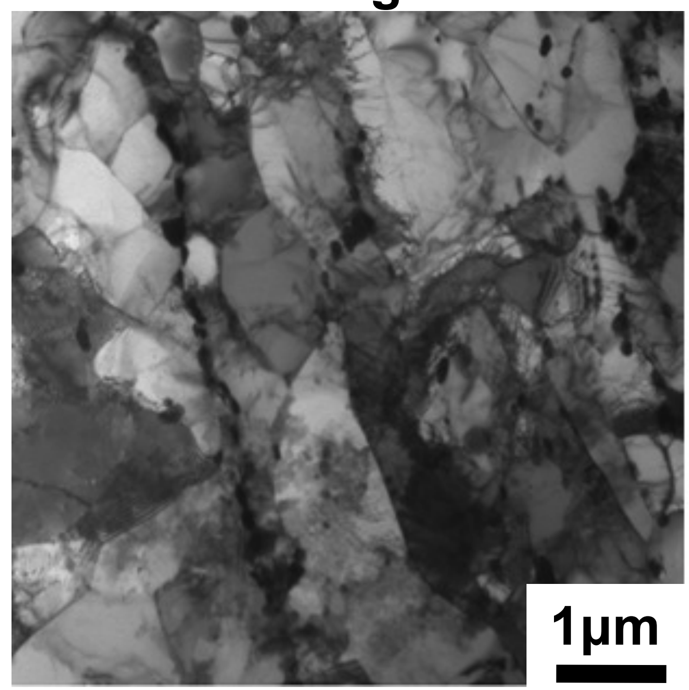
Enough $M_{23}C_6$ carbides along PAGBs and block boundaries



