Characterization of Zirconium Carbide Pellets for Nuclear Thermal Propulsion

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I. INTRODUCTION

Background

For decades humans have had visions of traveling to Mars. With a traditional chemical rocket, the trip to Mars would take 9 months, however a spacecraft powered by nuclear thermal propulsion using uranium carbide-based fuels could reach Mars in 2 months due to more powerful and efficient thrust. **[Figure 1]**

Design and testing of nuclear engines will require unique fuel configurations. Advanced manufacturing techniques are the most viable options for these applications in order to create the complex geometries necessary for efficient use with minimal waste, compared to traditional manufacturing methods. After manufacturing, parts require sintering to reach densities above 80%. **[Figure 2]**

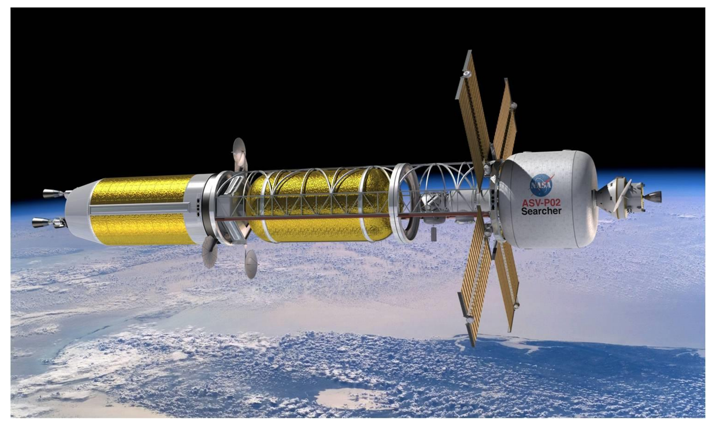

Figure 1: Concept art of a spacecraft powered by NTP [1]

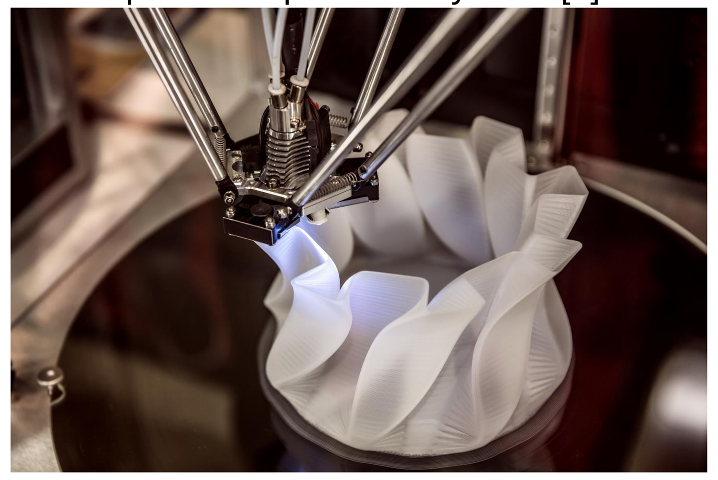

Figure 2: Plastic material via additive manufacturing [2]

Motivation

Uranium carbide (UC) fuels are planned for thermal propulsion. For prelimary studies, zirconium carbide (ZrC) was used as a surrogate material. ZrC is an extremely hard refractory ceramic material with thermal properties similar to UC. Studying ZrC is less expensive and does not require the same precautions as using radioactive materials.

Goal

Manufacture ZrC pellets and optimize different sintering parameters. The final goal was to produce samples with >80% theoretical density. Characterize samples via Scanning Electron Micrcopy (SEM), X-Ray Diffraction (XRD), and light element analysis techniques. These parameters will determine the sintering process for future additively manufactured parts.

II. EXPERIMENTAL

The pellets were formed with zirconium carbide (ZrC) powder, with or without a binder called Ethylenebiscotadecanamid (EBS). Pellets were then pressed with a ½" die set double punch system in a Carver hydraulic press. **[Figures 3 and 4]** .

