Mechanic properties and microstructure of CLAM steel irradiated in STIP-V

PENG Lei [1], GE Hongen [1], DAI Yong [2], HUANG Qunying [3]

[1] University of Science and Technology of China (USTC)

[2] Paul Scherrer Instiut, Switzerland

[3] Institute of Nuclear Energy Safety Technology, CAS, China

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Introduction

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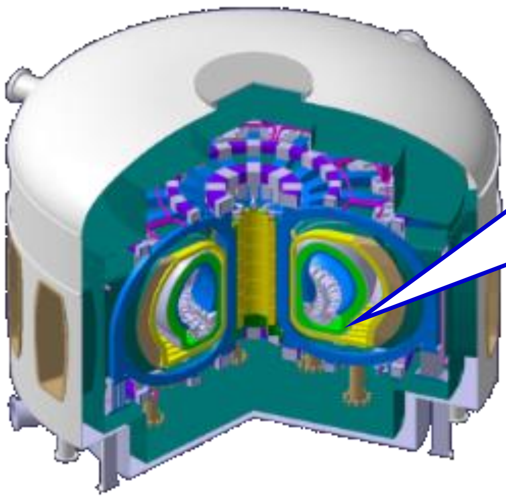
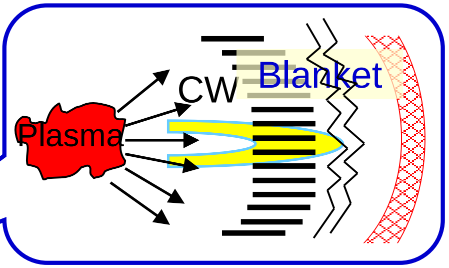
Conclusions

Neutron Irradiation in Fusion Reactor





- Work condition
  - *High Temp.*
  - *Neutron irradiation*
  - *High heat flux*
  - *Stress*
  - *Corrosion*

Irradiation condition

High energy	14 (MeV)
High flux	$>10^{15}$ (n/cm^2 s)
High DPA	>20 (dpa/yr)
High Helium	>10 (appm/dpa)
High temp.	300~500 (℃)

Irradiation effects

Swelling

Hardening

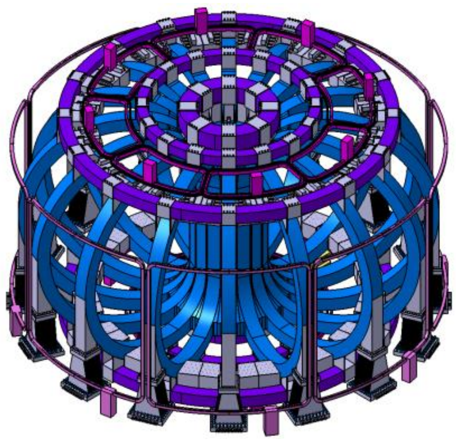
Embrittlement

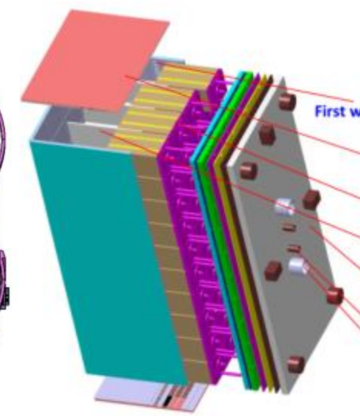
Creep

Fatigue

Candidate structure material
of *China Fusion Experimental Test Reactor (CFETR)*

	CFETR	ITER
Power/ MW	50-200	500
TBR	>1.2	--
Duty time	30%-50%	4%





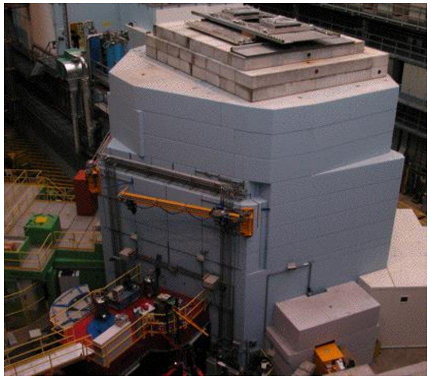
- Ferretic/Martensitic steel – China Low Activation Martensitic steel
  Large heats have been characterized, industrial heat production achieved
- Stainless Steel - CT91, C316Ti
  Large heats have been characterized, industrial heat production achieved

Neutron irradiation tests have been under way.

Neutron Irradiation Program

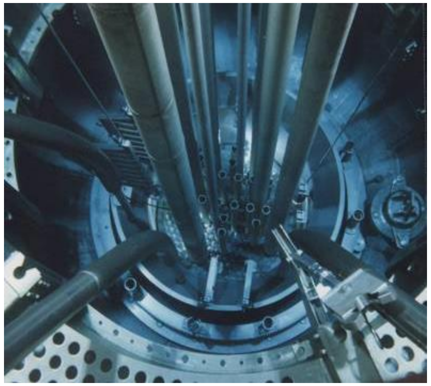
➢ Spallation Target Irradiation （PSI: SINQ ）

Period	Program	Dose/Temp.	Material
2007~2008 2010~2011 2013~2014	STIP-V STIP-VI STIP-VII	3~20 dpa 100~1600 appm He 300~500 ℃	CLAM C316Ti



➢ Fission Reactor Irradiation （NPIC: HEETR）

Period	Program	Dose/Temp.	Material
2010~2012 2012~2013	NPIC-I NPIC-II	1~3 dpa <1 appm/dpa 300~500 ℃	CLAM CT91



SINQ Target Irradiation Program – V/VI/VII

STIP-V (56 samples) irradiation was finished and PIE is under way.

