AGENZIA NAZIONALE PER LE NUOVE TECNOLOGIE, L'ENERGIA E LO SVILUPPO ECONOMICO SOSTENIBILE

IFMIF EU EDA

UNIVERSITÀ DEGLI STUDI DI PALERMO

A LIFETIME ESTIMATION OF THE IFMIF LITHIUM TARGET BAYONET BACKPLATE BASED ON PSEUDO-TRANSIENT ANALYSIS OF IRRADIATION-INDUCED SWELLING EFFECT

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ABSTRACT

In the framework of European fusion activities, a high flux neutron source is considered an essential device for testing candidate materials under irradiation conditions typical of future fusion power reactors. To this purpose, IFMIF (International Fusion Materials Irradiation Facility) project represents an important option to provide the fusion community with a source capable of irradiating materials samples at a rate of up to 20 dpa/fpy in a volume of 0.5 l. This is achieved by bombarding a high-speed liquid lithium target with a 10 MW double deuteron beam which yields a 14 MeV-peaked neutron spectrum. Within the engineering design work of the IFMIF/EVEDA project, which was concluded in half 2013, ENEA was in charge of the design of the lithium target system based on the so called bayonet backplate (BP) concept, which foresees the possibility to periodically replace only the most irradiated and thus critical component (i.e., the backplate) while continuing to operate the rest of the target for a longer period. With the objective of estimating the lifetime of the BP, a pseudo-transient calculation simulating one year of full-power operation has been performed by imposing a non-uniform neutron-induced volumetric swelling strain which evolves in time as a linear function of the accumulated displacement damage (dpa) according to available literature experimental correlations. Dpa damage distribution and time rate have been calculated by ENEA in the framework of an extensive neutronic analysis of the target system carried out through the MCNP transport code. The stress field evolution resulting from the increasing swelling deformation has been obtained through an uncoupled thermomechanical analysis carried out by the University of Palermo using a qualified finite-element code which takes into account all thermal and mechanical loads applied to the system during normal operation. In this paper, the results of the above analysis are presented and an estimation of the BP lifetime due to swelling effect is given on the basis of ITER design rules criteria. It is found that, although the bulk structure of the BP is expected to survive several months of continuous irradiation, a further improvement of the system design is suggested in order to achieve an optimized configuration.

IFMIF CONCEPT

TARGET ASSEMBLY

FE MODEL

NUMERICAL SIMULATION

Material: EUROFER-97

Neutronics:
- MCNP5 + McDeLicious-11 neutron source (KIT)
- McCad (KIT) + MCAM (FDS) for CAD/MCNP files conversion

Thermomechanics:
- 3D uncoupled FE model (ABAQUS® code)
- Primary (P) loads: mechanical loads
- Secondary (Q) loads: thermal loads + swelling

Operating conditions:
- Beams power = 10 MW
- Li inlet temperature = 250 °C
- Li inlet velocity = 15 m/s

MODELLING OF SWELLING EFFECT

$$\varepsilon_{swelling}(x,y,t) = dpa(x,y) \times S(t)$$

13 He appm/dpa
0.014 % / dpa

T = 400 °C

$\varepsilon_{swelling}$ (max) = 0.75% / year

Miwa Y. et al., *J. Nucl. Mater., 283* (2000)

STRESS EVOLUTION

ITER SDC-IC design rules

$(P+Q)_m$: primary + secondary membrane stress intensity

S_e : allowable stress intensity
[G. Aiello et. al., *J. Nucl. Mat., 414* (2011), 53-68]

Path AB

ε_{sw} (end of life) ~ 0.5 %

DESIGN OPTIMIZATION

1) Increase of the Li channel thickness

S = 1.8 mm (original thickness)
W = 2 mm (added thickness)

2) Reduction of the backplate thickness

D = 32.8 mm (original thickness)
D = 17 mm (reduced thickness)

Values at beginning of nominal operation	ORIGINAL design	MODIFIED design
Path AB - Level A criteria		
T_{max} [°C]	283	286
P_m / S_m	0.0035	0.0018
$(P_m + P_b) / (K_{eff} S_m)$	0.0026	0.0013
$(P_m + Q_m) / S_e$	0.7835	0.2087