Additional Hardening due to Hydrogen Trapping in Neutron Irradiated Vanadium Alloys

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Hydrogen Interaction in V Alloys

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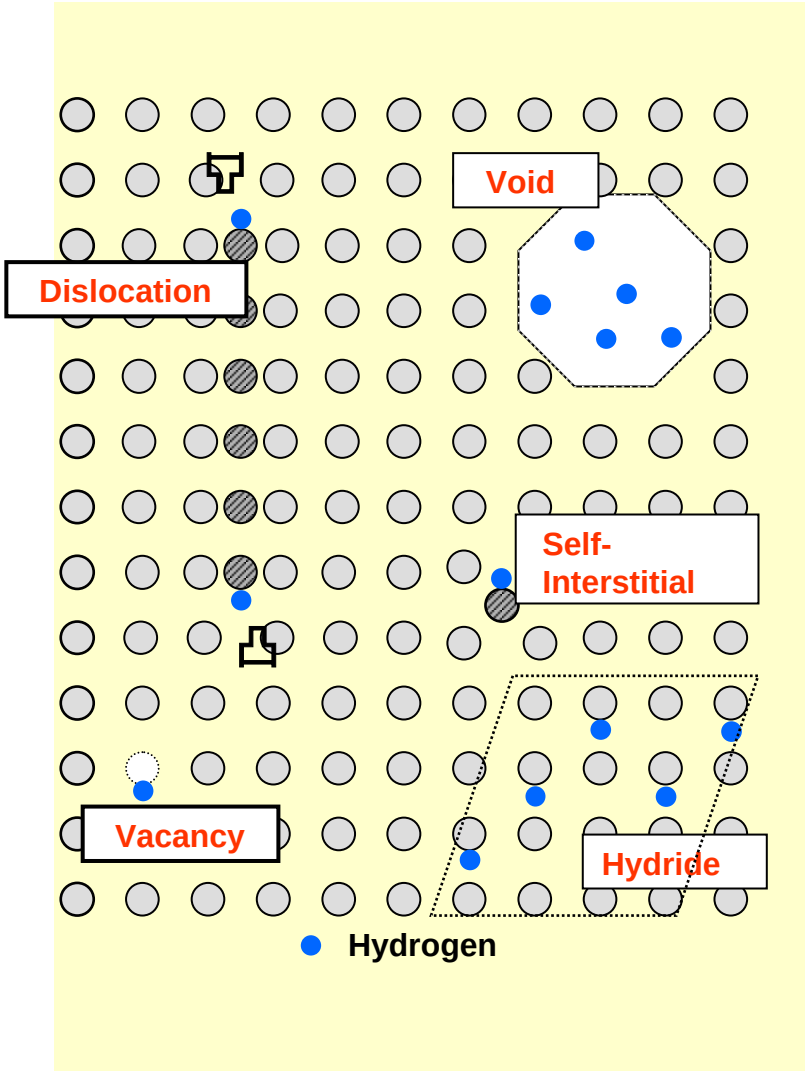


V –Cr-Ti alloys

+ A candidate material for fusion reactor components:
  - High temperature strength,
  - Low activation
  - Irradiation resistance
+ Behavior of interstitial impurities
  - Oxidation
  - Hydrogen embitterment

Hydrogen Behavior in V Alloys

+ Large solubility
+ Rapid diffusion
+ Interstitial Hydrogen
+ Substitutional Hydrogen:
  - H-V complexes (high binding energy)

Al-H : 50kJ/mol Ni-H : 42kJ/mol Fe-H : 60kJ/mol

+ Trapping with dislocation and voids

- **H-defects Interaction**
  - **H trapping by defects**
  - **H effect on defect cluster formation**
  - **H effect on mechanical properties**
  - **Stability of hydride structure**
  - **Upper temperature limit of hydrogen effect**
- **H charging to neutron-irradiated V alloys**
- **Gas emission experiment**
- **Microstructural observation**
- **Mechanical properties after H charging**
  - **Radiation hardening**
  - **Luders strain**

Experimental Procedure

Specimens

V, V-5Cr, V-5Ti, V-5Cr-5Ti

Annealing : 1000℃, 2 h

Neutron Irradiation

JMTR (JAERI/Tohoku U, Oarai)