STIP-VI (120 samples) and STIP-VII (120 samples) irradiation is finished in 2014.

Material		Zone	Irr. Temp.	Sample	Numble
STIP-V	CLAM	Zone 1	100~500 ℃,	12 ST, 18CH, 18 TEM, 2 SANS	56
STIP-VI	CLAM	Zone 1	300~350 ℃, 450~500 ℃	12 ST, 12CH, 12 TEM, 8 BB	44
	CLAM	Zone 3		12 ST, 12CH, 12 TEM, 8 BB	44
	CLAM-HIP	Zone 3	300~350 ℃ 450~500 ℃	8 BB,	8
	CLAM-EBW	Zone 3		12 ST, 12 TEM	24
	CLAM-PbLi	Zone 3		6 LT, 4 BB	10
STIP-VII	CLAM, C316Ti	Zone 1	300~350 ℃, 450~500 ℃	12CH, 8BF, 12 TEM	32
	CLAM, C316Ti	Zone 3		8BF, 12 TEM	20
	CLAM-HIP	Zone 3		8 BB	8
	CLAM-EBW	Zone 3		12 ST, 12 TEM	24

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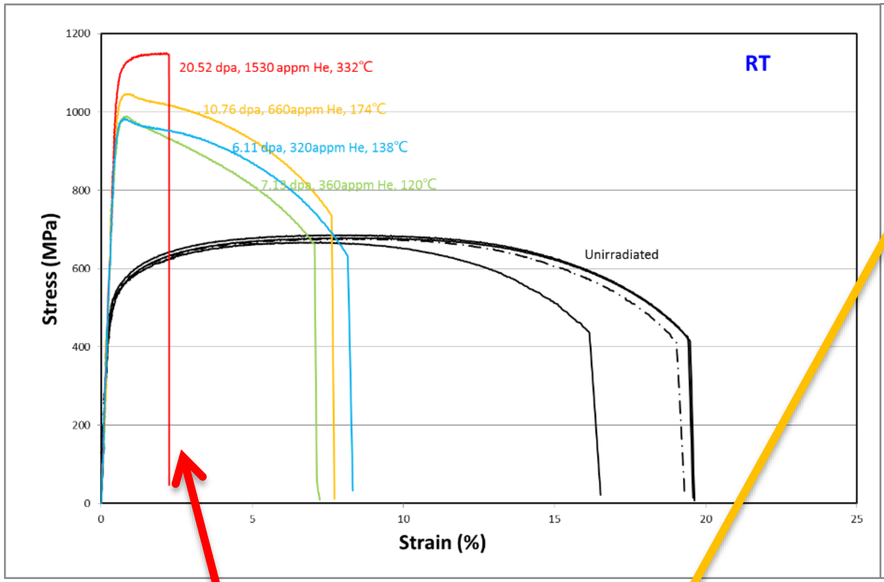
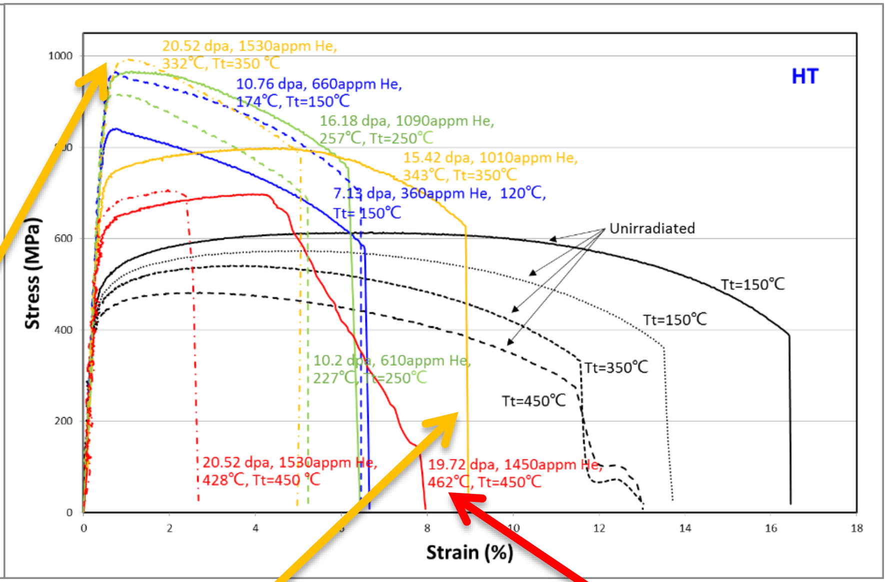
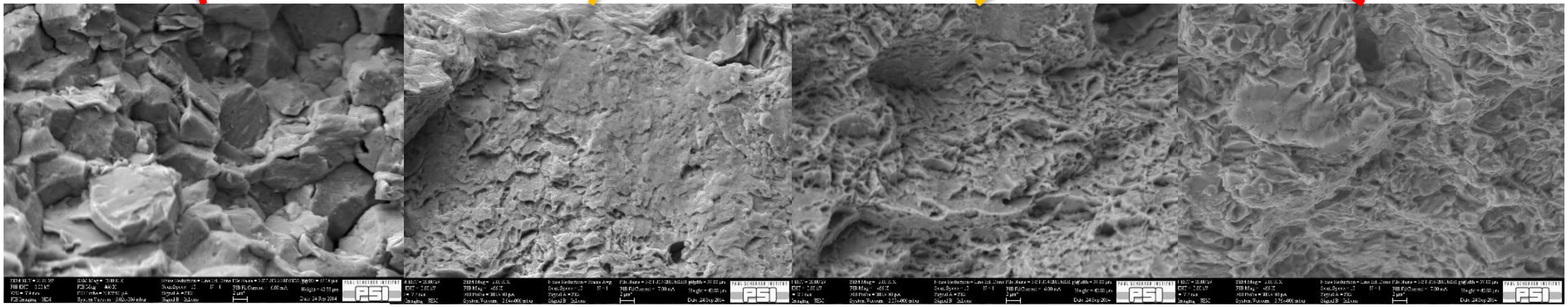
Tensile Curves & Crack Surface

