Deuterium interaction with low–activated chromium-manganese austenitic steel with increased content of carbide particles

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ABSTRACT

New low-activation austenitic chromium-manganese steel has been recently developed in Russia as a potential structural material for nuclear and fusion reactors. In the present work deuterium interaction with melt No 4 of new steel with increased content of carbide particles was investigated. Deuterium was introduced into steel samples by exposure to D_2 gas at a temperature of 200 °C and a pressure of $5{\cdot}10^5$ Pa and by 100 eV deuterium plasma irradiation at 200 °C with fluence of up to 10^{25} D/m^2. Deuterium retention in the new steel was investigated using thermal desorption method. Deuterium permeation into the new steel was studied in a temperature range of 150–380 °C and a deuterium pressure range of 10^3–$5{\cdot}10^4$ Pa. The temperature dependences of deuterium diffusivity and permeability of the new steel were obtained.

1. Low activation austenitic steel (LAAS)

Steels for fusion:

Austenitic Ni steels

Advantages: corrosion and heat resistance, not magnetic, resistive to radiation and He embrittlement, low DBBT
Disadvantages: high activation, long decline of induced activity

Reduced activation ferritic-martencitic steels (RAFMS)

Advantages: low activation, low swelling up to ≥ 100 dpa, heat resistance, radiation resistance, compatible with Li
Disadvantages: magnetic, DBTT ↑ under n-irradiation

Alternative: low activation austenitic Cr-Mn steels (LAAS)

Advantages: low activation, not magnetic
Disadvantages: LAASes developed in last 25 years of 20th century. Stopped because of phase instability.

A new reduced activation Cr-Mn austenitic steel has been developed

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- Low activation
- Dispersion-strengthened
- Not magnetic
- Stability of diamagnetic properties under long-time aging
- High stability of austenite

Hydrogen isotopes interaction with low-activation chromium-manganese steels:
- has never been investigated
- a security issue if using in fusion

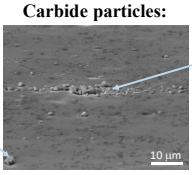
Goal of work: investigation of deuterium interaction with new low activation Cr-Mn austenitic steel (LAAS) with increased content of carbide particles

2. Object of research: LAAS melt No 4

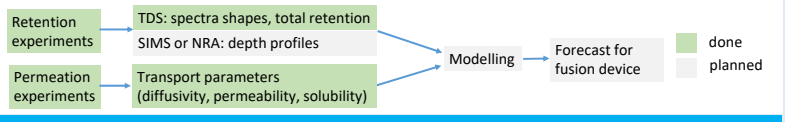
	Cr	Mn	Ni	Cu	W	V	Ti	Nb	Mo	Co	Al	Si	S	P	C	B
Wt.%	11,3	22,4	0,015	<0,05	1,08	0,2	0,17	0,01	0,01	0,02	0,04	0,47	0,006	<0,01	0.3	0,004

Carbide particles:

1. MC (M – Ti, V, W, Si)
a) several μm
b) 50-100 μm
c) Ti-based - 5-15 μm
JMatPro modelling:
Equilibrium content of MC → 0.5 at.%
Microscopy: content of MC - 0.2 – 0.3 at.%

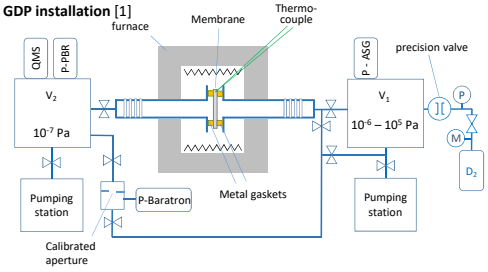


2. $M_{23}C_6$ (M - Cr, Mn, W, Si)
a) rows 0.6-1 μm - **prevailing**
b) 100 – 150 μm
JMatPro modelling:
Equilibrium content of $M_{23}C_6$ → 5 at.%
Microscopy: content of $M_{23}C_6$ - 2 – 3 at.%



Permeation experiment

GDP installation [1]



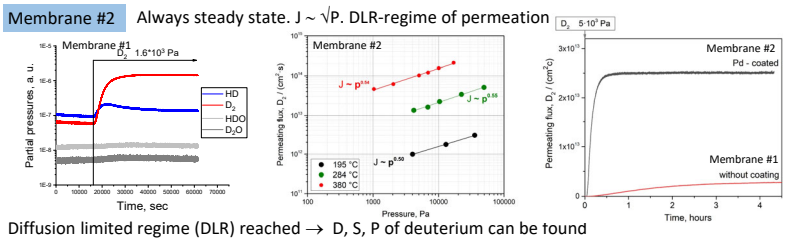
Membrane – central area of DN16CF flange

∅18 mm
thickness 0.25

Membrane # 1 natural oxides without coatings
Membrane # 2 oxides sputtered; 100 nm Pd coated on both sides

Membrane #1 No steady state. Permeating flux decreases after maximum → surfaces change