Temperature : 300 ℃

Total damage : 0.01 dpa

Cathodic Charging

0.1N-H_2SO_4

5mA/cm^2 、RT

Microscopy

200 kV TEM

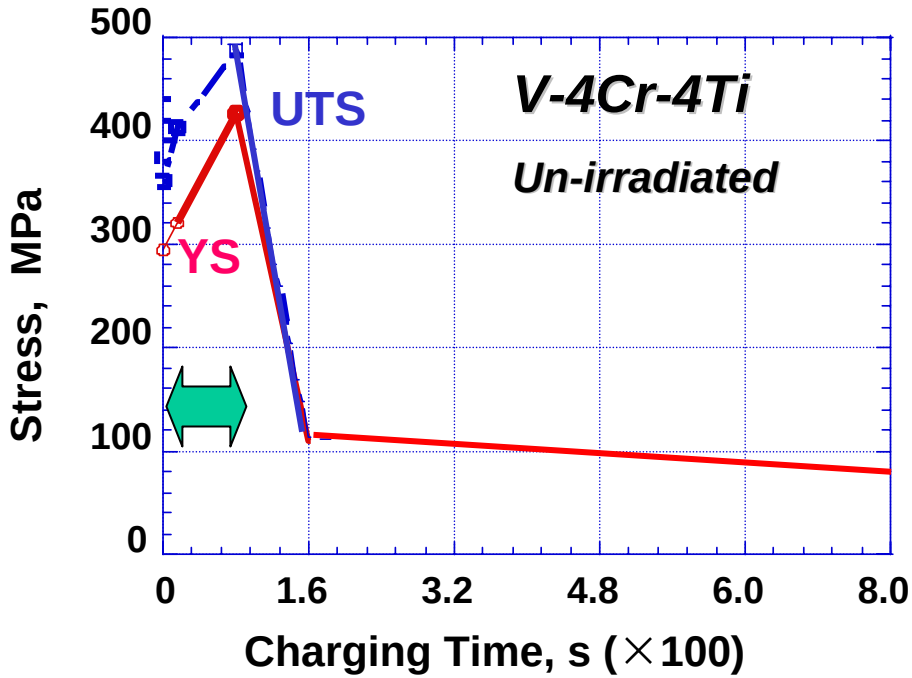
Hydrogen Emission:

Quadrupole mass spectrometry

Tensile Test:

Room Temperature, SR: 10^{-3} /s

Tensile Stress as a function of Hydrogen Charging (un-irradiated)



Solution hardening?

less than 1 at%H

Hydrogen Embitterment ?

more than 1 at%H

→ Hydride formation ?

To detect H/defect interaction from mechanical property, a low concentration of H charging is required.

Yield Stress as a function of H Charging

(neutron-irradiated, 300C, 0.01 dpa)

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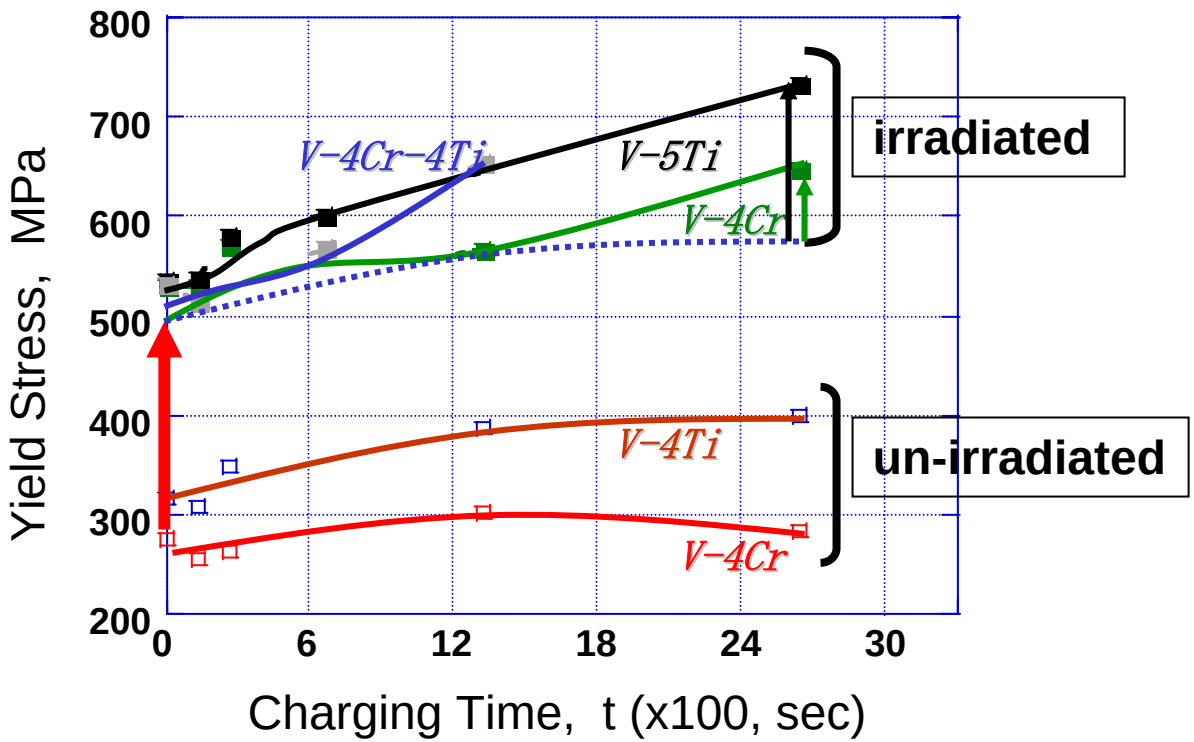

