Irradiation and Oxidation Behaviors of Ti_2AlC-a candidate cladding material for nuclear reactors

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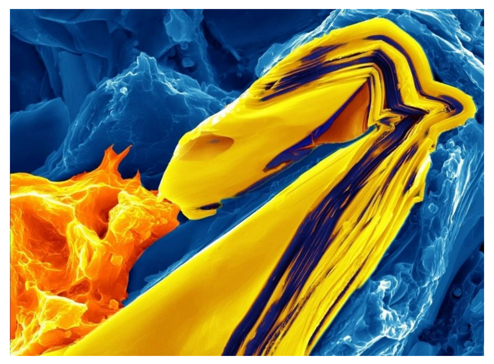
Material: MAX phase

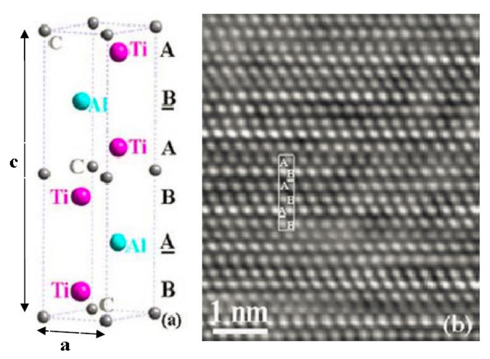
- **Ti_2AlC** is a member of MAX phases, which is a group of ternary carbides and nitrides whose general formula is Mn+1AXn (n=1, 2 or 3), where M is an early transition metal ,A is an A-group element, and X is carbon or nitrogen.



Babak Anasori , 2011

Similar to metal:
- Excellent electrical conductors
- Thermal conductivity
- Exceptionally damage tolerant
- Good machinability

Similar to ceramic:
- Corrosion resistance
- Creep resistance
- High-temperature stability
- Thermal shock resistance

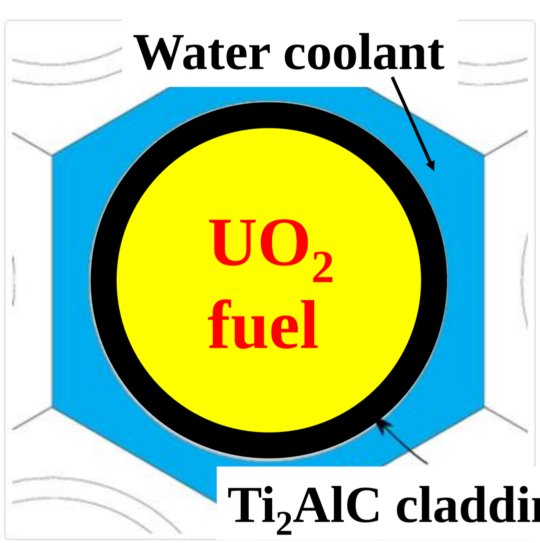


Motivation

The combination of oxidation resistance and low neutron activation of MAX phase makes it viable candidate for nuclear applications. This project seeks to:

I. The **irradiation resistance** and microstructure evolution of Ti_2AlC at elevated temperatures.

II. The **oxidation resistance** of Ti_2AlC in steam at high temperatures.



Ti_2AlC cladding is expected to provide exceptional tolerance to a similar accident of Fukushima reactors.