Near PAGBs

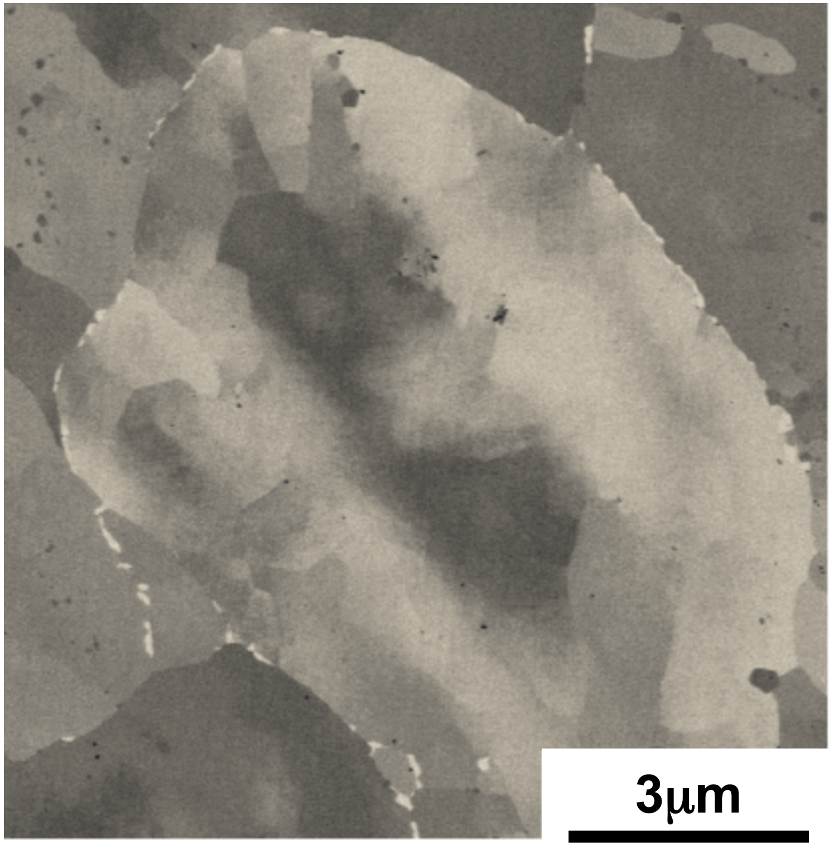


Inside grain

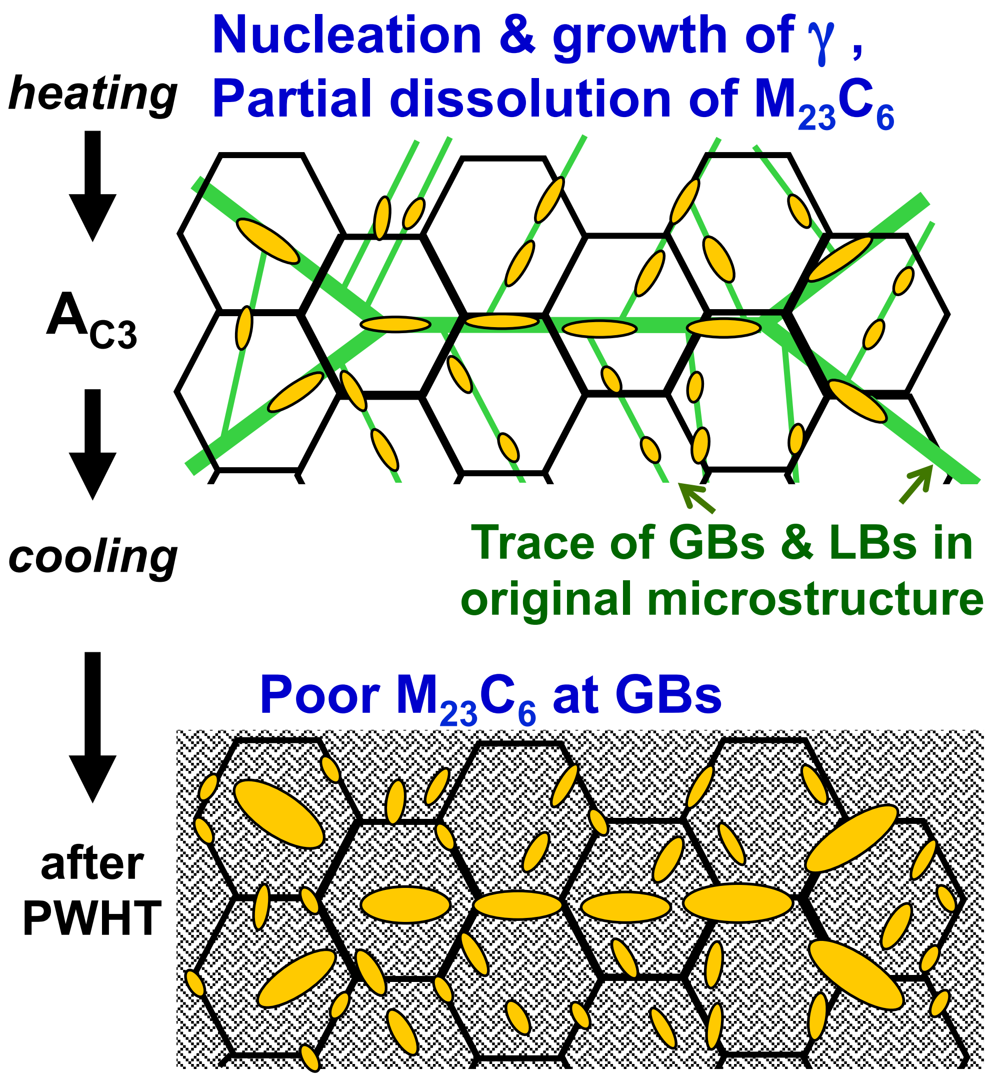


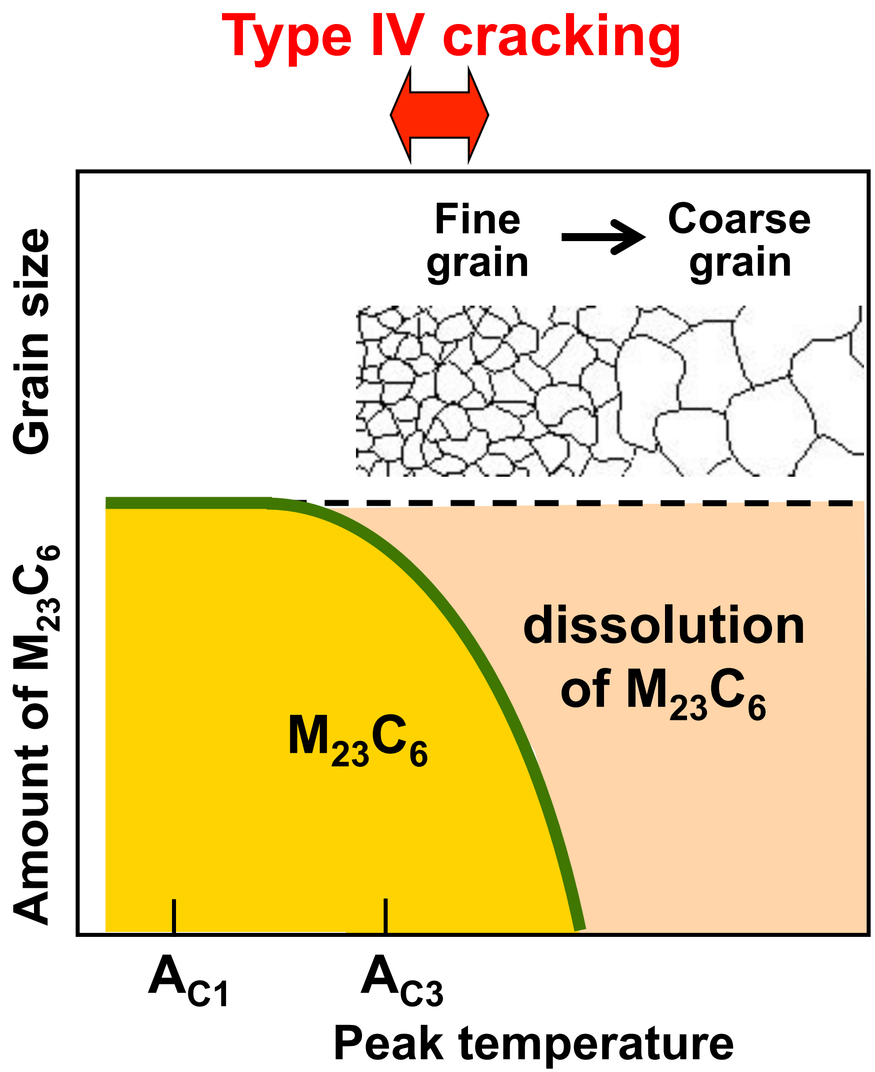
9Cr-90ppm B
after A_{C3} thermal cycle

Precipitation of Fe_7W_6 -μ phase at GBs of fine grains



Gr.92 after A_{C3} thermal cycle
Fine-grains & poor $M_{23}C_6$ along GBs





A_{C3} - HAZ of 9Cr-boron steel

Specimen surface (130 ppm B)

heating

↓

A_{C3}

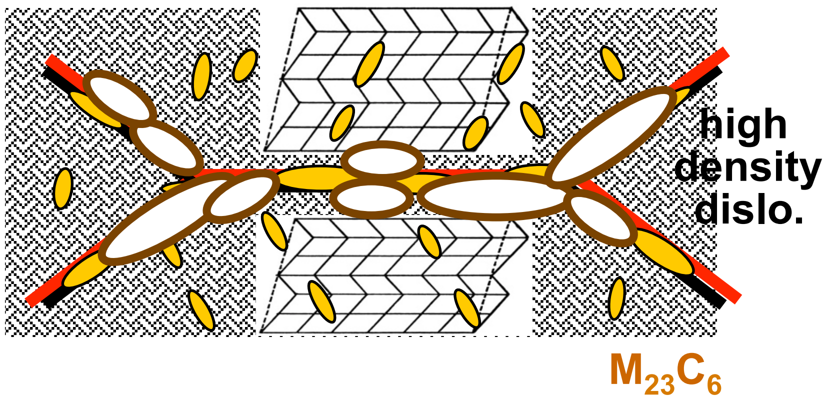
↓

cooling

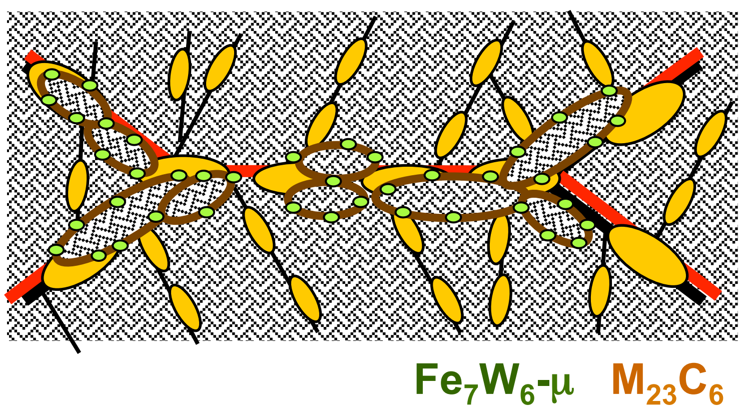
↓

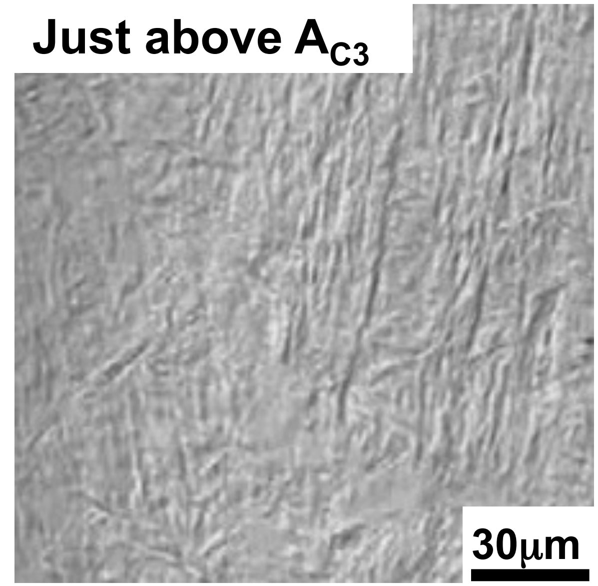
after PWHT

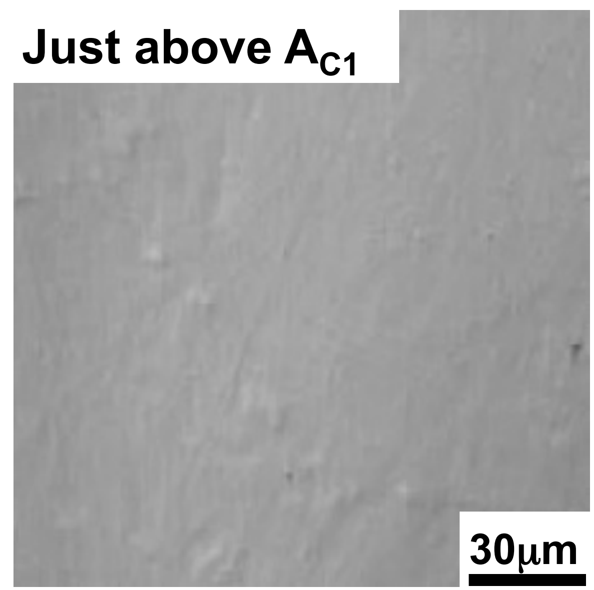
Coarse grains with high dislocation density



