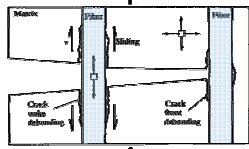


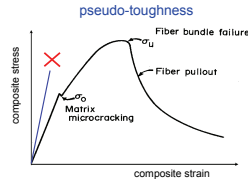
Motivation: Tungsten/Tungsten composite

A novel toughening method for tungsten (W), was proposed and developed based on the reinforcement of tungsten fibers (W_f/W_m composite) and engineered interfaces. The underlying toughening mechanism is analogous to that of a fiber-reinforced ceramic matrix composite (CMC). This work opened a new pathway to improve the toughness of tungsten as a structural material.

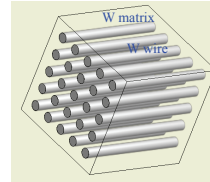
CMC composite toughening mechanism



- crack deflection
- interface debonding
- fiber sliding
- energy dissipation



W_f/W_m composite concept

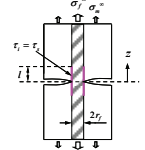


- W fiber, $\sigma_u > 2.5$ GPa, $\epsilon_u > 2\%$
- Interface thickness $< 1 \mu\text{m}$

The fracture properties of the engineered interface are the key factors controlling the overall composite toughness.

Analysis system:

Single filament (fiber) composite

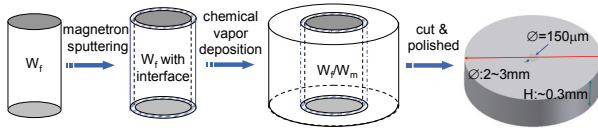


Goal and focus of this work

The main focus of this work lies in the investigation of the interfacial fracture behavior of W_f/W_m composites with various engineered interfaces to demonstrate the feasibility of synthesizing a toughened W_f/W_m composite using the CMC toughening mechanism.

Experiment

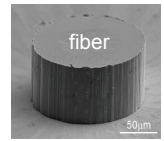
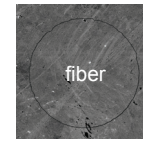
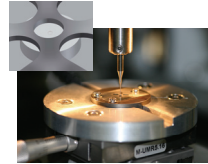
Specimen preparation



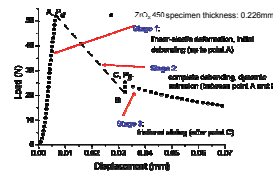
Designed interfaces

Oxide coating	Multiple-layer coating	Ductile coating	Lubricating coating
ZrO _x 150 nm 260 nm 450 nm 950 nm	ErO _x 600 nm 1000 nm	ZrO ₂ /Zr m ZrO ₂ /W m ErO ₂ /W m Er/W m	Cu 170 nm Cu 480 nm Cu/W m Carbon 600 nm

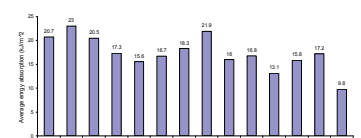
Fiber push-out test



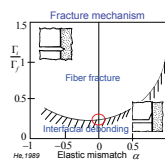
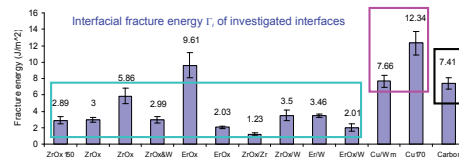
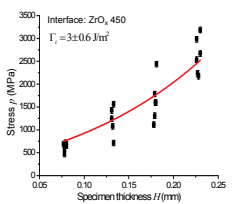
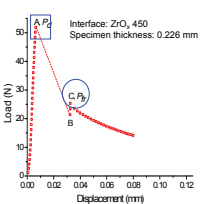
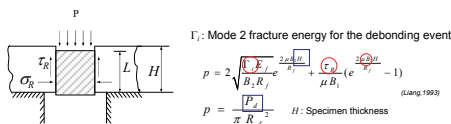
Result-Push-out test curve



The area below the curve corresponds to the total amount of work done by the applied load—average energy absorption Δ , kJ/m²



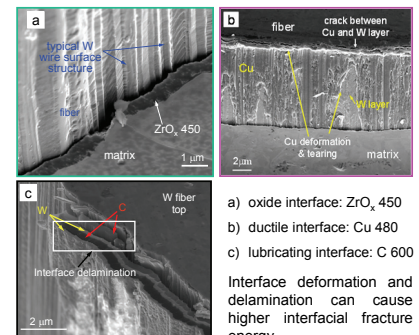
Result-Interfacial fracture energy (Γ_i) calibration and debonding criterion verification



Debonding criterion
Interface fracture energy Γ_i
Fiber fracture energy Γ_f ($\approx 320 \text{ J/m}^2$)

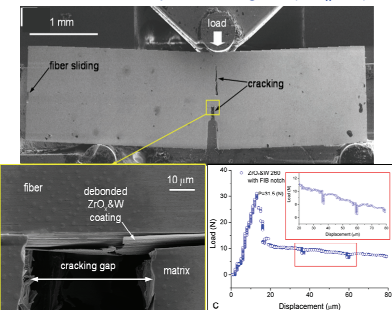
The calculated ratios lie between 0.003 and 0.034, satisfying the 0.25 criterion.

The debonding criterion is satisfied!

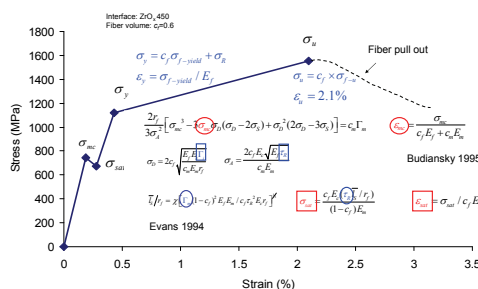


Result-Crack deflection demonstration

Micro-mechanical 3-point bending test (ZrO₂ 260)



Result-Behavior prediction of W_f/W_m composite with multiple fibers



The stress-strain curves is typical for a toughened composite, supporting the motivation of this work.

Conclusion

- A toughening method for tungsten is proposed based on the reinforcement of tungsten fibers (W_f/W_m composites) and engineered interfaces.
- The interfacial parameter determination results show that selected interfaces satisfy to the interfacial debonding criterion.
- The interfacial debonding and fiber sliding were demonstrated by micro-mechanical 3-point bending test.
- The predicted stress-strain curve of the W_f/W_m composites with multiple fibers agree with the theoretical one, supporting the primary motivation of the work.