Hot Hydrogen Testing of Tungsten-Uranium Dioxide (W-UO2) CERMET Fuel Materials for Nuclear Thermal Propulsion

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CERMET fuel materials are being developed at the NASA Marshall Space Flight Center for a Nuclear Cryogenic Propulsion Stage. Recent work has resulted in the development and demonstration of a Compact Fuel Element Environmental Test (CFEET) System that is capable of subjecting depleted uranium fuel material samples to hot hydrogen. A critical obstacle to the development of an NCPS engine is the high-cost and safety concerns associated with developmental testing in nuclear environments. The purpose of this testing capability is to enable low-cost screening of candidate materials, fabrication processes, and further validation of concepts. The CERMET samples consist of depleted uranium dioxide (UO_2) fuel particles in a tungsten metal matrix, which has been demonstrated on previous programs to provide improved performance and retention of fission products[1]. Numerous past programs have utilized hot hydrogen furnace testing to develop and evaluate fuel materials. The testing provides a reasonable simulation of temperature and thermal stress effects in a flowing hydrogen environment. Though no information is gained about radiation damage, the furnace testing is extremely valuable for development and verification of fuel element materials and processes. The current work includes testing of subscale W-UO_2 slugs to evaluate fuel loss and stability. The materials are then fabricated into samples with seven cooling channels to test a more representative section of a fuel element. Several iterations of testing are being performed to evaluate fuel mass loss impacts from density, microstructure, fuel particle size and shape, chemistry, claddings, particle coatings, and stabilizers. The fuel materials and forms being evaluated on this effort have all been demonstrated to control fuel migration and loss. The objective is to verify performance improvements of the various materials and process options prior to expensive full scale fabrication and testing. Post test analysis will include weight percent fuel loss, microscopy, dimensional tolerance, and fuel stability.

Materials and Process Optimization: An iterative approach is being used to sequentially optimize the materials and process technologies for fabrication of CERMET fuels. The fuels will be based on the starting materials, compositions, microstructures, and forms that were demonstrated on previous programs[2]. CERMETS with mono and mixed size fuel particles are being fabricated for characterization. The list below provides a summary of the mechanisms and approaches that are being optimized to improve the performance of CERMET fuels.

Mechanisms of fuel loss from CERMETS:
- Vaporization of fuel particles
- Thermal decomposition of fuel/matrix
- Diffusion through pores and cracks
- High vapor pressures exerted by impurities
- Differences in CTE of tungsten and fuel particles

Materials and processes to minimize fuel loss:
- Size of the fuel particles and shape
- Tungsten coating of spherical UO_2 particles
- Complete surface cladding with tungsten
- Addition of fuel stabilization materials

Hot Hydrogen Screening: Subscale testing is being performed in the Compact Fuel Element Environmental Test (CFEET) system at MSFC. The CFEET test samples are approximately 0.5” diameter x 1” length for solid slug and prototypic 7-hole channel configurations. Figure 1 shows images of the CFEET system and test sample. Initial CFEET testing of surrogate CERMET samples using a 15 kW power supply resulted in peak temperatures of ~2000C (2273 K) in flowing hydrogen. Current work is focused on demonstrating operational performance of approximately 2726°C (3000 K) in flowing hydrogen using an upgraded 50 kW power supply. After completion of the power supply upgrade, depleted uranium based samples will be tested to evaluate performance. Figure 2 shows images of hexagonal W-UO_2 samples during recent HIP fabrication at MSFC. The samples were fabricated with angular and spherical 75-125 micron sized UO_2 powder feedstocks.