Un-recrystallized γ transforms to martensite during cooling



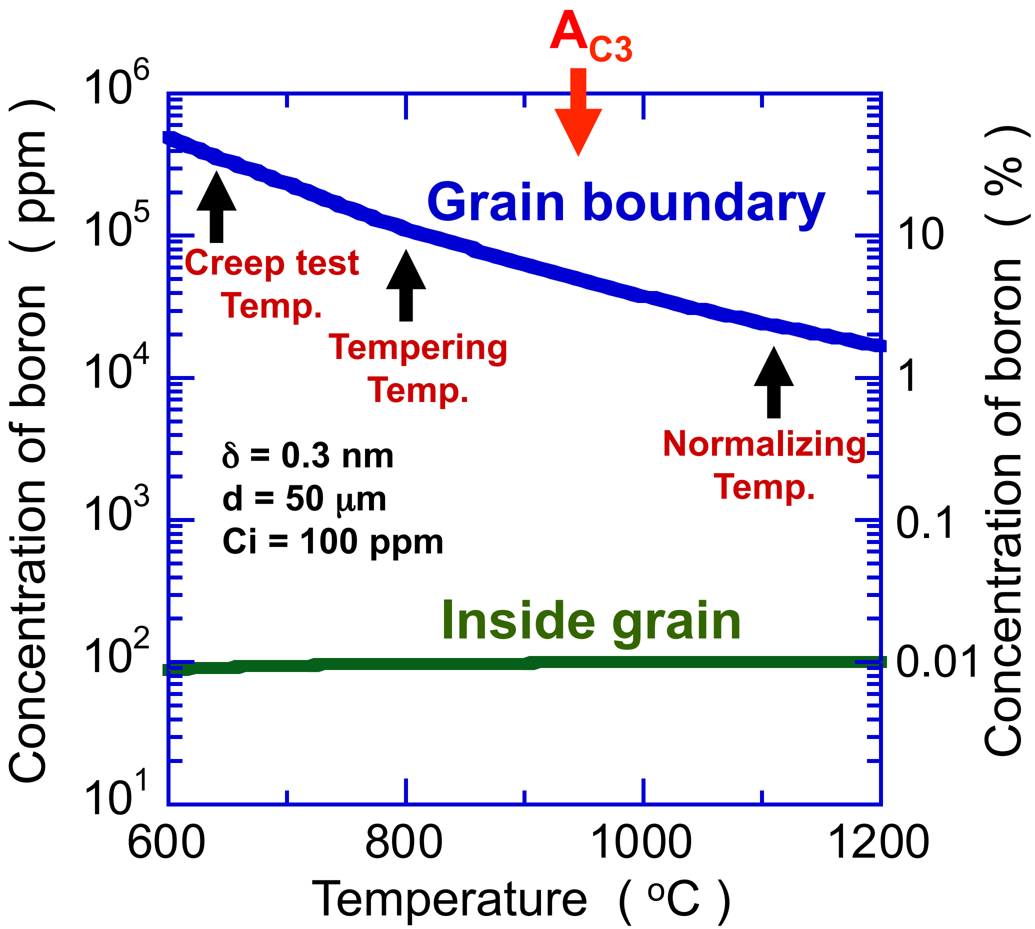


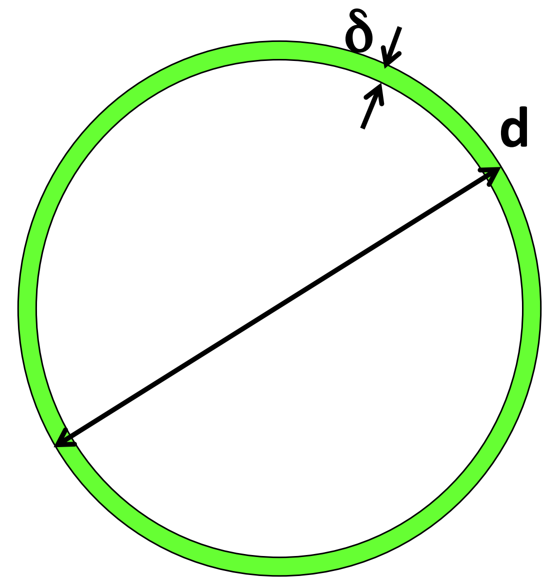


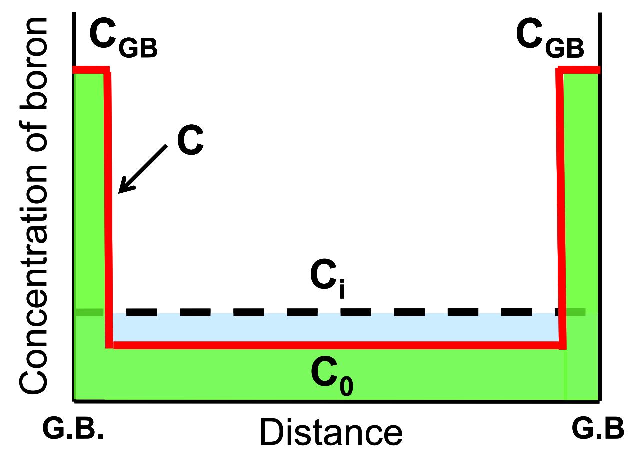
Segregation of boron at G.B.

$$C_{GB} = C_0 \exp (B / RT)$$

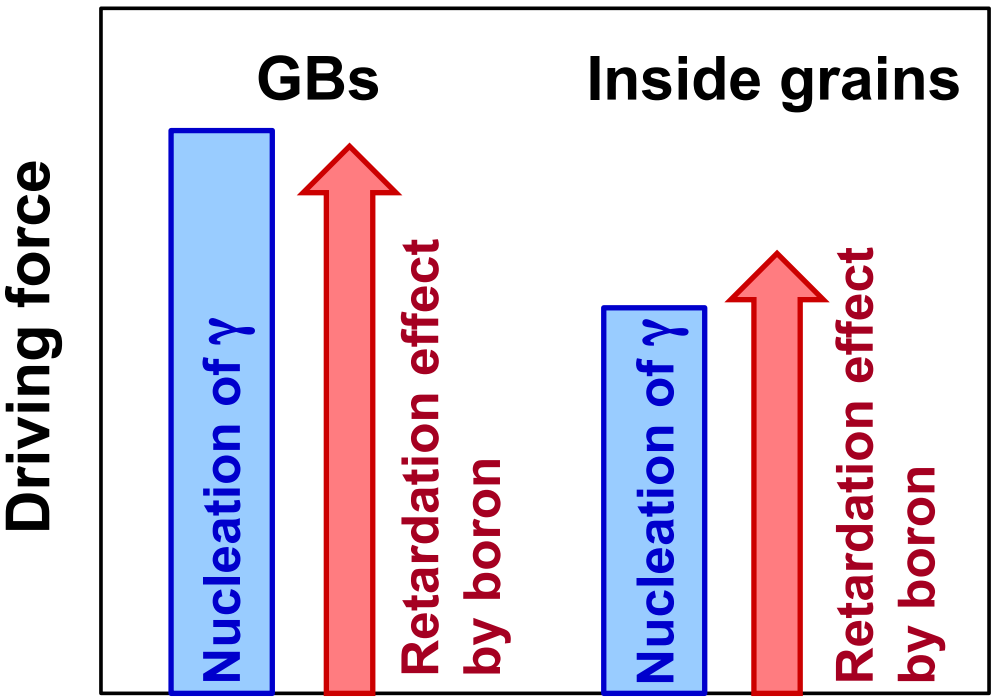
B = 62.7 kJ / mol (316ss)
L. Karlsson et al. (1988)