Experiment set up

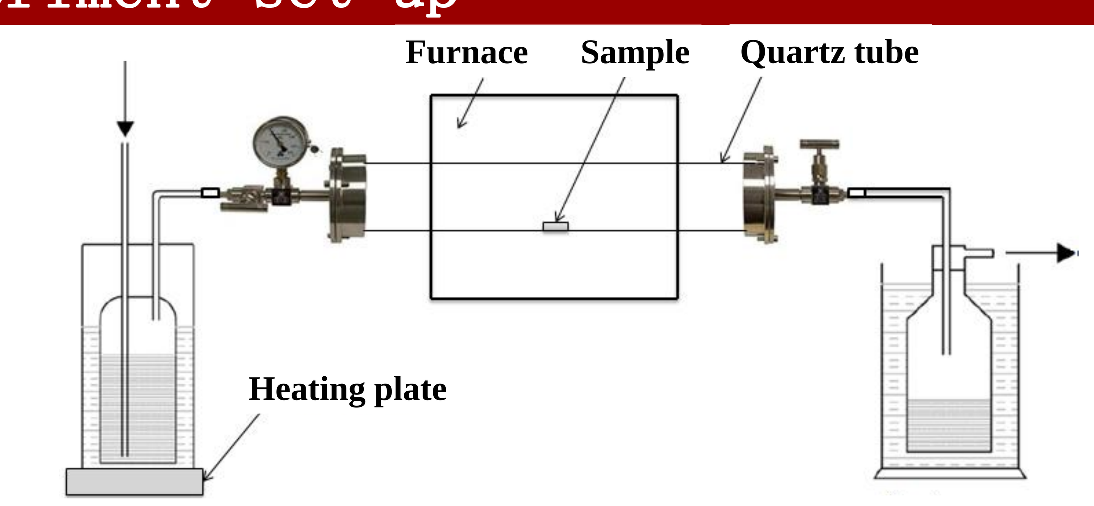


Figure 1. Experimental set up for high temperature steam oxidation.

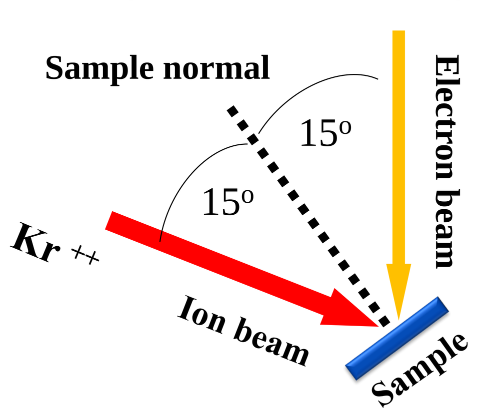
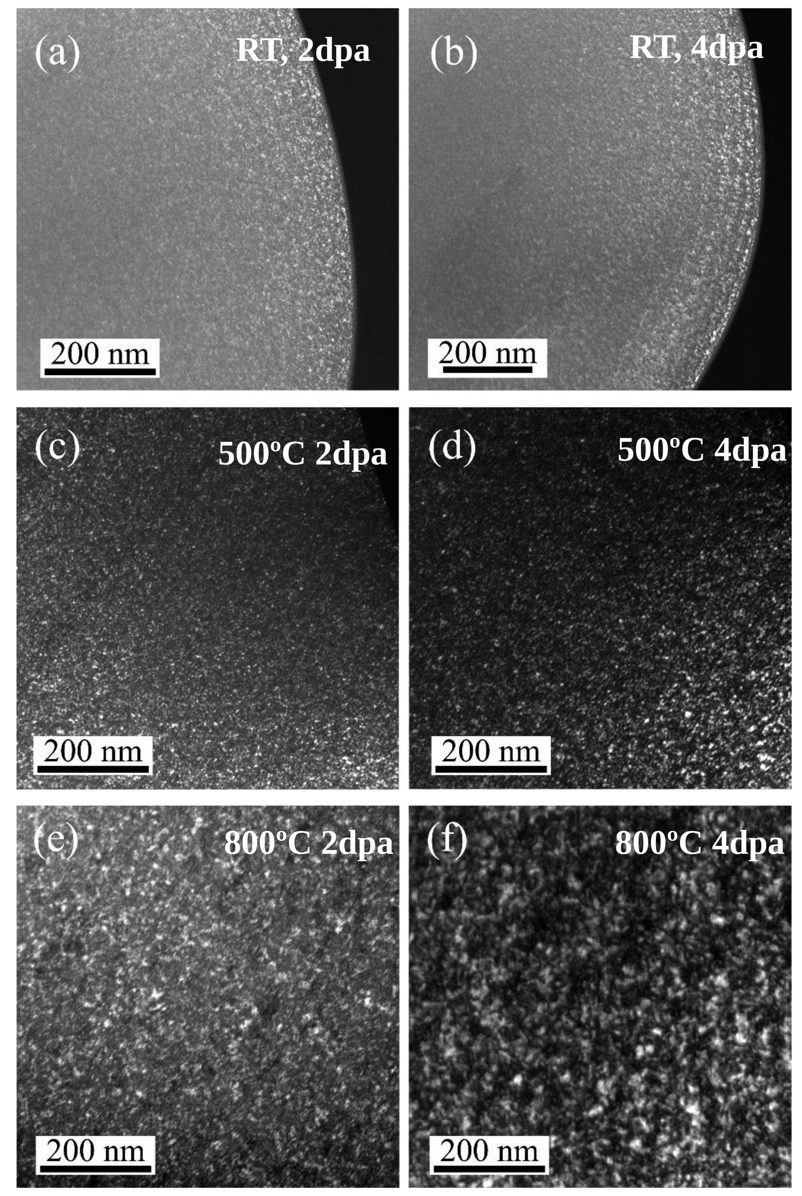


