Irradiation and Oxidation Behaviors of Ti<sub>2</sub>AlC—a candidate cladding material for nuclear reactors

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**Material: MAX phase**

- Ti<sub>2</sub>AlC is a member of MAX phases, which is a group of ternary carbides and nitrides whose general formula is M<sub>n</sub>Al<sub>x</sub>N<sub>y</sub>(n=1, 2 or 3), where M is an early transition metal, A is an A-group element, and X is carbon or nitrogen.

**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

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**Motivation**

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

I. The **irradiation resistance** and microstructure evolution of Ti<sub>2</sub>AlC at elevated temperatures.

II. The **oxidation resistance** of Ti<sub>2</sub>AlC in steam at high temperatures.

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**In situ irradiation test of Ti<sub>2</sub>AlC**

**I. Evolution of microstructure**

- (a) RT, 2dpa
- (b) RT, 4dpa

**Figure 4.** Weak-beam dark field images of irradiation defects in Ti<sub>2</sub>AlC at 4 dpa and 800 °C under two conditions.

**II. Evolution of irradiation defects**

- (a) 25 °C, [0001] zone
- (b) 4 dpa, 800 °C, [0001] zone

**Figure 5.** Diffraction pattern of Ti<sub>2</sub>AlC after irradiation: (a) 4 dpa, 25 °C, [0001] zone; (b) 4 dpa, 800 °C, [0001] zone.

**Figure 6.** The evolution of (a) size and (b) areal density of irradiation defects in Ti<sub>2</sub>AlC as a function of irradiation dose and temperature.

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**Steam oxidation test of Ti<sub>2</sub>AlC**

**I. Weight gain curves**

**Figure 8.** Weight gain of Ti<sub>2</sub>AlC and zircaloy vs. exposure time in steam. The weight gain of Ti<sub>2</sub>AlC is much lower than Zircaloy.

**II. Surface of oxidation scales**

**Figure 9.** Surface morphology of Ti<sub>2</sub>AlC oxidized in steam. TiO<sub>2</sub> dominant

**Figure 10.** EDS analysis of the cross-section of oxidation scales. TiO<sub>2</sub> as top layer

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**Conclusions**

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

- No amorphization or phase transformation was observed. Ti<sub>2</sub>AlC is more irradiation resistant at 800 °C than at 25 °C.

- Ti<sub>2</sub>AlC showed excellent oxidation tolerance in steam at 600, 800 and 1000 °C due to the formation of a continuous protective Al<sub>2</sub>O<sub>3</sub> layer.

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**Experiment set up**

- Sample normal
- Irradiation plane

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

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

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**Figure 3.** Evolution of irradiation defects in Ti<sub>2</sub>AlC 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<sub>2</sub>AlC at 4 dpa and 800 °C under two conditions.

**Figure 5.** Diffraction pattern of Ti<sub>2</sub>AlC after irradiation: (a) 4 dpa, 25 °C, [0001] zone; (b) 4 dpa, 800 °C, [0001] zone.

**Figure 6.** The evolution of (a) size and (b) areal density of irradiation defects in Ti<sub>2</sub>AlC as a function of irradiation dose and temperature.

**Figure 7.** HRTEM images of the (0 0 0 1) plane of Ti<sub>2</sub>AlC samples after irradiation: (a) 4 dpa, 25 °C; (b) 4 dpa, 25 °C; (c) 4 dpa, 800 °C.

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**III. High resolution TEM images**

- 8.8% disorder
- 34.3% disorder
- 24.8% disorder

**Figure 7.** HRTEM images of the (0 0 0 1) plane of Ti<sub>2</sub>AlC samples after irradiation: (a) 4 dpa, 25 °C; (b) 4 dpa, 25 °C; (c) 4 dpa, 800 °C.

**Table 1**

<table>
<thead>
<tr>
<th>Irradiation Dose (dpa)</th>
<th>Temperature (°C)</th>
<th>Crystal Plane</th>
<th>Disorder Fraction</th>
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<tr>
<td>2</td>
<td>25</td>
<td>(0001)</td>
<td>8.8 ± 1.1</td>
</tr>
<tr>
<td>4</td>
<td>25</td>
<td>(0001)</td>
<td>34.3 ± 2.1</td>
</tr>
<tr>
<td>4</td>
<td>800</td>
<td>(0001)</td>
<td>24.8 ± 3.0</td>
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