The Effect of Design on the Ballistic Resistance of Ceramic-Metal Multilayers

**Significance:** Ceramic-metal composites are recognized for their resistance to ballistic penetration but their performance is sensitive to design. The objective of the study is to identify design principles that impart high ballistic resistance to the target.

**Details of the Impact Test Simulations**
- Impact Velocity: 1220 m/s
- Target Parameters and Ranges:
  - Mass ratio: \( m_t = \frac{m_c}{m_m} \) (0.2)
  - Thickness ratio: \( t_t = \frac{t_c}{t_m} \) (0.1)

**Results from the Parametric Study**
- **Effect of Design on Target Deflection**
- **Target Energy Dissipation and its Effect on Failure**

**Design Space of Equal-Weight C-M Systems**
- Model Validation to Experiments

**Conclusions**
1. For fixed areal density, systems that combine ceramic and metal have improved ballistic resistance, relative to monolithic systems.
2. The design with the greatest ballistic resistance is the bilayer with the ceramic layer on the impact face and the metal layer at the rear.
3. Failure resistant designs are found to have large ratios of ceramic-to-metal mass.

Modeling of Periodic Materials with Novel Properties

Low coefficient of thermal expansion (CTE) lattices can achieve a large portion of theoretical bounds for stiffness (left-bottom). By combining two materials with appreciably different and potentially large CTEs material systems can be designed that have zero or even negative thermal expansion. While there are potentially many applications, this particular material was developed for use on hypersonic aircraft (left-top) as an aerocool material to replace brittle thermal barriers such as those used on the space shuttle (left-center).

A cellular material has recently been identified that achieves theoretical bounds for isotropic stiffness (above). When constructed of diamond its properties define the boundary of property space (right-top). Its stiffness exceeds those of stochastic foams by more than an order of magnitude.

Microstructural Evolution under Severe Plastic Deformation

Severe Plastic Deformation (SPD) can create an evolution in the microstructure: Dislocation Density \( g \) and Grain Size \( d \)

Recrystallization (RX) occurring during SPD, caused by saturation of dislocations, gives Grain Refinement

The mechanical properties of a metal are given by its Microstructure: \( g \) and \( d \)

Evolution of the Yield Strength

CDRX shows monotonic behavior

DDRX (discontinuous RX) shows multiple peaks: multiple RX cycles

Prediction of the evolution of the Yield Strength, from CDRX to DDRX

Modeling the Oxidation Embrittlement of SiC/SiC Composites

SiC/SiC composites consist of SiC matrix reinforced with BN-coated SiC fibers.

The first use of SiC/SiC composites in commercial engines
- 10% improvement in thrust
- 15% reduction in fuel consumption
- 15% reduction in CO\(_2\) emissions
- Over 20,000 hours of testing

SiC/SiC composites are susceptible to oxidation embrittlement at intermediate temperatures (700°~900°C).

Stress rupture in pristine state

After oxidation in H\(_2\)O\(_2\)

Embrittlement mechanism

- Oxidation induced stress evolution within SiC fibers
- Oxidation induced stress evolution within SiC fibers
- Stress intensification and predicted fiber lifetime

1. Growth stress depends on the growth kinetics and microflow of SiO\(_2\) scales.
2. Fiber core stress and stress intensity factor are not monotonic with temperature.
3. Fiber lifetime reaches minimum at intermediate temperatures (840°~940°C).
4. Above a threshold temperature, fiber fracture cannot occur.