Typical pellet fabrication parameters: **[Figure 5]**

- 0.8500g – 0.9000g of ZrC powder
- 3.8 – 4.0 Mt of force
- Between 4 - 5 press cycles
- Last press held for 3:00 – 3:30 mins
- 6.73 g/cm^3 theoretical density of ZrC

Pellets were sintered in a tungsten furnace under argon with varying temperatures and times **[Figure 6]**.

- 1700°C – 2000°C
- 3 – 6 hour runs
- 400°C 3 hour burnoff for the EBS
- Niobium crucible

Pellets were mounted in epoxy and polished from 400 – 3um silicon carbide grit paper and examined using SEM as well as XRD.

Figure 3: Carver hydraulic press

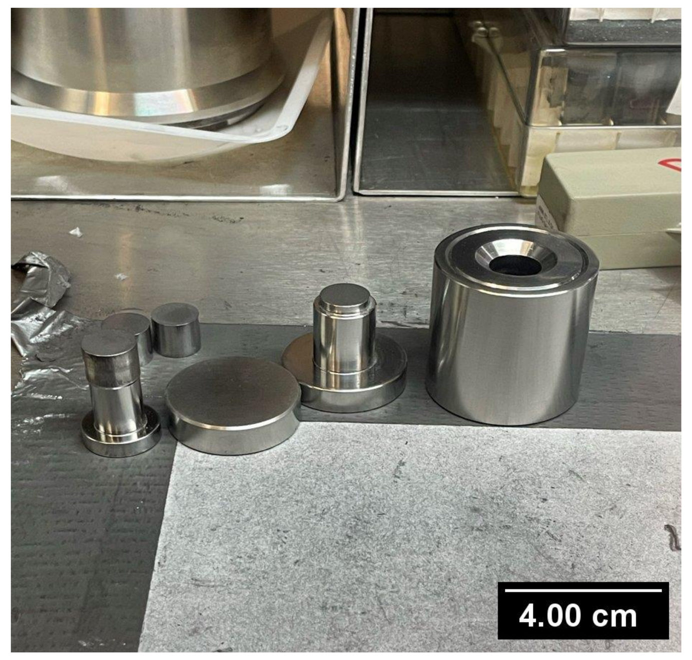

Figure 4: 1/2" die double punch die set

Figure 5: ZrC green pellet. The pellet is 12.70 mm in diameter.

Figure 6: Tungsten Furnace

III. RESULTS

Density measurements were taken post sintering and plotted on the graph below.