+ Radiation hardening
+ Additional hardening due to H charging

Yield Stress as a function of H Charging

(neutron-irradiated, 300C, 0.01 dpa)

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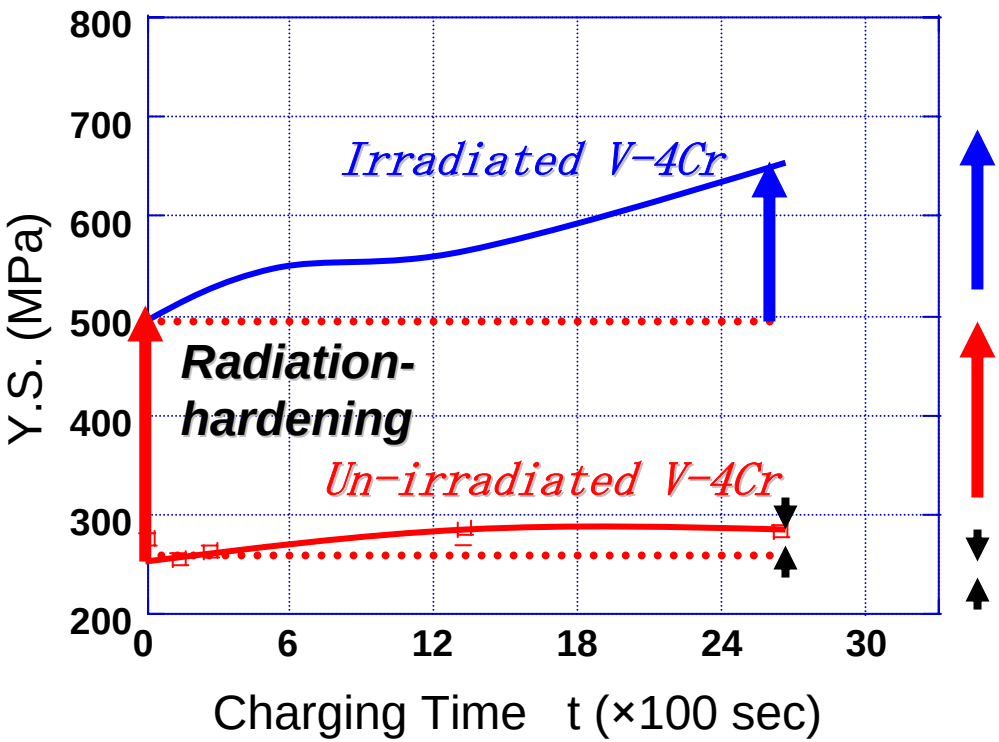