Test at R.T.

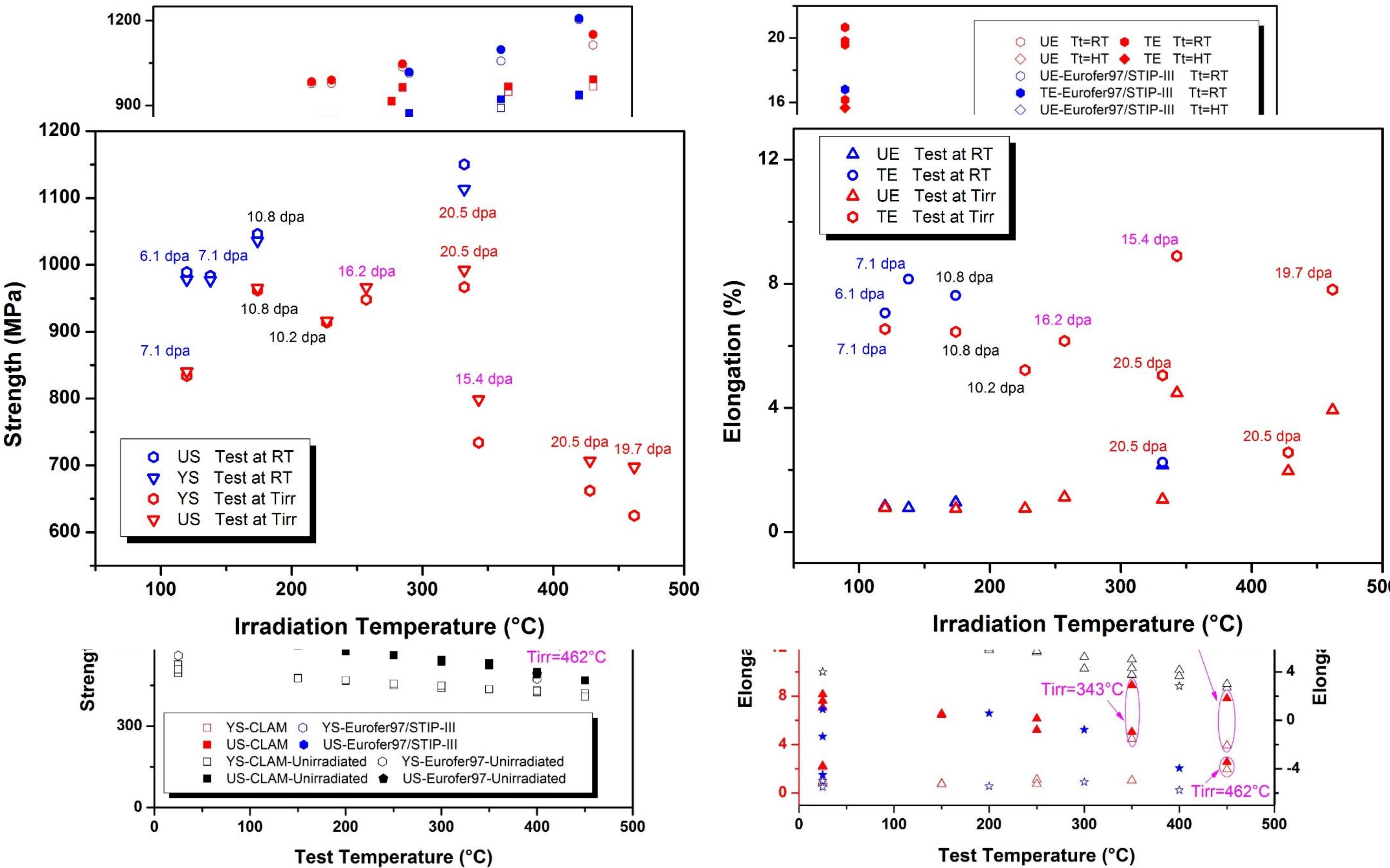


Test at irradiation temperature

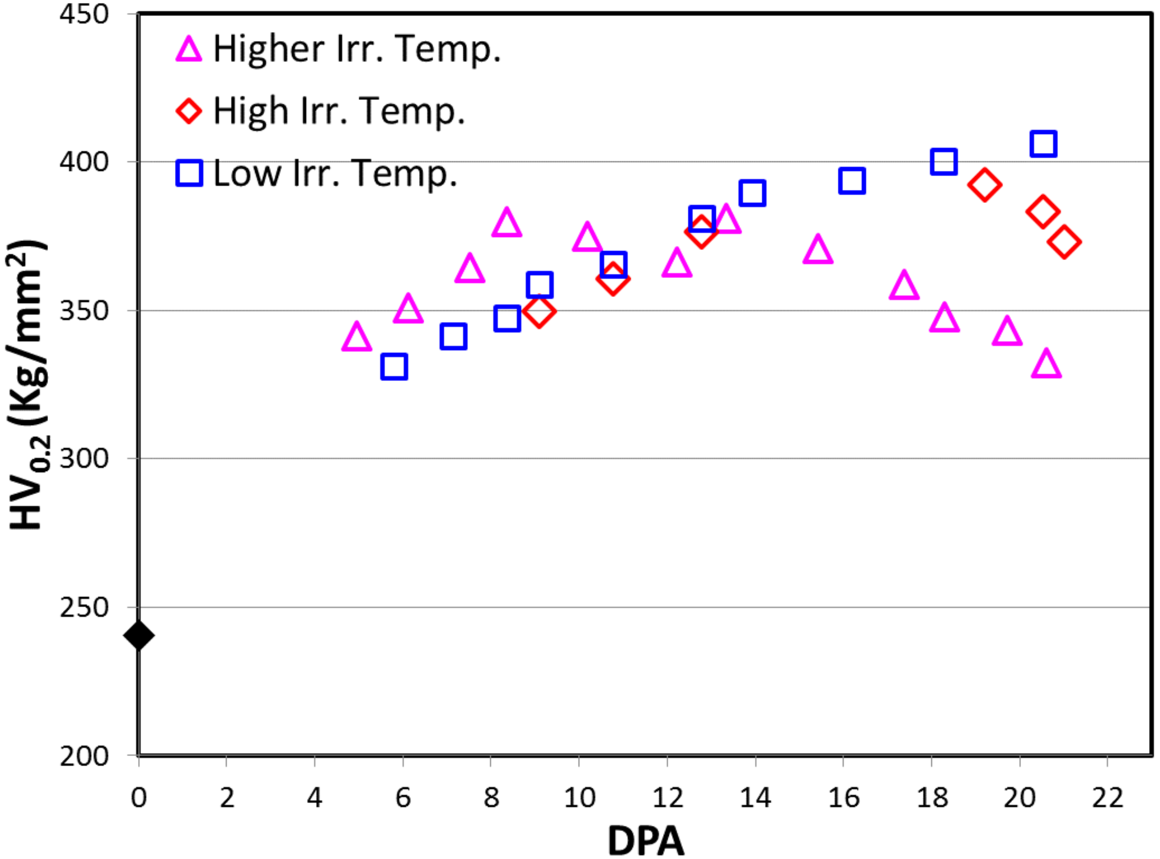




Strength and Elongation