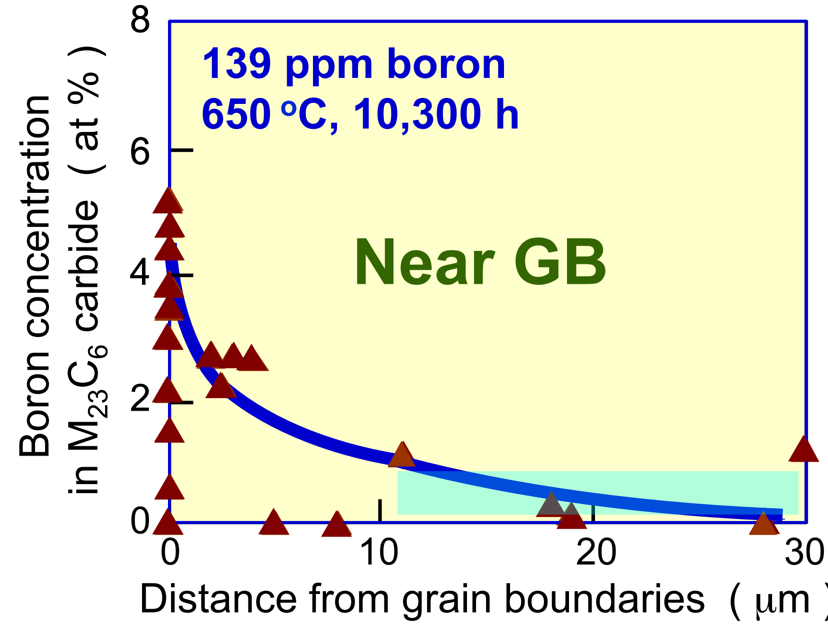


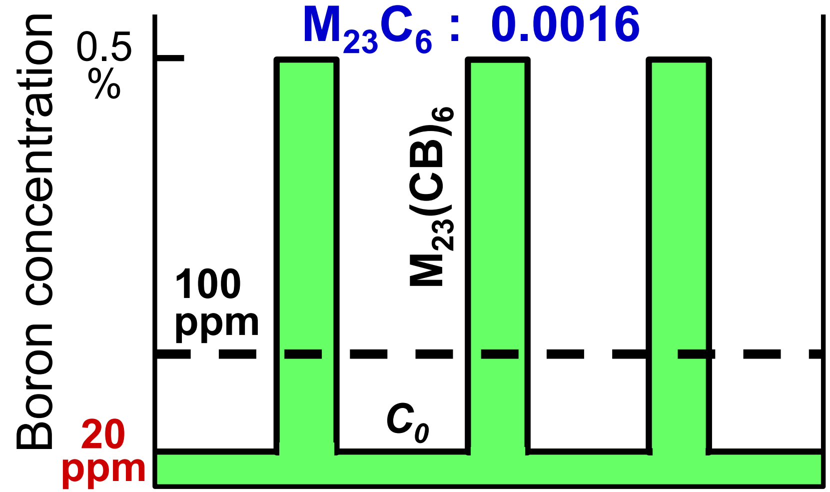




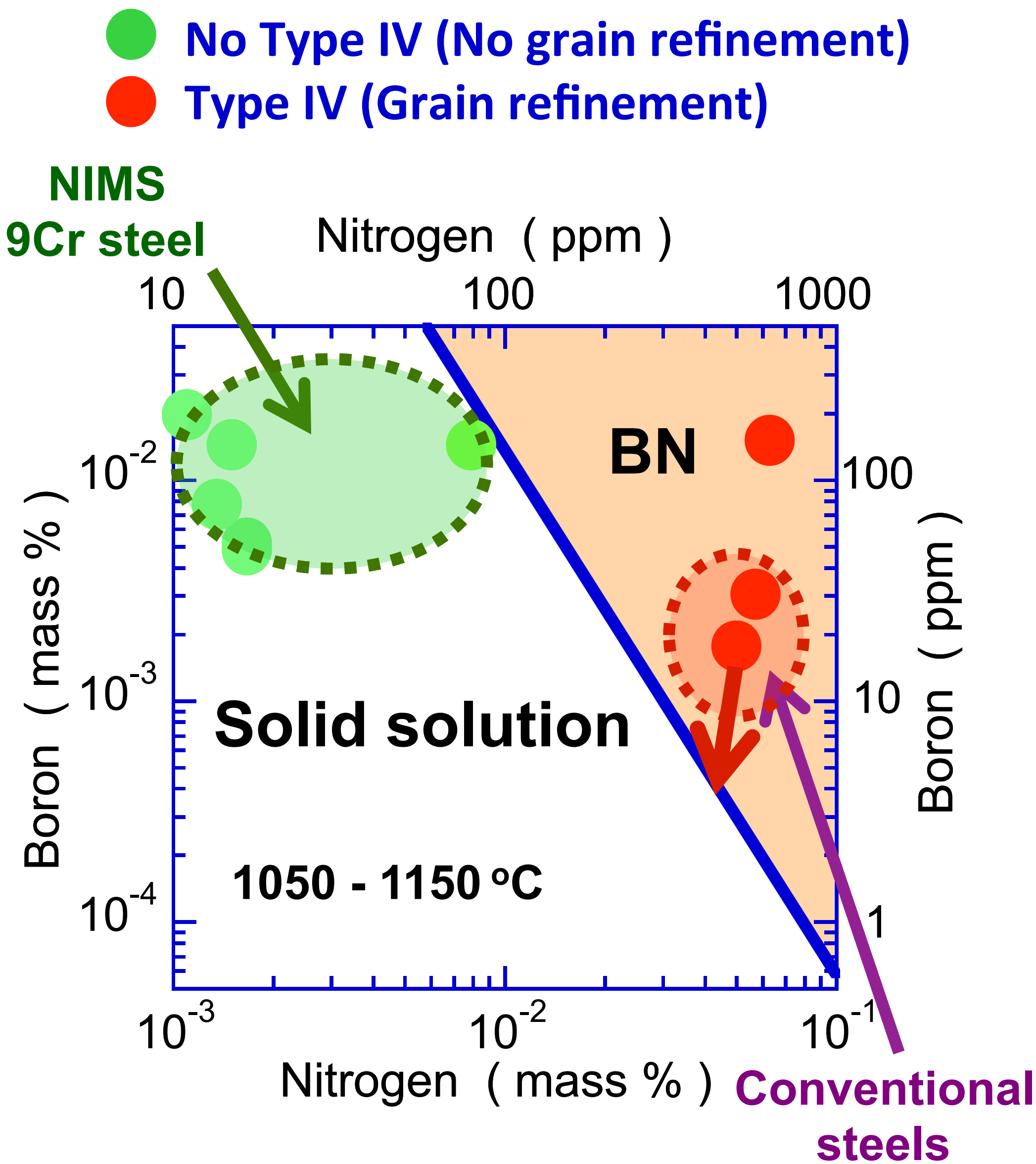
Competition : nucleation and retardation by boron