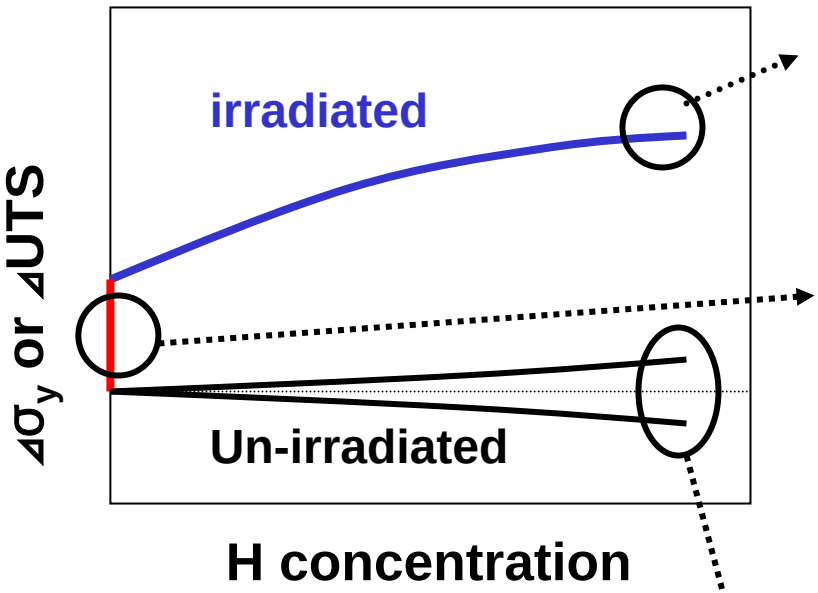
Additional hardening
H-defect interaction ?

Radiation-hardening

Solution Hardening

Additional hardening due to H-trapped defect clusters

Hardening due to H-trapped Defects

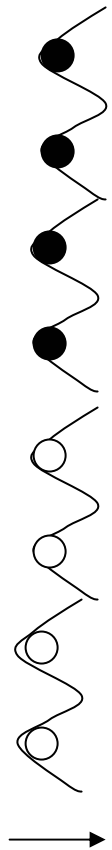


Additional hardening

obstacles:
Hydrogen-trapped defect clusters

Radiation-hardening

obstacles:
defect clusters (dislocation loops)



Dislocation motion

Hardening or Softening ?

Interaction between mobile dislocation and hydrogen (in solution and second phase)

Luders Strain as a function of Hydrogen Charging before and after Irradiation

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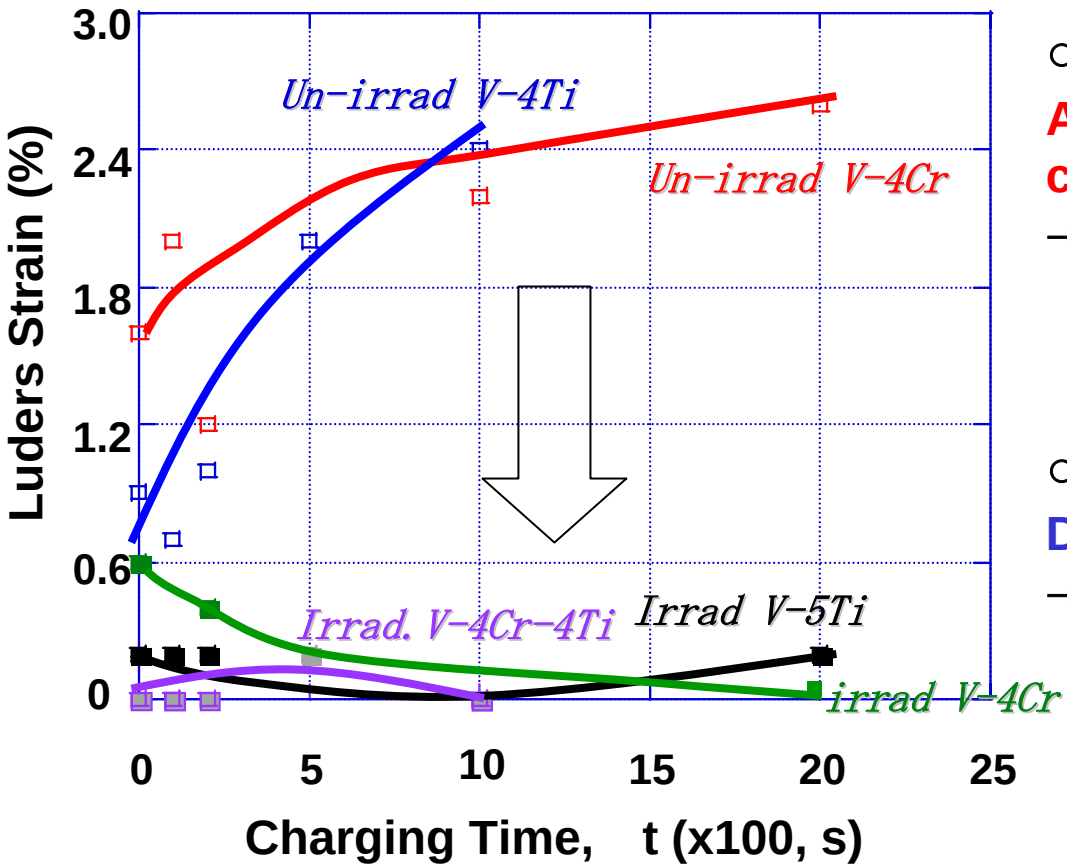