Figure 1: CFEET system and sample configuration

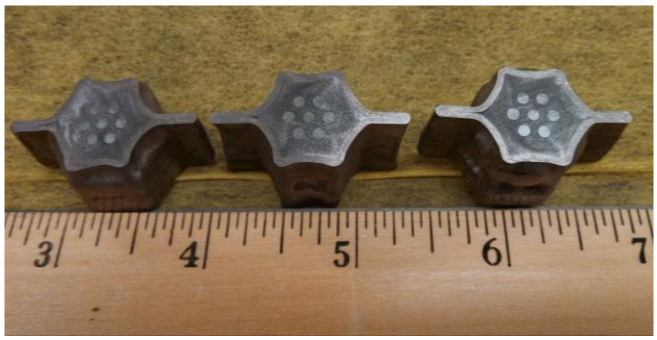

Figure 2: Hexagonal W-UO2 test samples

Developing a quality UO_2 starting feedstock has been a significant technical challenge. Figure 3 shows consolidated microstructures for blended W-UO_2 and W coated UO_2 particles that were fabricated on previous programs. As shown, CVD particle coatings significantly reduce agglomeration and provide a more uniform distribution of UO_2 within the W matrix.[3,4] The continuous W matrix yields improved mechanical properties and serves as a barrier to prevent interconnecting of UO_2 particles. In addition, the CVD process can be controlled to produce a low angle grain boundary orientation in the W coating. The low angle orientation minimizes ground boundary mismatch and reduces the buildup of hydrogen. Baker et al. demonstrated that high angle grain boundary mismatch increases the availability sites for accumulation of hydrogen gas, which results in explosive rupture and failure during thermal cycling.[5] Testing showed that low grain boundary mismatch in tungsten bi-crystals were relatively unaffected by cycling in flowing hydrogen. After 25 thermal cycles, there was no evidence of grain boundary voids in the low angle mismatch specimen. High angle specimens "explode" during the third or fourth cycle. Saunders et al. also reported that unclad W-UO_2 cermets resulted in 23 wt% UO_2 loss when tested at 2500°C (2773 K) for 2 hours in hydrogen, whereas the same material with W coated UO_2 particles resulted in 0.80 weight % loss.[6]

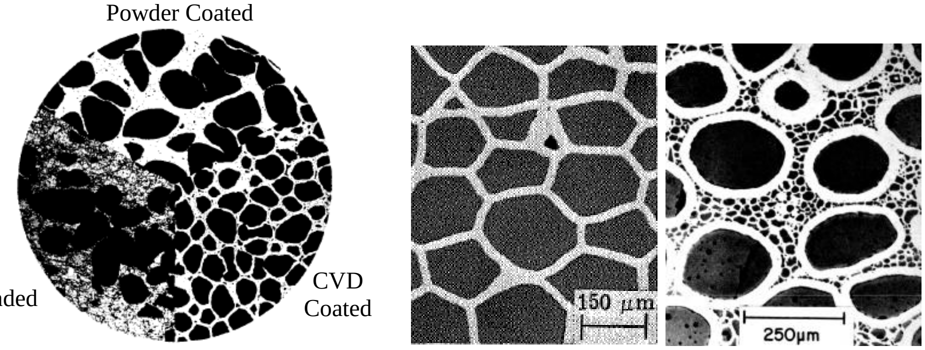

Figure 3: Consolidated microstructure effects of blended W and UO_2 powders and W coated UO_2.

The purpose of this paper is to provide a status on the hot hydrogen testing and a comparison to previous data. Table 1 provides a preliminary test matrix for the near term CFEET testing.

Table 1: Preliminary CFEET Test Matrix

Sample Description (W-60 volume % UO_2)	**Specimen Geometry**	**Temperature**	**Thermal Cycles**	**Environment**
Uncoated UO_2	Slug	2850K	10	Flowing H2
Coated UO_2	Slug	2850K	10	Flowing H2
Uncoated UO_2	7-Hole ANL 200MW	2850K	10	Flowing H2
Uncoated UO_2 w/claddings	7-Hole ANL 200MW	2850K	10	Flowing H2
W Coated UO_2	7-Hole ANL 200MW	2850K	10	Flowing H2
W Coated UO_2 w/claddings	7-Hole ANL 200MW	2850K	10	Flowing H2

References:

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