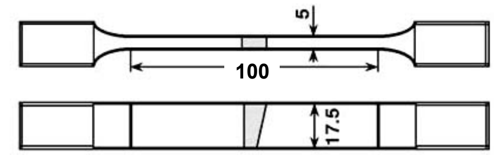


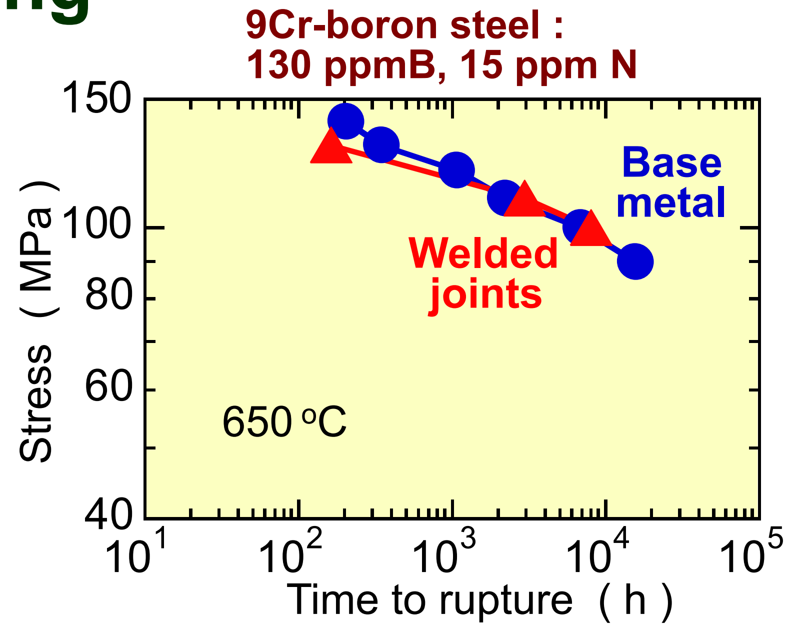


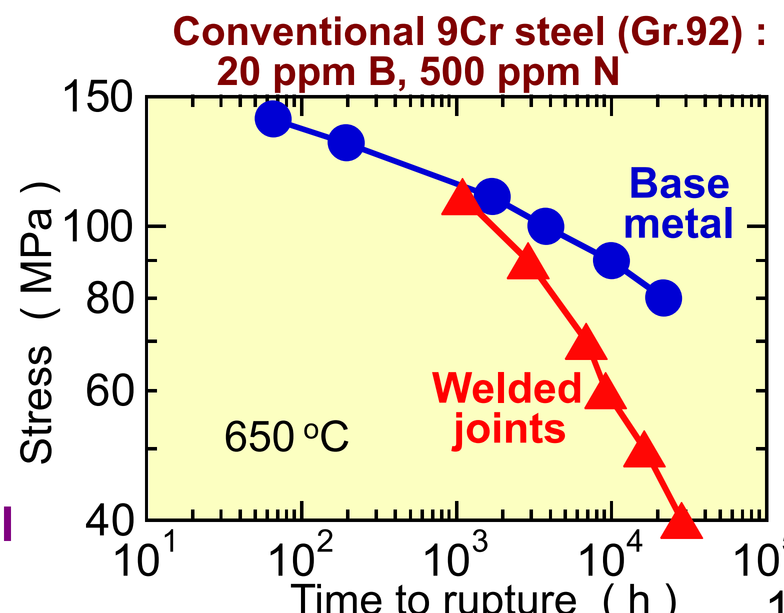


Soluble boron is essential for suppression of Type IV cracking

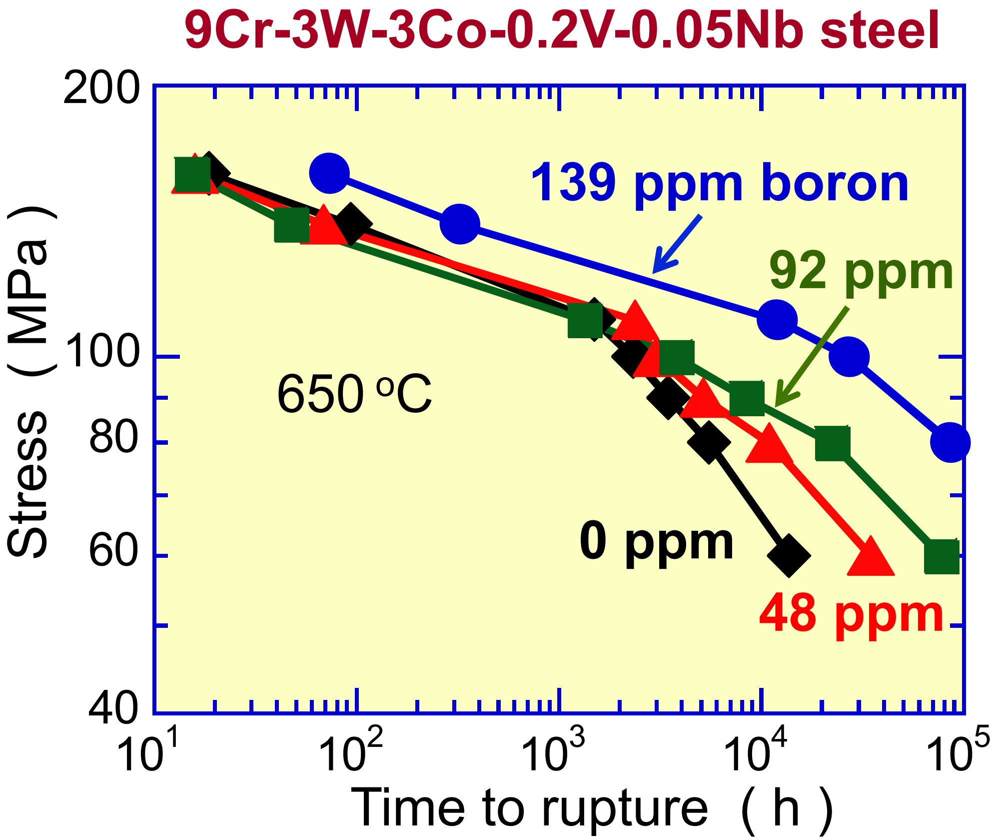


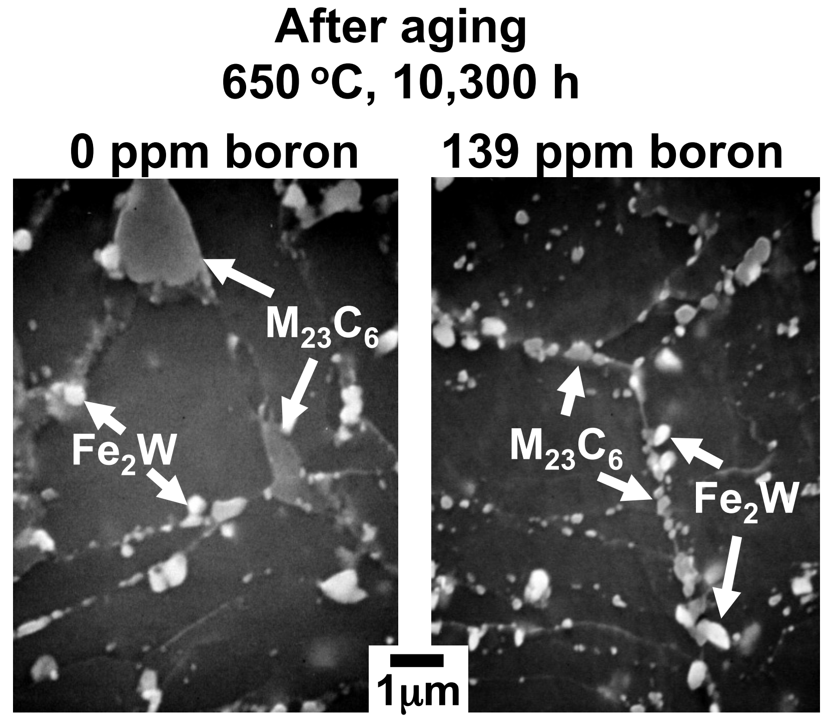


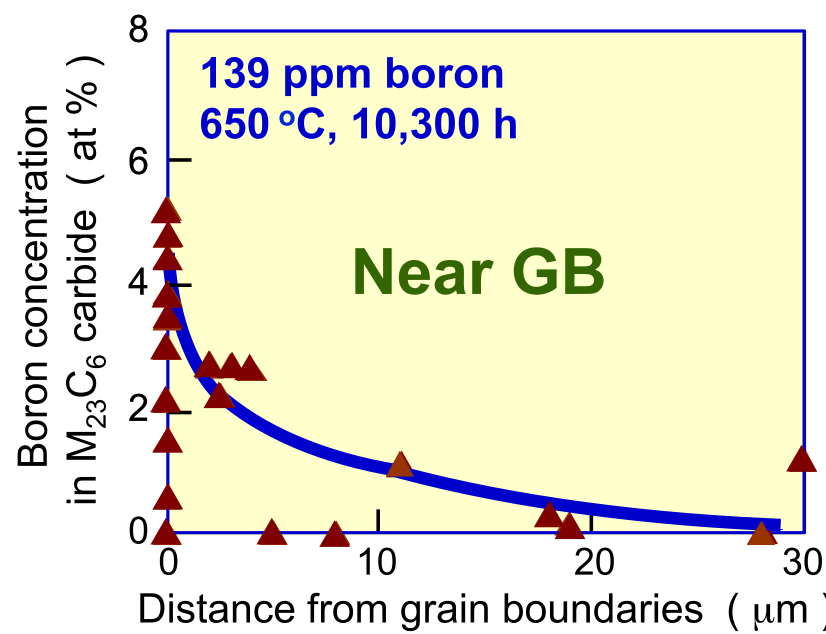




Base metal : boron improves creep strength

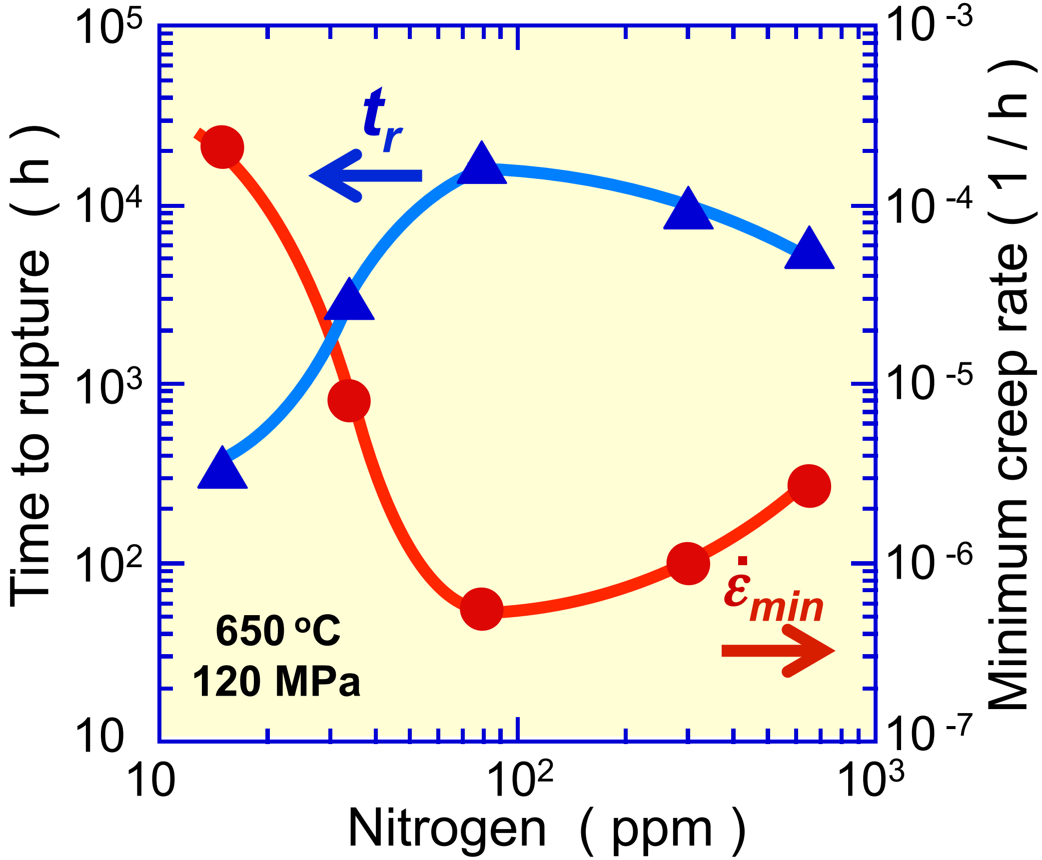