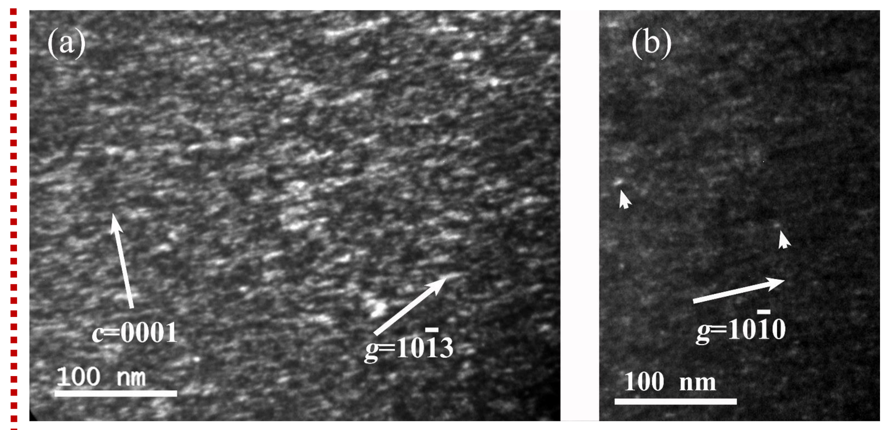
Figure 2. The IVEM-Tandem in-situ irradiation facility

In situ irradiation test of Ti_2AlC

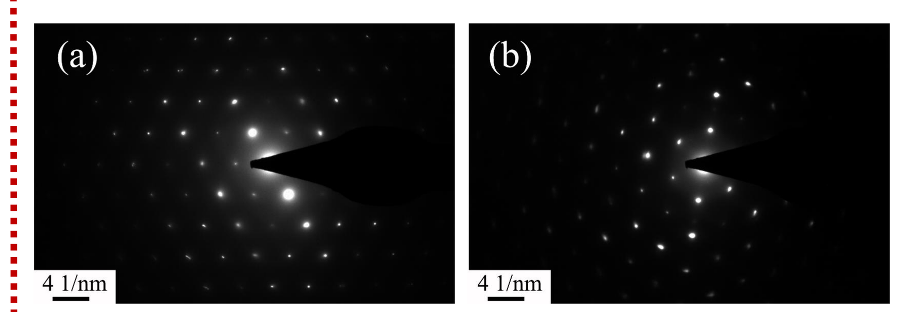
I. Evolution of microstructure



➢ **Figure 3.** Evolution of irradiation defects in Ti_2AlC as a function of irradiation dose and temperature during 1 MeV Kr ion irradiation.