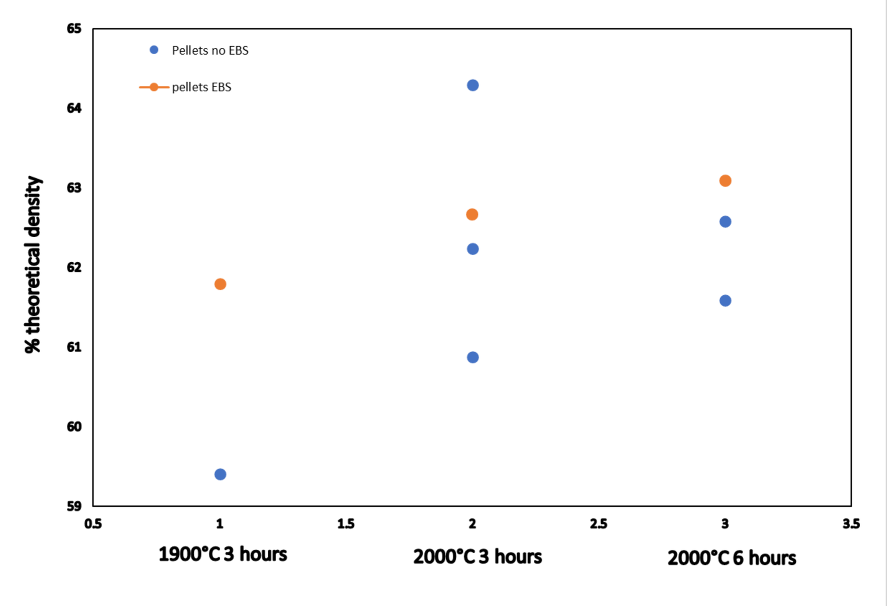

Figure 7: Density data from sintering runs

Sintering

Samples were sintered between 1700 - 2000°C in a niobium crucible. Each run contained 3 pellets, two with EBS and one with no EBS. Pellets that were sintered at 1700°C were not examined due to no evidence of proper sintering.

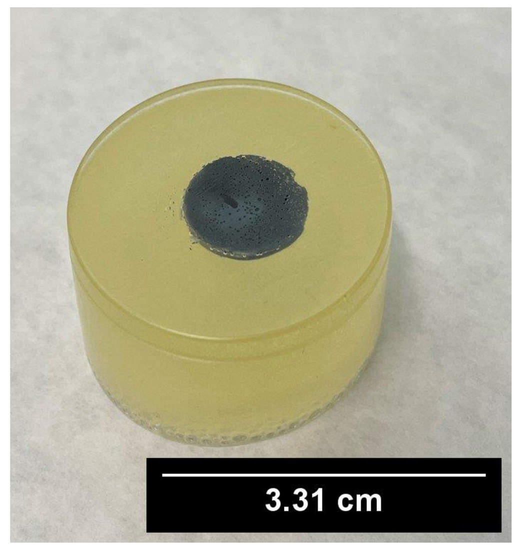

Figure 8: Sintered pellet mounted in epoxy for characterization

XRD

XRD was done on pellet that was sintered at 2000°C for 6 hours and contained EBS. The pellet was ground to a fine powder and mixed with vacuum grease to prevent oxidation **[Figure 10].**