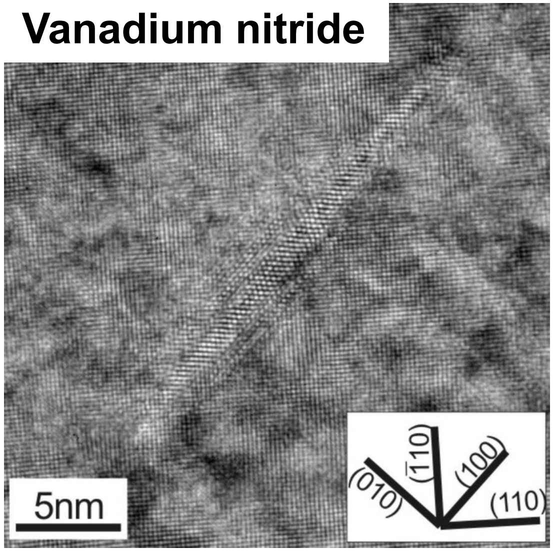


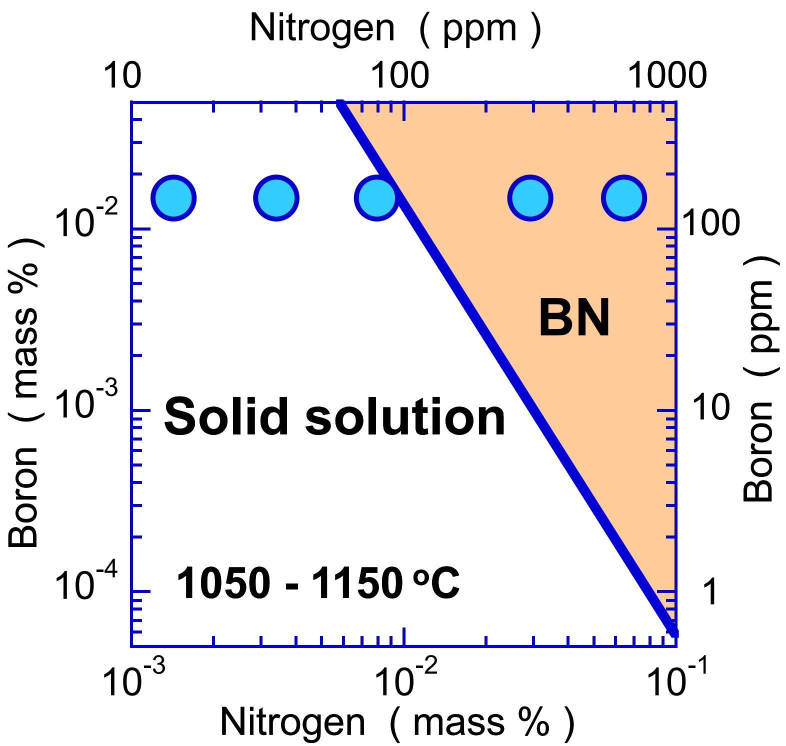


Additive strengthening due to boron and fine VN

9Cr-3W-3Co-0.2V-0.05Nb steel
140 ppm boron



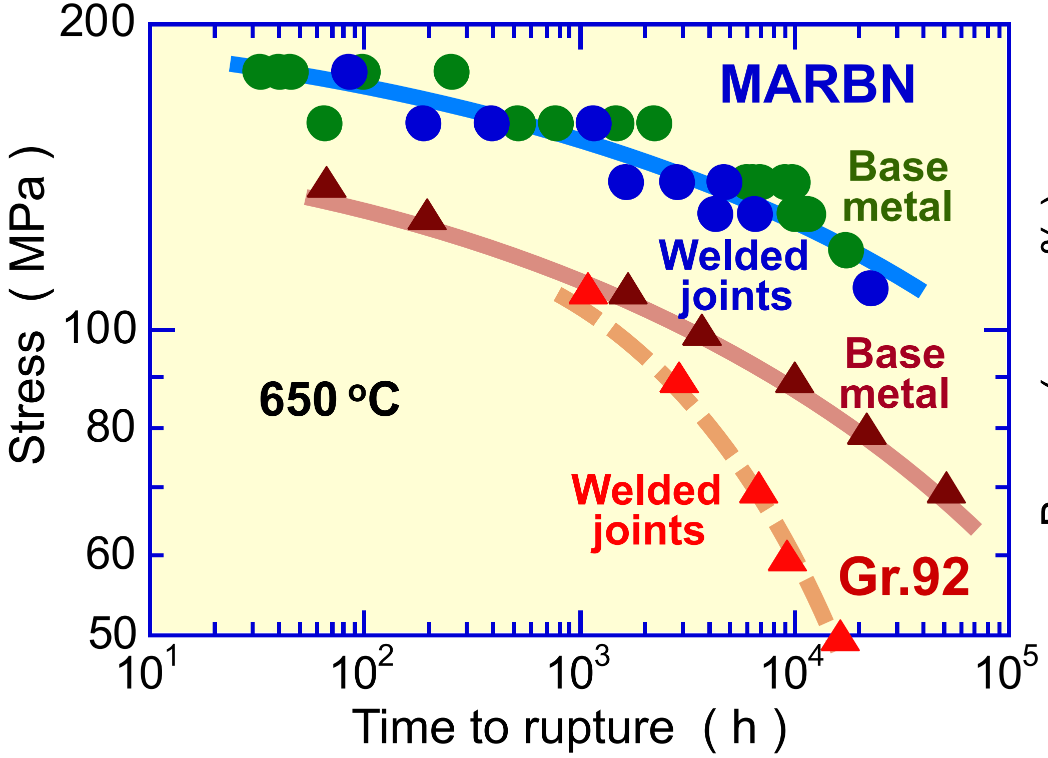


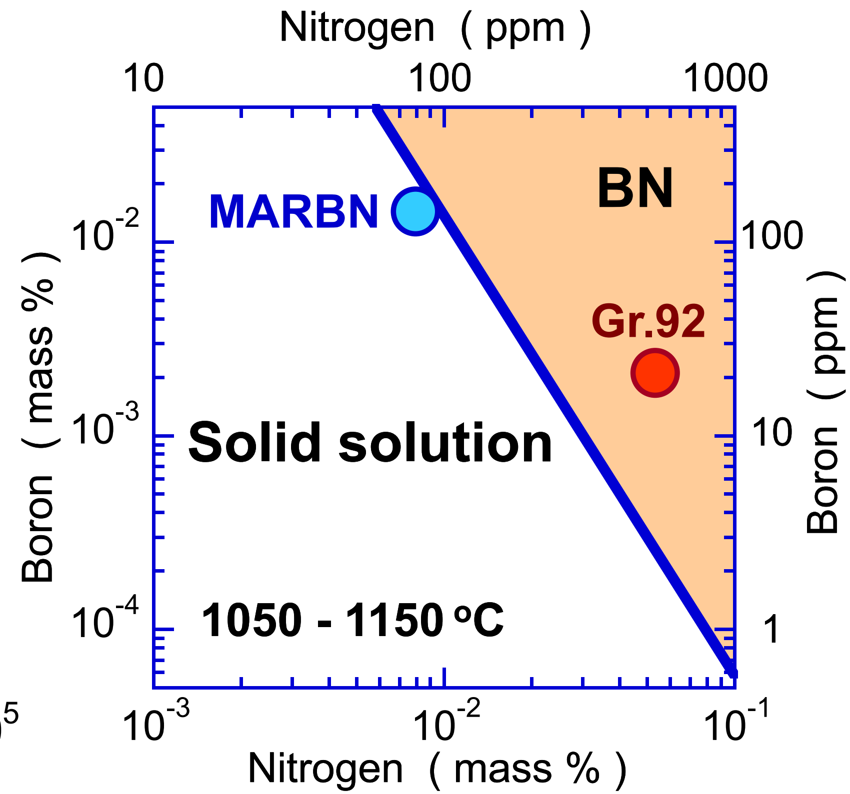


NIMS 9Cr steel : MARBN

*MARBN : **MAR**tensitic 9Cr steel strengthened by **B**oron and MX **N**itrides*

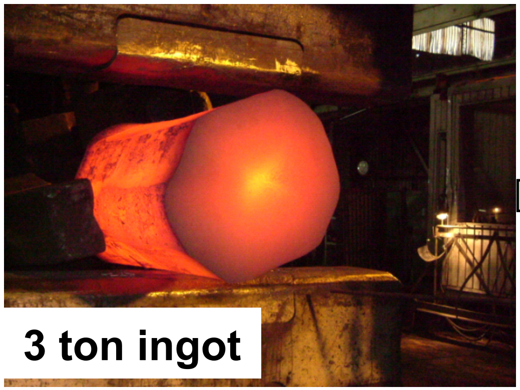
120 - 150 ppm boron & 60 - 90 ppm nitrogen