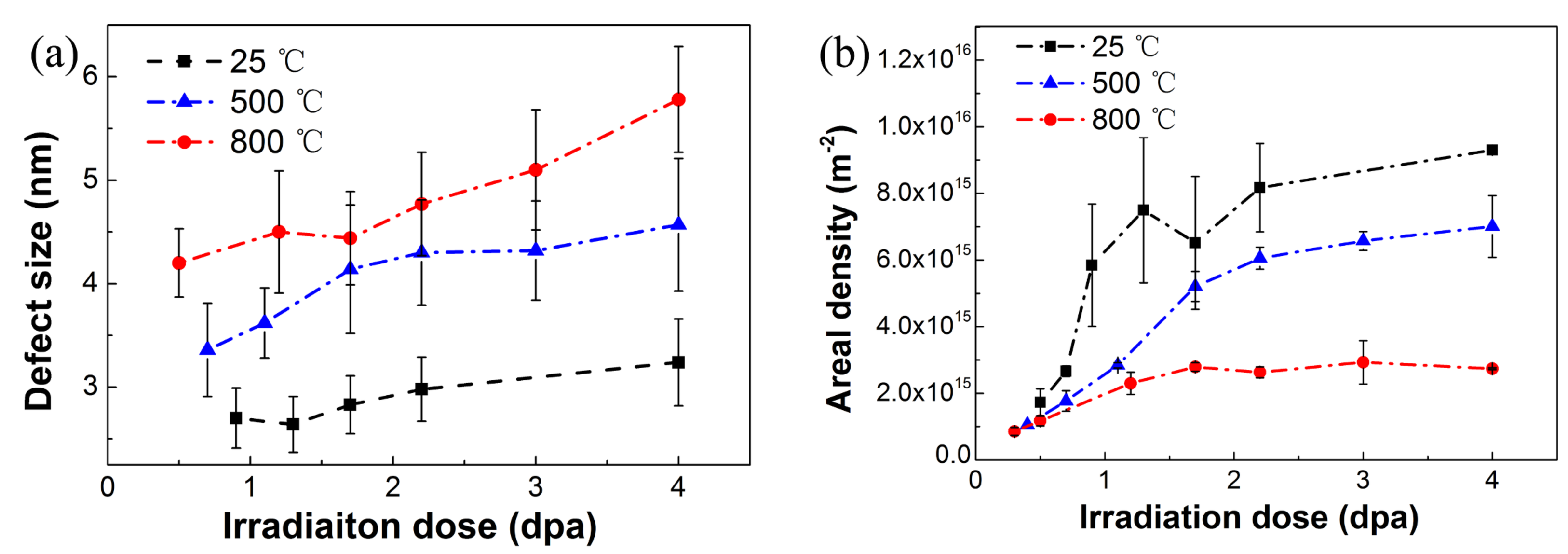


➢ **Figure 4.** Weak-beam dark field images of irradiation defects in Ti_2AlC at 4 dpa and 800 °C under two conditions.



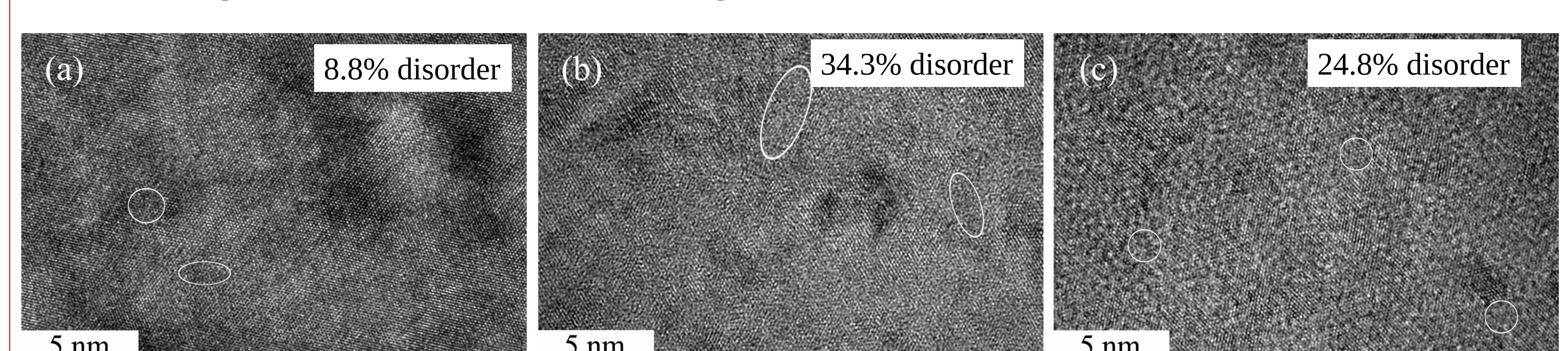
➢ **Figure 5.** Diffraction pattern of Ti_2AlC after irradiation: (a) 4 dpa, 25 °C, [0001] zone; (b) 4 dpa, 800 °C, [0001] zone.