Micro-hardness (HV0.2)



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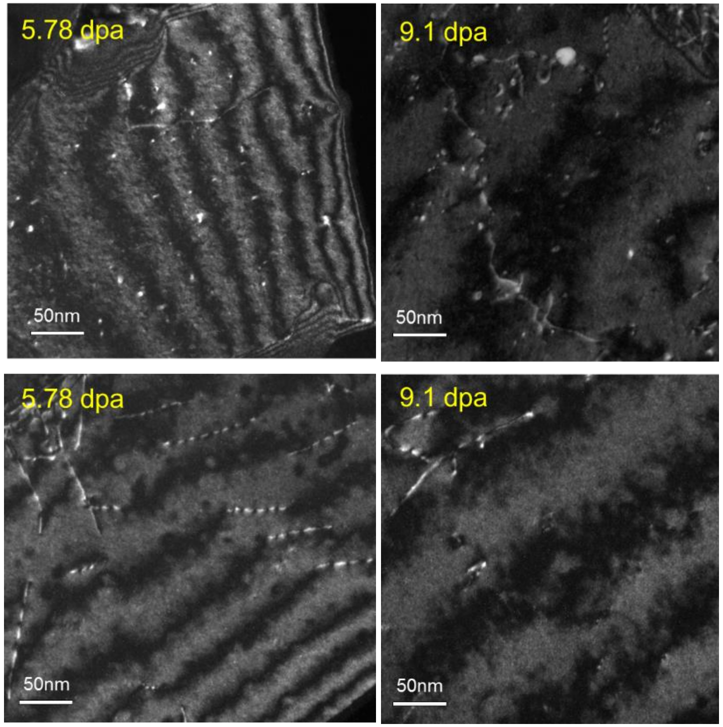
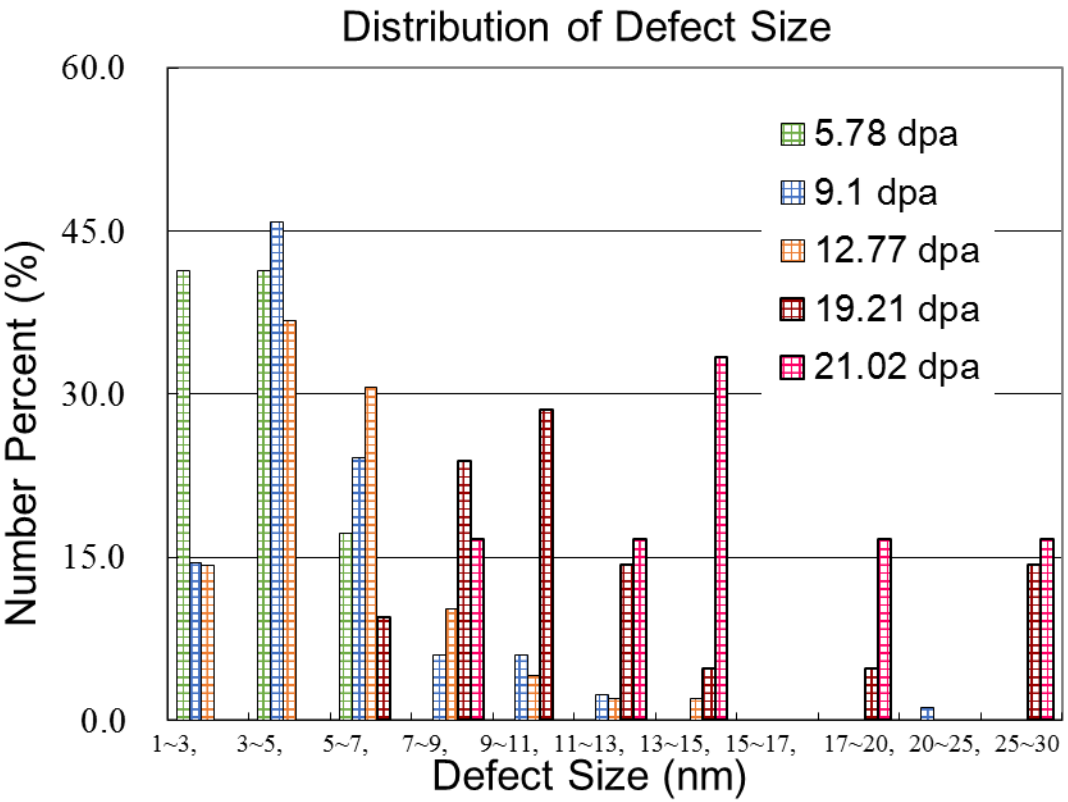
Clusters & Loops