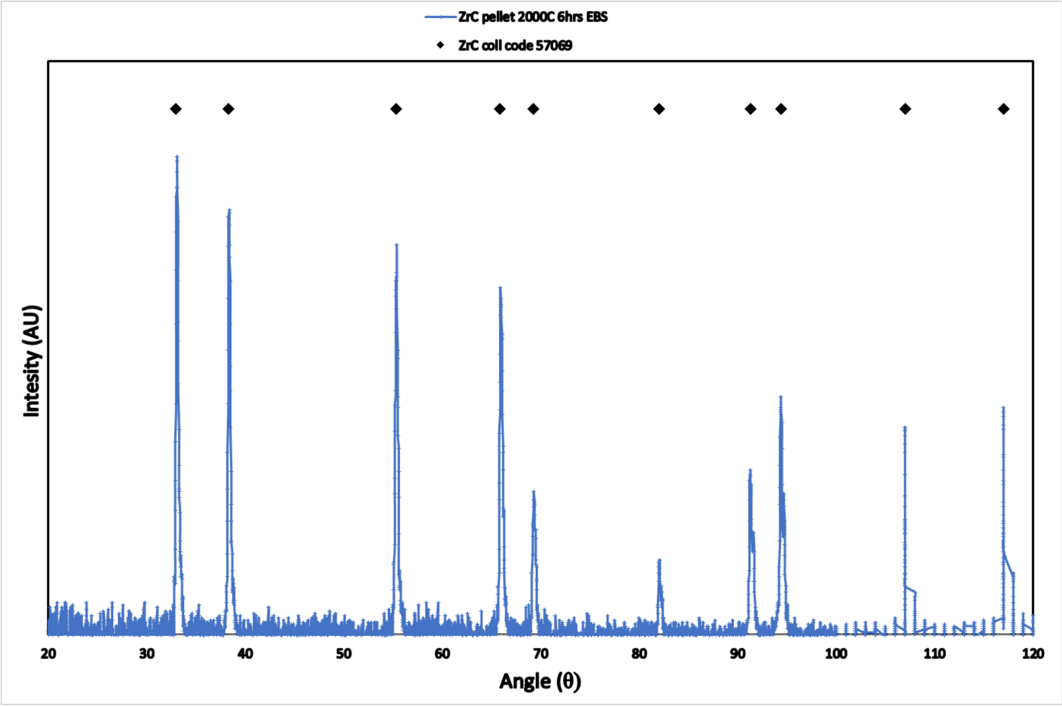

Figure 9: Results from XRD

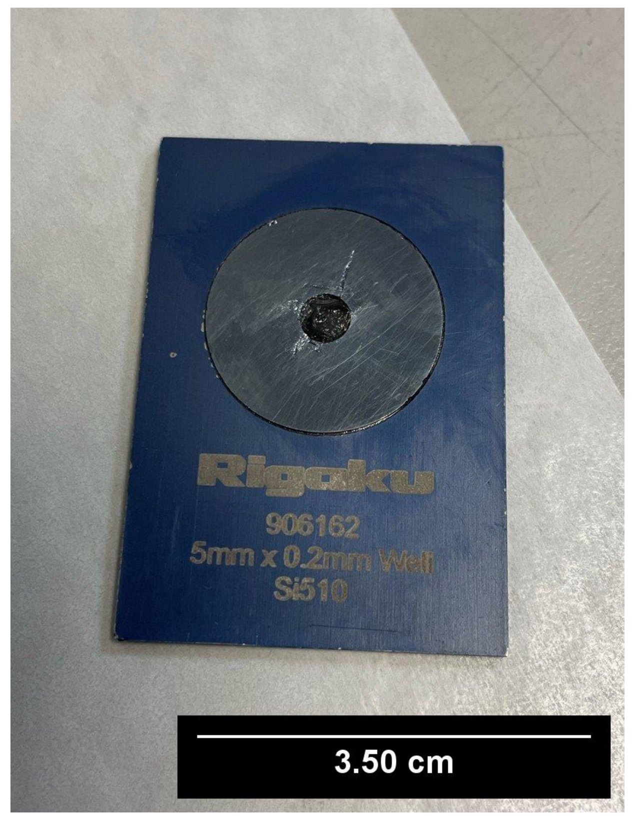

Figure 10: ZrC + vacuum grease on XRD stage

SEM

SEM shows slight sintering in resulting pellets for samples that contained EBS. Pellets without EBS did not begin to sinter. From EDS we concluded that there was no contamination from EBS. Also there was a lack of visible secondary and metallic phases.