II. Evolution of irradiation defects



➢ **Figure 6.** The evolution of (a) size and (b) areal density of irradiation defects in Ti2AlC as a function of irradiation dose and temperature.

III. High resolution TEM images



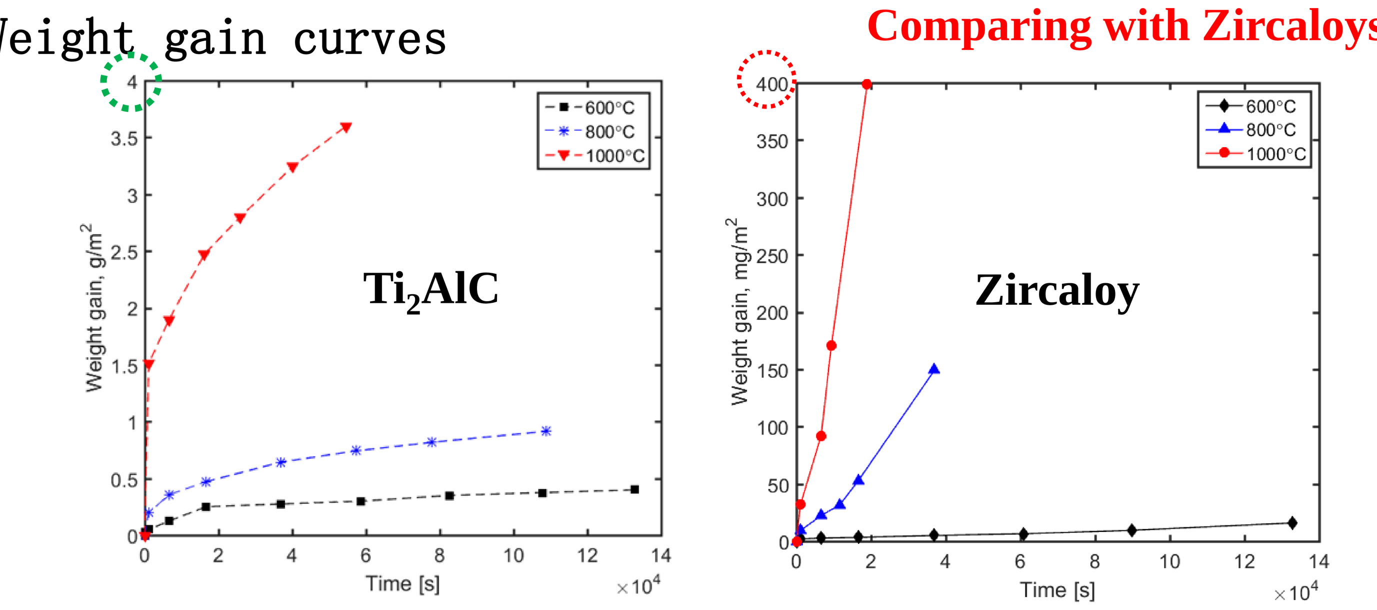
➢ **Figure 7.** HRTEM images of the (0 0 0 1) plane of Ti_2AlC samples after irradiation: (a) 4 dpa, 25 °C; (b) 4 dpa, 25 °C; (c) 4 dpa, 800 °C.

Irradiation Dose	Temperature	Crystal plane	Disorder fraction
2 dpa	25 °C	(0001)	8.8±1.1
4 dpa	25 °C	(0001)	34.3±2.1
4 dpa	800 °C	(0001)	24.8±3.0

