Institute for Applied Materials

Bubble formation in dual beam He/Fe irradiated EUROFER97

B. Kaiser[1], E. Gaganidze[1], C. Dethloff[1], D. Brimbal[2], P. Trocellier[2], L. Beck[2] and J. Aktaa[1]

[1] *Karlsruhe Institute of Technology, Institute for Applied Materials (IAM), P.B. 3410, 76021 Karlsruhe, Germany*

[2] *CEA, DEN, Service de Recherches de Métallurgie Physique, Laboratoire JANNUS, F-91191 Gif-sur-Yvette, France*

Abstract

Low activation ferritic/martensitic steels are candidates for structural materials in future fusion power plants. In order to study nucleation of helium bubbles under neutron irradiation EUROFER97 was exposed to He and Fe ions. The evolution of helium bubbles is modelled by using kinetic rates.

1. Irradiation experiment

Irradiation facility:

- CEA, JANNUS Saclay

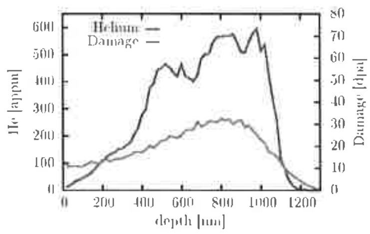
Dual beam irradiation parameters:

He-ions:
- 1.2 MeV

Fe-ions:
- 3.0 MeV

Temperatures:
- 330°C
- 400°C
- 500°C

SRIM damage and helium depth profile:



Details in references [1, 2].

2. TEM microstructure analysis

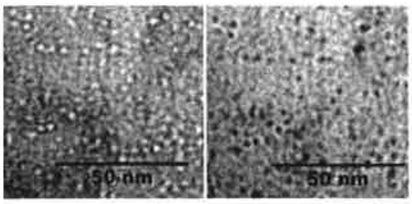
Sample preparation:

- Asymmetric electrolytic polishing, ref [1]
- FIB-lamella (access to a depth of 400-800nm)

Bubbles in bright-field images:

- Under-focus: white dots
- Over-focus: black dots
- Tecnai G² (200 kV) in the hot cells of the FML-laboratory at KIT

$T_{irr} = 400°C$:



TEM bright-field micrographs at 400°C with focus at $\pm 2\mu m$ showing a homogeneous void distribution.

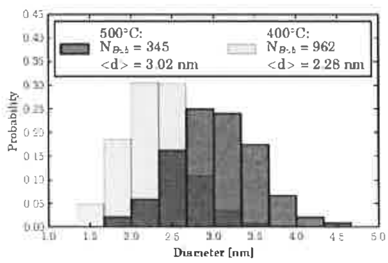
$T_{irr} = 500°C$:

a) homogeneous b) non-homogeneous

TEM bright-field micrographs in under-focus condition at 500°C showing a) spatially homogeneous and b) non-homogeneous distributions of bubbles.

3. TEM bubble size distribution

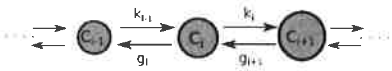
- Assumption of spherical voids
- Bubble diameter measured in under focused bright-field micrographs



- No bubbles visible for T_{irr} = 330°C (but until now only one TEM disc was analysed)
- The higher the temperature the larger the bubbles

4. Kinetic rate theory

Voids grow and shrink by the absorption and emission of one mobile unit cluster $HeV_{1/x}$.



- C_i: Concentration of $He_iV_{i/x}$ cluster
- $k_i = 4\pi R_i D_{He}^{eff}$: Absorption coefficient
- $g_i = k_i\Omega^{-1}\exp\left[-\frac{F_i^b}{k_bT}\right]$: Emission coefficient
- x: Constant helium-vacancy ratio
- D_{He}^{eff}: Vacancy assisted diff.-mechanism

$$\dot{C}_1 = G_{He} - L_{Sinks} - \sum_i k_i C_1 C_i + \sum_i g_i C_i$$
$$\dot{C}_i = -(g_i + k_i C_1)C_i + g_{i+1}C_{i+1} + k_{i-1}C_1C_{i-1}$$

- G_{He}: Helium production rate
- L_{sink}: Capturing of helium at grain boundaries and dislocation lines

Details in reference [3].

5. Thermodynamic helium bubble model

Bubbles radius R_i and binding energies F_i^b of the mobile unit cluster to bubbles required for the calculation of absorption and emission coefficients.

Two approaches:

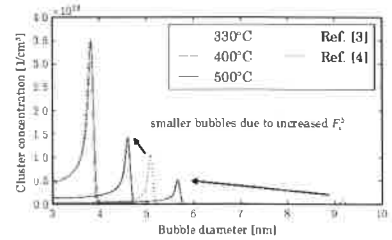
- C. Dethloff, Ref. [3]
  - Energy accounts only for surface tension
  - Bubble size given by number of vacancies
- T. Jourdan: "Variable gap model", Ref. [4] Parametrization of MD-calculations
  - He-He interaction energy
  - He-Fe interface energy
  - Fe surface and elastic energy
  - Bubble radius at energy minimum

Comparison between models:
(x=0.5-1.5; T_{irr} =330°C-500°C)

- Variable gap model leads to higher binding energies → reduced emission
- Elastic deformation does not influence bubble radius

6. Results of the rate-theory

Influence of the different thermodynamic bubble models on bubble size distributions for $x = 1$.



C. Dethloff, ref. [3]:

- High emission of unit clusters for small clusters
- High absorption of unit clusters for large clusters

⇒ Redistribution from small to large bubbles

T. Jourdan: Variable gap model, ref. [4]:

- Reduced emission rate induces less redistribution to large clusters ⇒ smaller bubbles

⇒ Results closer to TEM analysis

Acknowledgement & References

[1] D. Brimbal et al., J. Nucl. Mater. 465 (2015)
[2] O. Troeber et al., CIMTEC 2014 FJ-6:L07
[3] C. Dethloff et al., J. Nucl. Mater. 426 (2012)
[4] T. Jourdan et al., J. Nucl. Mater. 418 (2011)

This work has been carried out within the EFDA Goal Oriented Trainee Program WP12 RadEff