TEM Image condition: WBDF (g, 5g), g = 110

As irradiated



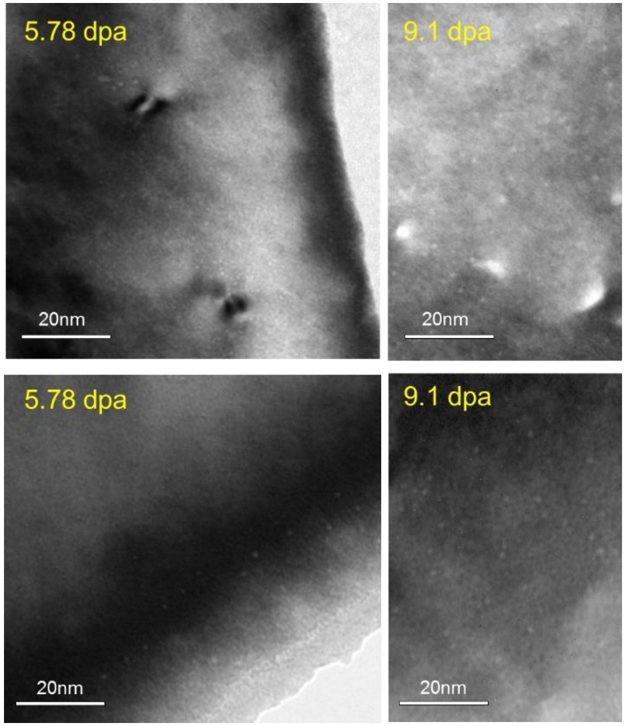


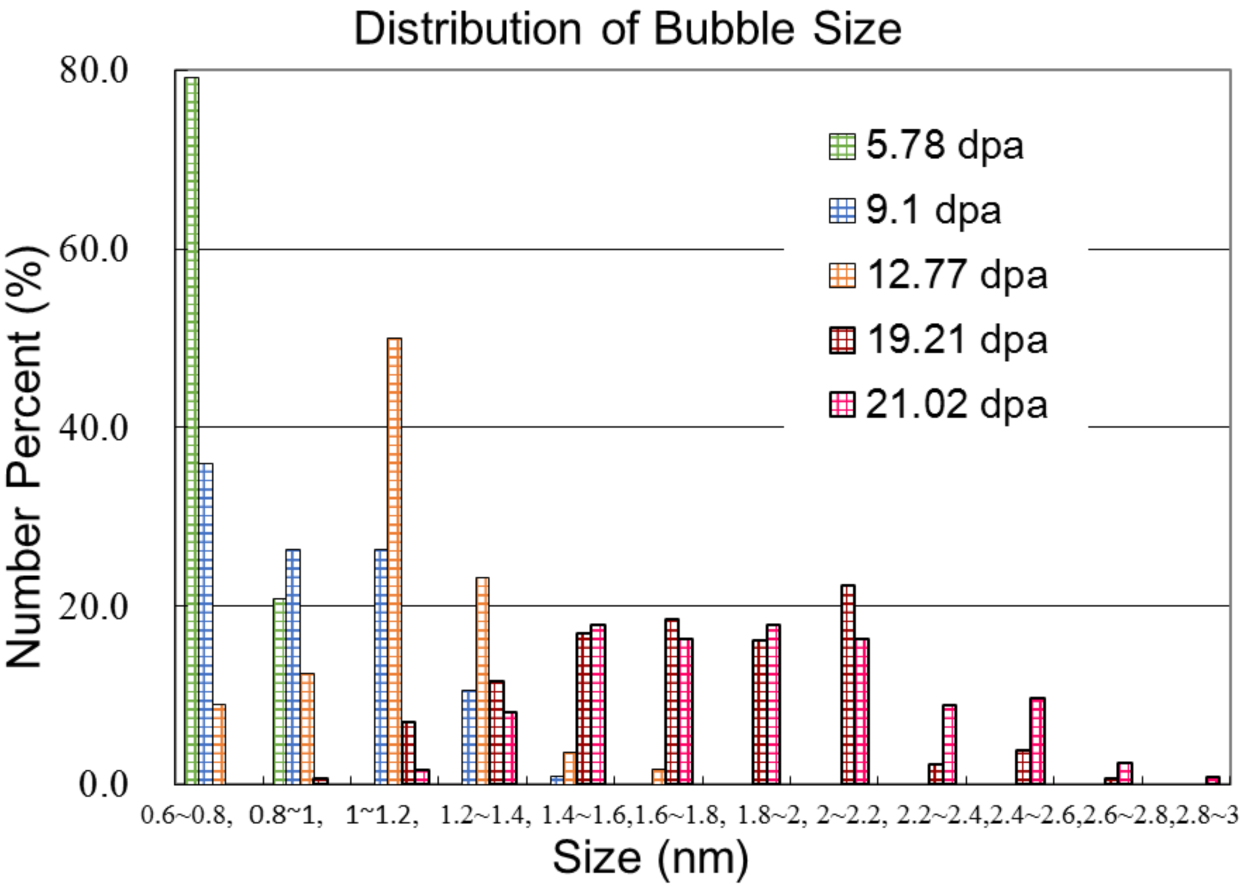
After annealing (600°C *1h)