○ **Un-irradiated V alloys:**
Appearing Luders strain after H charging with small amount
→ dislocation interacts with H in solution

○ **Irradiated V alloys :**
Disappearing Luders strain
→ reducing H in solution (H trapping due to defect clusters)

Summary

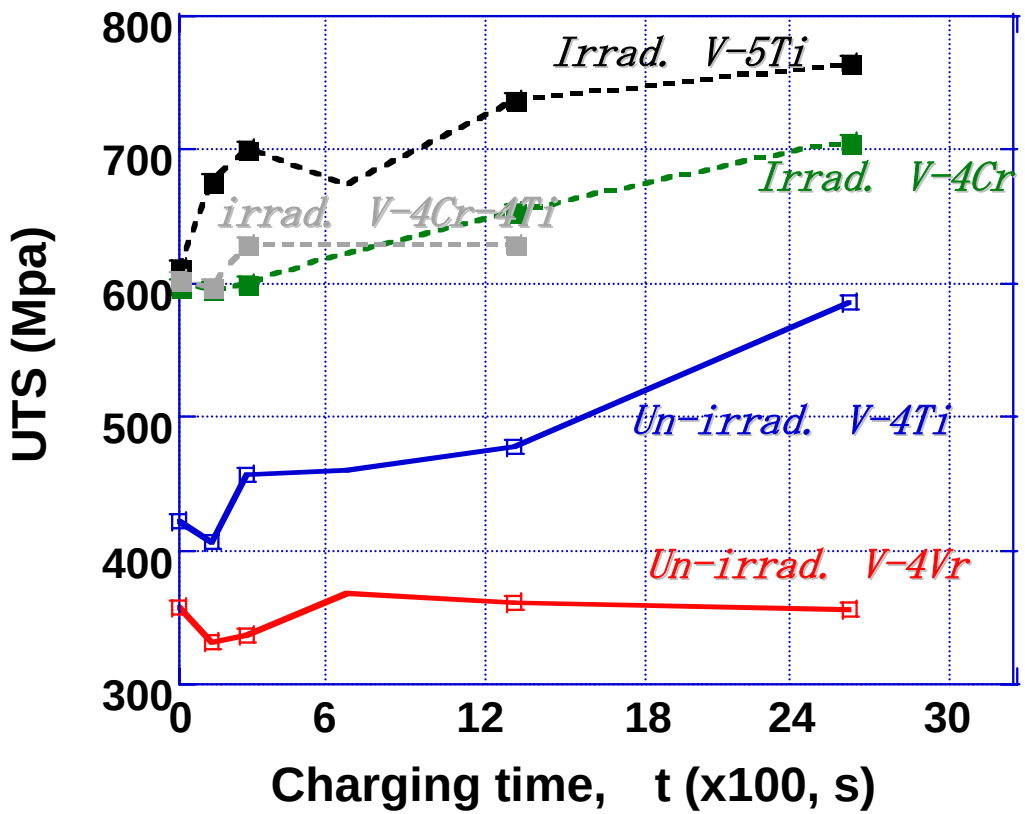
Tensile test and microstructural observation have been carried out for neutron-irradiated V and V alloys after cathodic charging.

(1) Additional hardening due to H charging: After cathodic charging an additional hardening takes place in neutron-irradiated V and V alloys (300 C, 0.01 dpa), as well as radiation hardening.
+ Dislocation loops can contribute for the radiation hardening.
+ The additional hardening results from the trapping of hydrogen to the dislocation loops, which contribute to increase in the hardness of the barrier for mobile dislocations.

(2) Disappearing Luders Strain by irradiation: In un-irradiated V and V alloys Luders strain develops after cathodic charging, but it disappears in irradiated samples.
+ Developing of Luders strain means hydrogen is in solution and interacting with mobile dislocations.
+ In irradiated samples the defect clusters can trap hydrogen and deduces the amount of freely diffusing hydrogen.

(3) Hydrogen trapping by defect clusters: Radiation-produced defect clusters trap hydrogen easily around room temperature, and hydrogen can affects on the mechanical properties, even if with low concentration.

Ultimate Tensile Stress as a function of H Charging

(neutron-irradiated, 300C, 0.01 dpa)

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