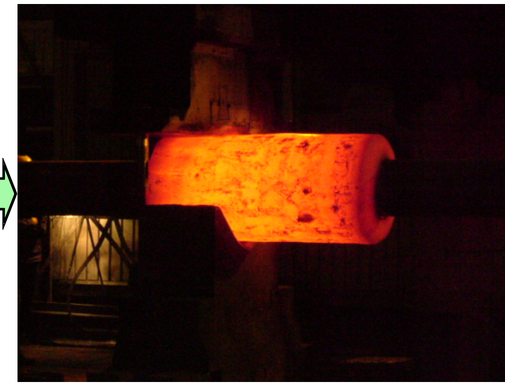


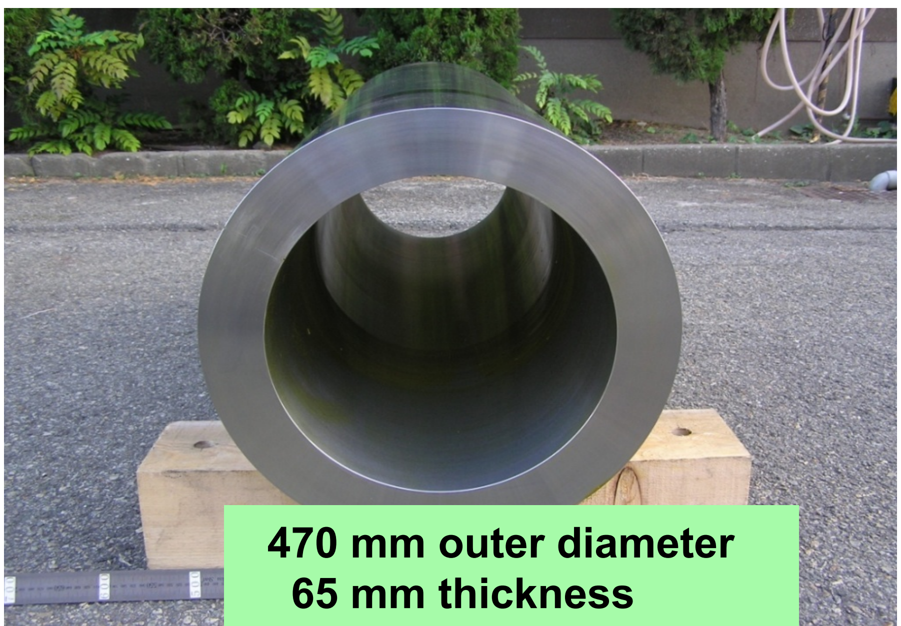
Production of thick-walled MARBN pipe

MARBN (9Cr-2.8W-3Co-0.2V-0.05Nb-0.08C-0.008N-0.014B)



3 ton ingot





470 mm outer diameter
65 mm thickness
1300 mm length

Welding by automatic TIG

Summary

(1) The degradation of creep strength in HAZ is not caused by grain refinement but reduction of boundary hardening is the most important.