Bubbles

TEM Image condition: WBBF, g = 110

As irradiated





After annealing (600°

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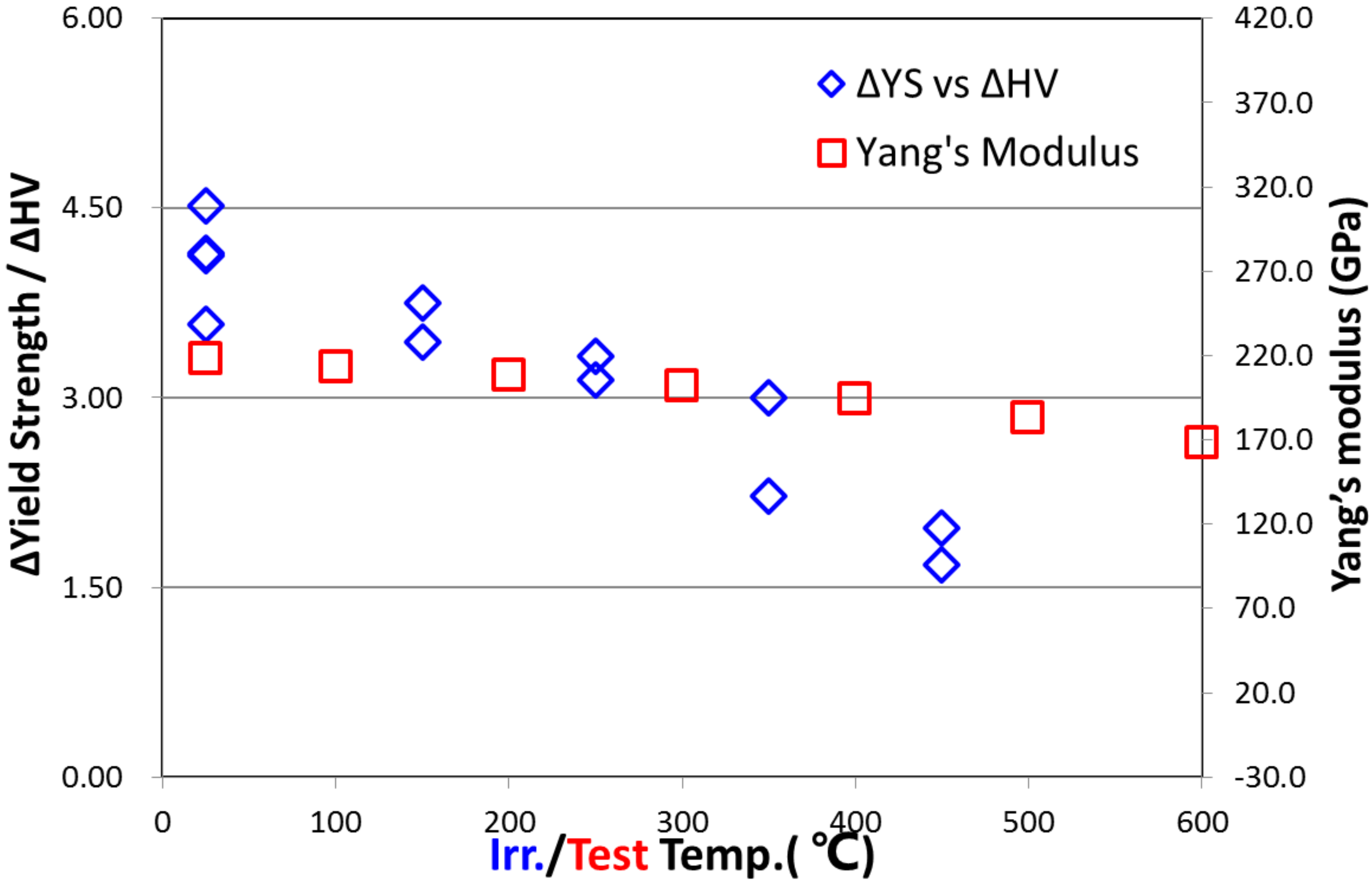
