FABRICATION OF TUNGSTEN-URANIUM DIOXIDE (W-UO_2) CERMET FUEL MATERIALS FOR NUCLEAR THERMAL PROPULSION. J. W. Broadway[1], R. R. Hickman[2], O. R. Mireles[3] and D. J. Vermilion[4], NASA Marshall Space Flight Center, Huntsville, Alabama 35802.

Introduction: Researchers at NASA's Marshall Space Flight Center in Huntsville, Alabama are developing the capabilities, processes and procedures to fabricate and test CERMET based fuels for Nuclear Thermal Propulsion (NTP). The CERMET fuel development is being completed under the Nuclear Cryogenic Propulsion Stage (NCPS) Project, one of NASA's Advanced Exploration Systems (AES) Programs. The ceramic-metal matrix composite (CERMET) based fuel is comprised of 60vol% uranium dioxide (UO_2) and 40vol% tungsten (W). As part of the NCPS Project, MSFC has setup dedicated facilities to fabricate, test and analyze NTP fuels. The CERMETs are fabricated using the hot isostatic press, powder metallurgy processes and are tested in a high temperature, hydrogen environment. Currently there are no nuclear fuels qualified for use in an NTP system. The activities at MSFC are focused on developing a robust fuel, optimized for maxim structural life of the fuel and to minimize the fission product release from the CERMET microstructure. The development of feedstocks, chemical vapor deposition (CVD) coated particles, HIP consolidation, post HIP processing and hot hydrogen testing are the main focus of the MSFC fuel fabrication development.

A robust CERMET fuel must operate at temperatures near 3000K in a high pressure, hydrogen environment. The W matrix provides the structural integrity for the fuel at operating temperature and has good hydrogen compatibility. UO_2 does not have good hydrogen compatibility. At temperature in a hydrogen environment, the UO_2 will dissociate and form free uranium. As the fuel experiences the thermal cycles of engine start and shutdown, the free uranium will vaporize and cause rapid degradation of the fuel until complete failure of the fuel occurs. To optimize the cycle life of the fuel, the starting powder size and shape play a large role in the post HIP microstructure and life cycle capability[1].

CERMET fuel development begins with the proper feedstocks, or starting particles. To achieve a high density post HIP microstructure, the starting particles must be an optimum size, shape and density. A blend of fine and coarse particles is desired to fill a HIP can in order to remove voids in the interstitial areas between spherical particles. The fine and coarse blend also maximizes the packing density inside the HIP can. During the HIP process shrinkage and consolidation of the particles occurs. A high packing density of particles inside the HIP can, near 60% is the rule, will minimize the shrinkage and result in a higher density of the fuel post HIP. The spherical shape of the particle provides a better post HIP microstructure as well. The use of angular particles will lead to stress concentrations within the microstructure. The cyclic thermal loading and high stress areas near grain boundaries will quickly cause microcracking in the fuel. UO_2 particles with the required size, shape and density are not commercially available. MSFC is working with the Oak Ridge National Laboratory and the Center for Space Nuclear Research to fabricate 100μm sized, spherical shaped particles. Figure 1 shows spherical particles fabricated by ORNL.

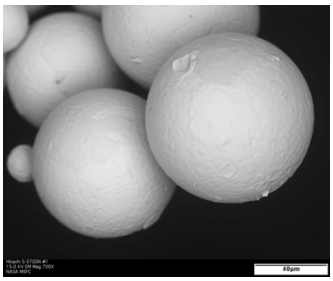

Figure 1. SEM image of spherical UO_2 particles fabricated by Oak Ridge National Laboratory

HIP consolidated fuel elements are fabricated by blending W and UO_2 particle into a sealed can. At elevated temperature and pressure the particles form a consolidated structure. An optimum post HIP microstrucutre would have uniformly distributed ceramic particles throughout the metal matrix. In the case of a CERMET nuclear fuel, nonuniformaly distributed fuel particles will cause hot spots in the fuel and would not exhibit the structural integrity required to survive in an NPT reactor. Many techniques exist in powder metallurgy to ensure a uniform post HIP microstructure. Powder blending, CVD coated particles and powder binding are three techniques being researched at MSFC.