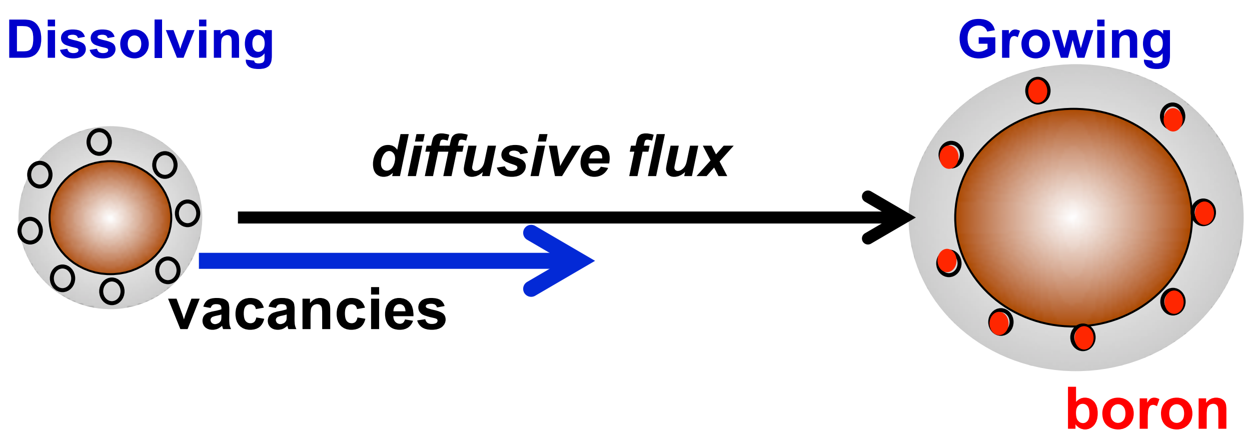
(2) Soluble boron produces substantially same microstructure in HAZ as base metal, which suppresses Type IV cracking.

(3) NIMS 9Cr steel (MARBN) exhibits high creep strength and no Type IV cracking at 650 °C.

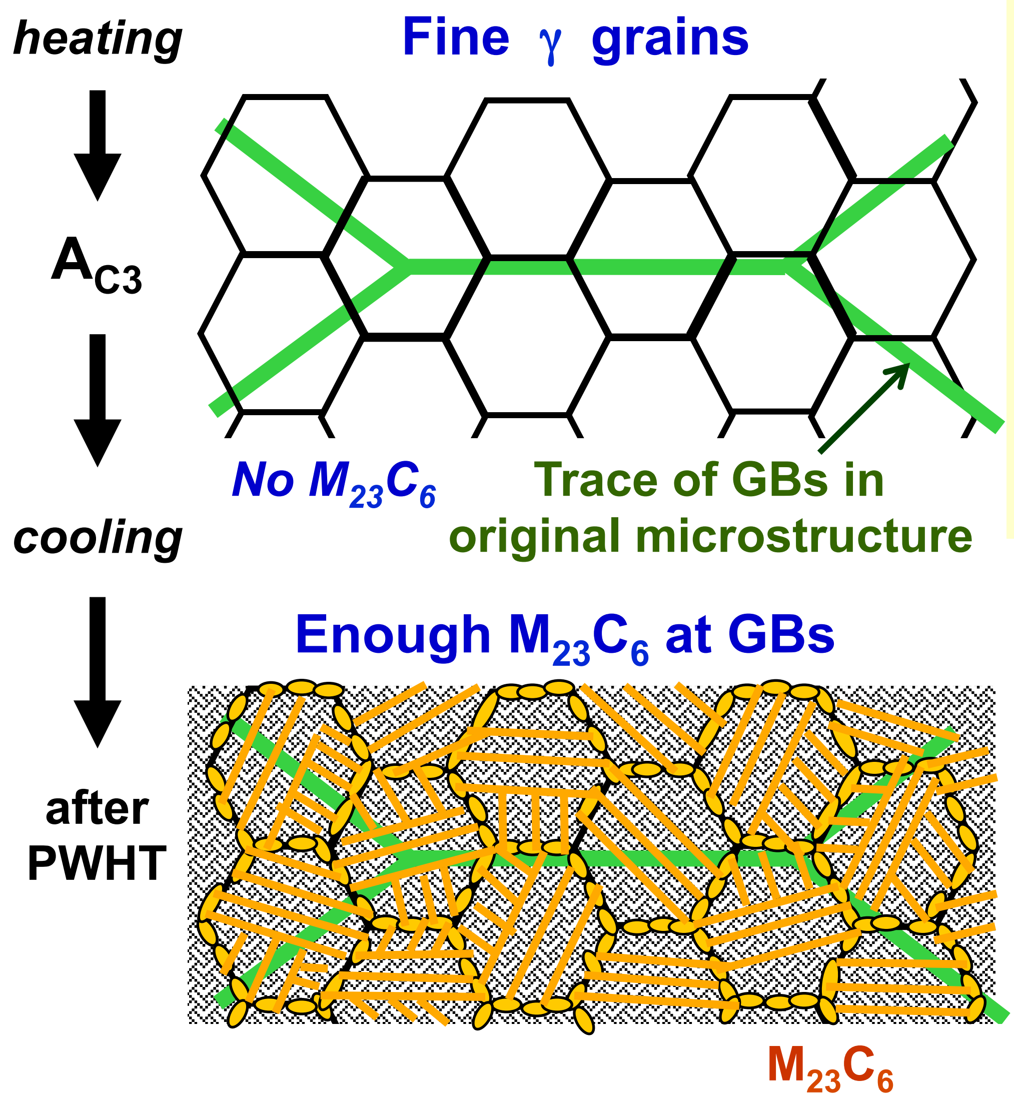
Boron reduces coarsening rate of $M_{23}C_6$

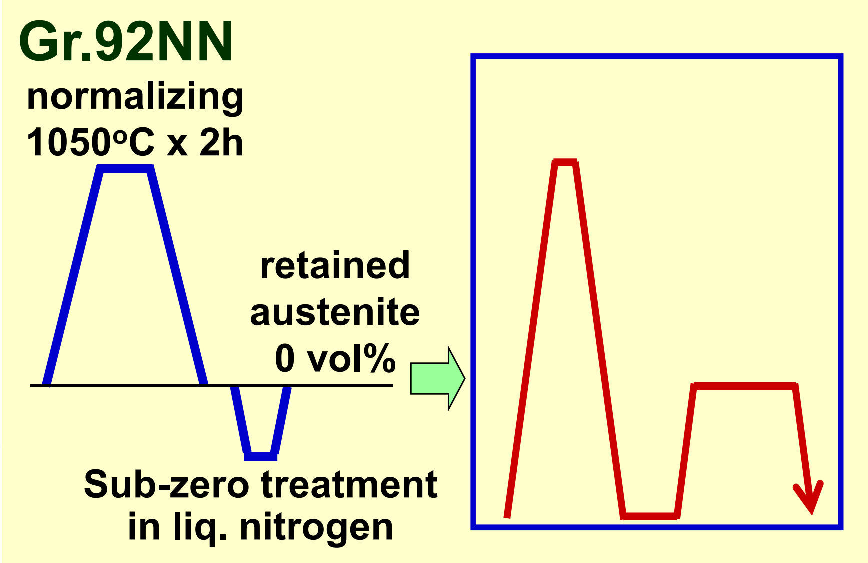
Coarsening of carbide particle in solid matrix requires accommodation of local volume change.

If boron atoms occupy vacancies, local volume change cannot be accommodated.



Gr.92NN after A_{C3} thermal cycle
Fine-grains & enough $M_{23}C_6$ along GBs





No retained austenite

- No austenite memory effect
- Nucleation & growth of γ

No tempering

- PWHT corresponds to low temperature tempering