Membrane #2 Always steady state. J ~ √P. DLR-regime of permeation



Diffusion limited regime (DLR) reached → D, S, P of deuterium can be found

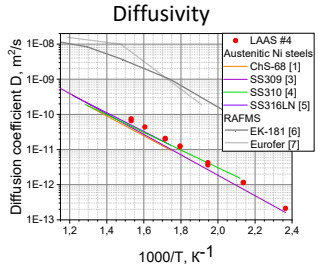
$$J_{DLR} = \frac{DS\sqrt{p}}{L}(1 + 2\sum_{n=1}^{\infty}(-1)^n \exp(-\frac{D\pi^2 n^2}{L^2})) \quad [2]$$

D – diffusivity
S – solubility
P = DS - permeability
p – pressure above inlet surface
L – membrane thickness

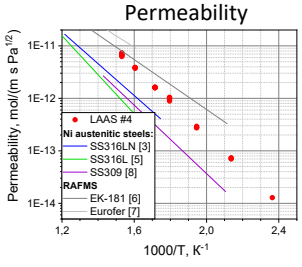
Natural oxides decrease permeating flux by factor of 10

DEUTERIUM DIFFUSIVITY AND PERMEABILITY

Diffusivity



Permeability



$D(T)\ [m^2/s] = 3.2{\cdot}10^{-6}\ e^{-58000/RT}$

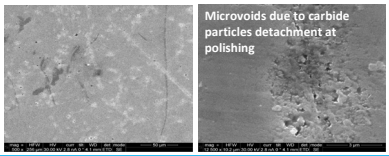
$P(T)\ [mol/(m{\cdot}s{\cdot}Pa^{1/2})] = 6.9{\cdot}10^{-6}\ e^{-62600/RT}$

The deuterium diffusivity in LAAS is close to that in nickel steels of 300th class.
The deuterium permeability in LAAS is several times higher than in usual nickel austenitic steels.

RETENTION

Samples for retention experiments

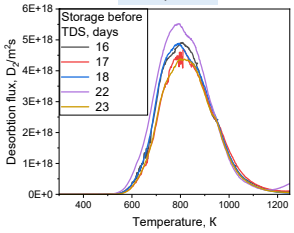
- Electric discharge sawing
- Double-side mechanical polishing to a mirror-like finish
- Cleaning in acetone
- Final size: 10x10x0.9 mm
- Annealing in vacuum 773 K, 2 hours



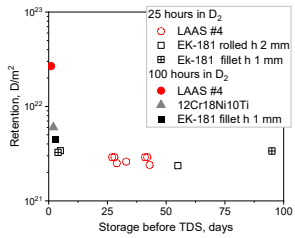
Saturation with D in gas

Exposure in D_2
$5{\cdot}10^5$ Pa, 200 °C, 25 or 100 hours
↓
storage at air
↓
Retention study:
TDS, 0.5 K/s

TDS spectra



Total retention

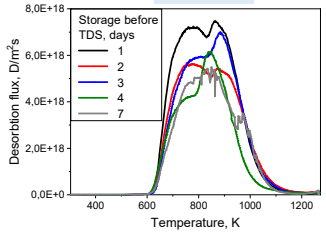


25 hours exposure in D_2:
LAAS and RAFMS Ek-181 retain the same amount
100 hours exposure in D_2:
Retention in LAAS is 3.5 times higher than in Ni SS
Retention in LAAS is 6 times higher than in RAFM

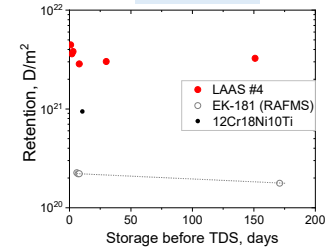
Plasma irradiation

D plasma
$5{\cdot}10^{25}$ D/м^2, 200 °C
↓
Storage in a high vacuum
↓
Retention study:
TDS, 0.5 K/s

TDS spectra



Total retention



Deuterium retention in LAAS#4
An order of magnitude higher than in > RAFMS
2-3 times higher than in Ni austenitic steel

Possible reason for high retention in LAAS – high content of carbide particles

CONCLUSION

The deuterium interaction with low-activation chromium-manganese austenitic steel was investigated.

- The temperature dependencies of diffusivity and permeability of the new steel were obtained in a temperature range of 150 – 380 °C. The deuterium diffusivity in LAAS is close to that in nickel steels of 300th class. The deuterium permeability in LAAS is several times higher than in usual nickel austenitic steels.
- At 350 °C natural oxides on the surfaces of 0,25 mm thick LAAS membrane reduce permeating deuterium flux by an order of magnitude.
- Deuterium retention in LAAS after exposure in D_2 gas (200 °C, of $5{\cdot}10^5$ Pa, 25 h) and after D-plasma irradiation (200 °C, 10^{25} D/m^2) was investigates. LAAS #4 retains higher amount of D than Ni austenitic and than RAFM steel.

ACKNOWLEDGEMENTS

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