Steam oxidation test of Ti_2AlC

I. Weight gain curves

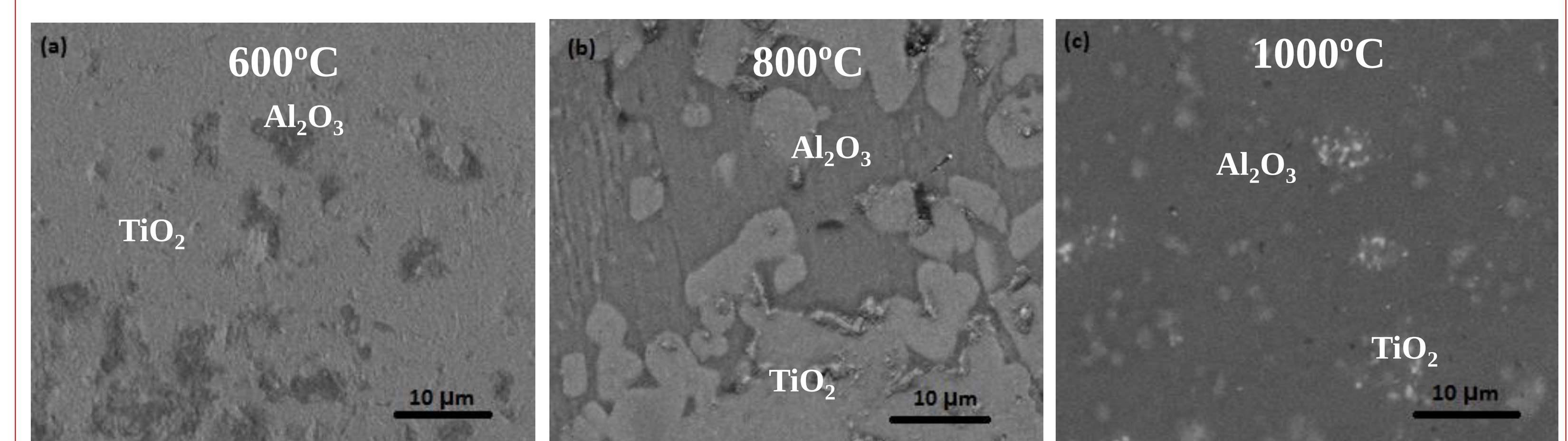
Comparing with Zircaloys



➢ **Figure 8.** Weight gain of Ti_2AlC and zircaloy vs. exposure time in steam.

The weight gain of Ti_2AlC is much lower than Zircaloys.

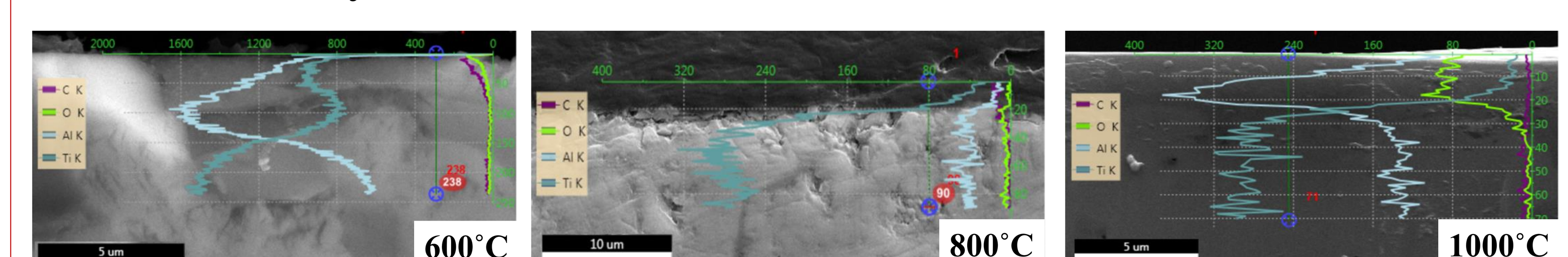
II. Surface of oxidation scales



➢ **Figure 9.** Surface morphology of Ti_2AlC oxidized in steam.

TiO_2 dominant → **Al_2O_3 dominant**

III. EDS analysis of oxidation scales



➢ **Figure 10.** EDS analysis of the cross-section of oxidation scales.

TiO_2 as top layer → **Al_2O_3 as top layer**

Conclusions

➢ During irradiation test, small dislocation loops formed on the basal plane and accumulate in the microstructure. The dislocation loops **slowly grows** with the irradiation dose and raising temperature.

➢ **No amorphization** or phase transformation was observed. Ti_2AlC is **more irradiation resistant** at 800 °C than at 25 °C.

➢ Ti_2AlC showed **excellent oxidation tolerance** in steam at 600, 800 and 1000 °C due to the formation of a continuous **protective Al_2O_3 layer**.

Acknowledgements

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