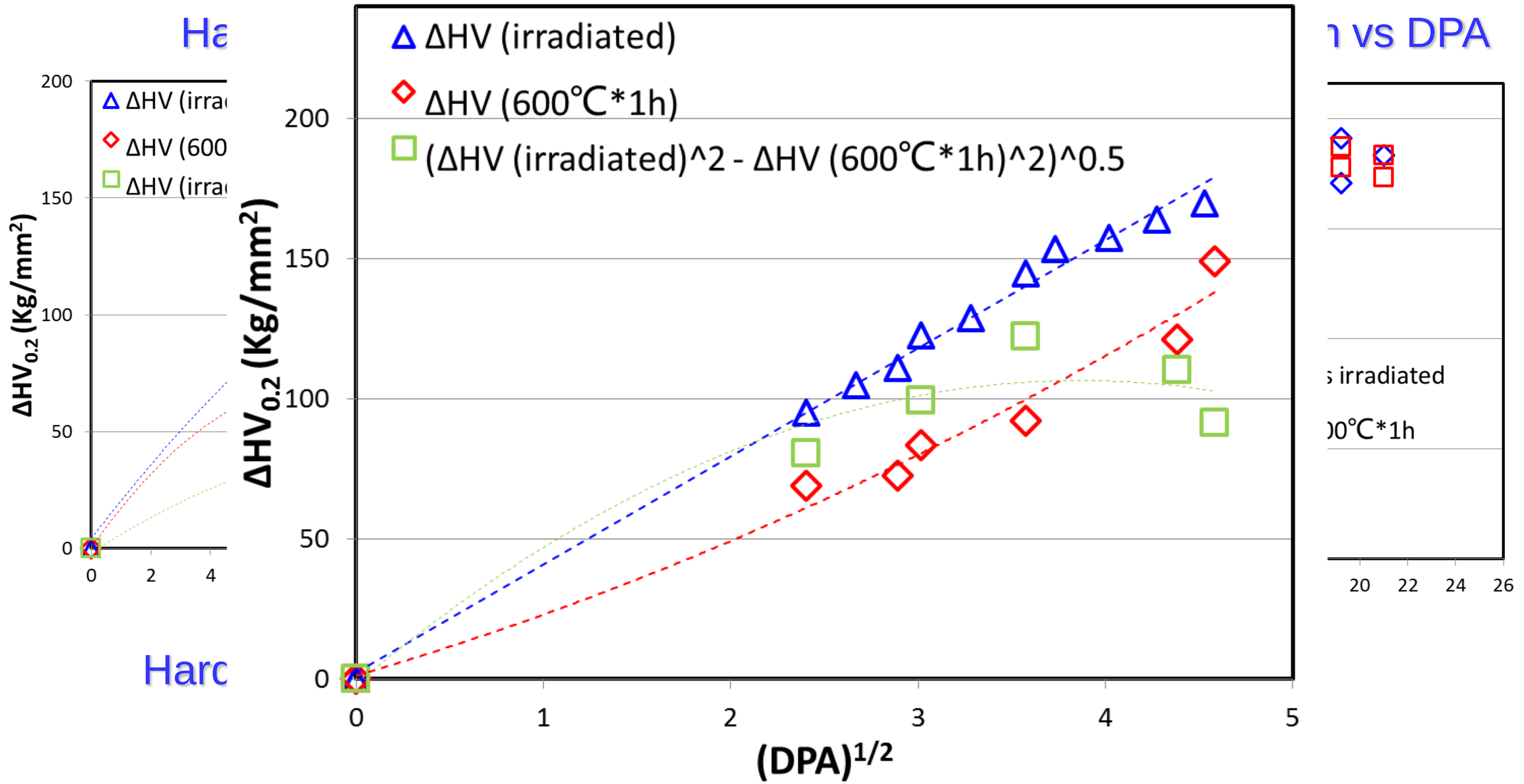
Hardening



Δ YS (at R.T.) = *3.21* ΔHV0.2,

Annealing Effect



Barrier Strength of Defects

Barrier strength (α)