MSFC has fabricated numerous samples using zirconium oxide (ZrO_2) as a surrogate for UO_2. These samples were processed by the simple blending of the powders in a shaker prior to filling the HIP can. The results of those samples were acceptable with visible

agglomeration of the ZrO_2 but may meet the requirements of a baseline fuel form. An example of a resulting W-ZrO_2 mixed particle HIP sample can be seen in Figure 2. The ZrO_2 particles used are spray dried agglomerated spherical particles and were not 100% dense.

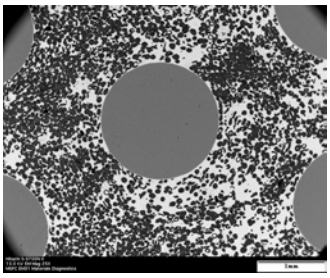

Figure 2. SEM image of aW-ZrO_2 HIP fabricated CERMET fuel sample. The five circles are the H_2 coolant channels. The light colored particles are W and the dark colored particles are ZrO_2. Areas of ZrO_2 agglomeration are clearly visible throughout the cross section.

To date, the W-UO_2 HIPed samples have not produced a useful post HIP microstructure. The UO_2 spheres are fully dense particles with good spherocity. Extreme segregation occurred between the W and UO_2. The areas of high UO_2 are brittle and cracking occurred during post HIP processing while preparing for hot hydrogen testing. SEM images of the cross section can be seen in figure 3. The W-UO_2 powder was blended and the HIP can filled using the same processing techniques as all the previous surrogate samples. The difference in the resulting microstructures between the surrogate and UO_2 sample are a clear indication of the

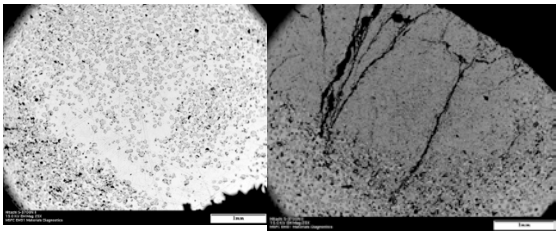

Figure 3. SEM images of a HIP fabricated W-UO_2 CERMET fuel. The light particles are W and dark particles are UO_2. Gross segregation of the particles occurred. The image on the right shows radial cracking in the area of high UO_2 content.

importance of the feedstock materials used for CERMET fuel fabrication.

One method to mitigate fuel particle agglomeration is to use a particle binder. Wet and dry binders exist in powder metallurgy that allows the proper attachment of one type of powder particle to another. Once the desired particle blend is achieved, the binder is removed by a low temperature thermal cycle. Compacts are being fabricated comparing several types of binders. One concern when using binders is residual contaminants remaining once the thermal cycle is complete.

CVD W coated UO_2 particles is a process also being developed at MSFC as one way to mitigate the segregation issues being seen. The CVD process is being developed to individually coat each UO_2 particle to a 40vol% thickness of W. Having a W coating on each fuel particle ensures no interconnected fuel particles exist and provides a layer of W cladding to protect the particle from H_2 interaction.

Fuel fabrication processes are being developed for sub scale and full-scale elements. Subscale elements are hexagonal, ¾ inches flat to flat, 1-5 inches in length and have 7 coolant channels for a representative channel configuration. Subscale samples will be tested in the Compact Fuel Element Environmental Test (CFEET) system. CFEET uses RF heating to cycle fuel samples at representative reactor temperatures in a flowing hydrogen environment. CFEET is the main tool for quickly screening fuel samples. The ANL-200MW reactor is the full-scale reference design of the NCPS project. The full scale CERMET fuel is 1.08 inches flat to flat, 17.8 inches in length with 61 coolant channels. Full-scale elements are tested in the Nuclear Thermal Reactor Element Environmental Simulator (NTREES) test system. NTREES utilizes RF heating to cycle fuel samples at representative reactor temperatures in a high-pressure hydrogen environment.

The NCPS project at MSFC has made great progress to develop the capability to fabricate and test CERMET NTP fuel materials. An updated status of all MSFC NCPS CERMET fuel fabrication development will be detailed in the oral presentation.

References:

[1] Gedwill, M.A., Sikora, P.F., Caves, R.M., “Fuel-Retention Properties of Tungsten-Uranium Dioxide Composites”, NASA TM-1059, Lewis Research Center. Cleveland, Ohio, February 1965.