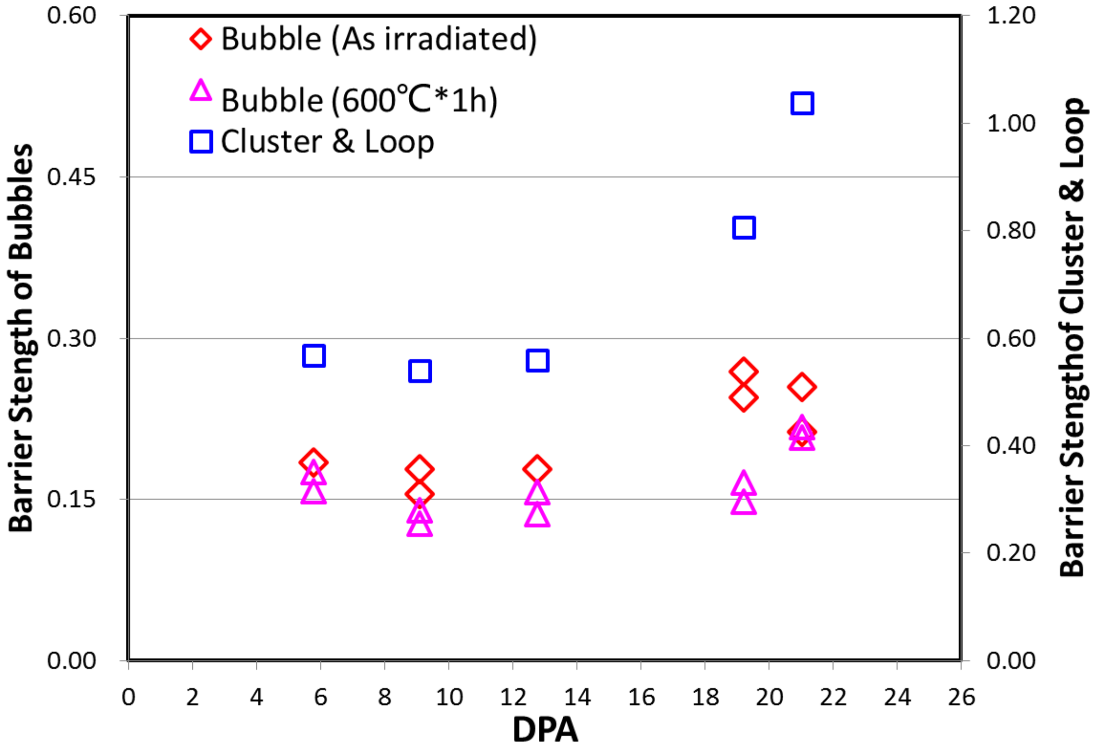
$\Delta\sigma = 3.21\ \Delta Hv$

$\Delta\sigma = 3.06\ \Delta\tau_s$

$\Delta\tau_s = \alpha Gb(Nd)^{1/2}$

α →→

[Stoller, Zinkle . JNM 349 (2000) 283-287]

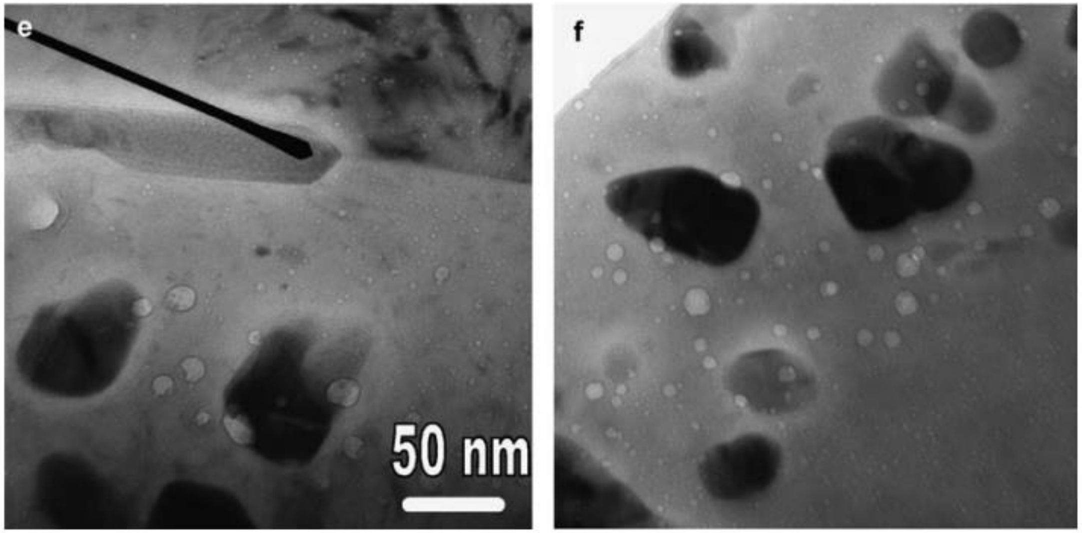


Barrier strength (α) of cluster/loop with size<20 nm is about 0.2~0.25.
Barrier strength (α) of Helium bubble with size<1.5 nm is about 0.13~0.21, and decrease after annealing.

More microstructure observations of higher irradiation temperature samples is under way

Possible reason for high irradiation temperature softening：

1. Large scale and low density of bubbles?
2. Precipitates change (scale, density, composition)?



20.3dpa/400˚C/1800 appm He irradiated in STIP-II, [Jia. JNM 356 (2006) 105]

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The present results of CLAM steel irradiated in STIP-V show that:

1) There is a good linear correlation between hardening and square root of irradiation dose (<22 dpa) / Helium concentration (<1530 appm) before annealing.
2) High irradiation temperature (>350℃) could educe hardening in lower temperature and softening. And hardening peak is at 250~350 ℃.
3) 600˚C /1h annealing can mostly anneal out the irradiation induced defects and possibly make small bubbles (<1nm) grow to big bubbles (1~1.5 nm)
4) Barrier strength of cluster/loop with size<20 nm is about 0.2~0.25. Barrier strength of Helium bubble with size<1.5 nm is about 0.13~0.21, and decrease after annealing.

Thank you for attention!