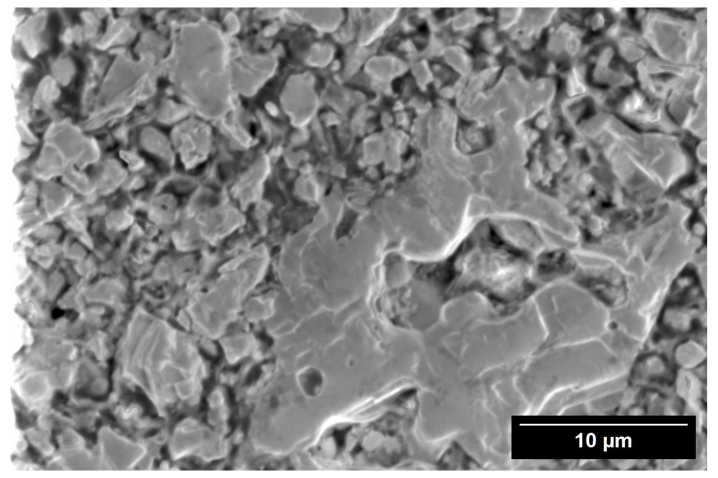

Figure 11: 1900°C 3hr with EBS

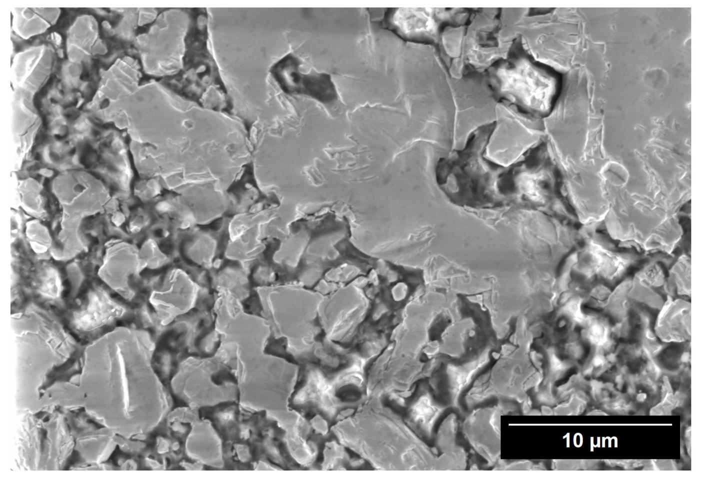

Figure 12: 2000°C for 3hr with EBS

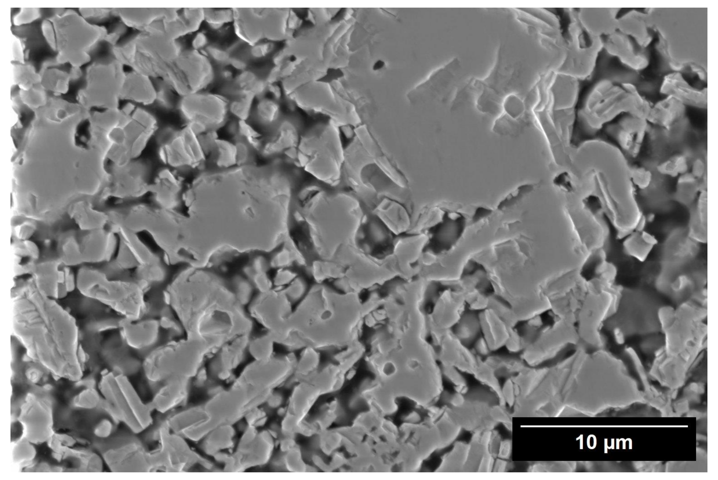

Figure 13: 2000°C for 6hr with EBS

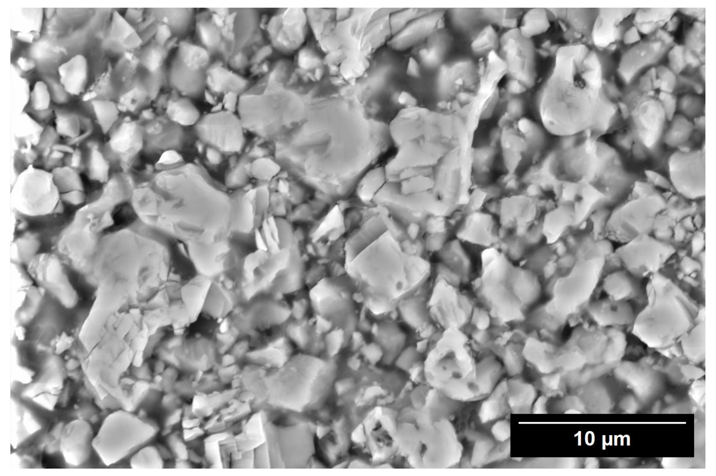

Figure 14: 2000°C for 6hr no EBS

IV. DISCUSSION

Conclusions

The goal to produce pellets with >80% theoretical density it was not achieved. However, the following conclusions were made after characterization of the pellets:

1. Pellets with EBS have slightly higher density and shows signs of sintering. Increasing sintering times and temperatures will increase amount of sintering and final density.
2. The final pressing parameters for the pellets seem to be the best way to form stable green pellets. The final pressing parameters:
   - 3.8 Mt force
   - 4 press cycles
   - 3 minute hold on the last press

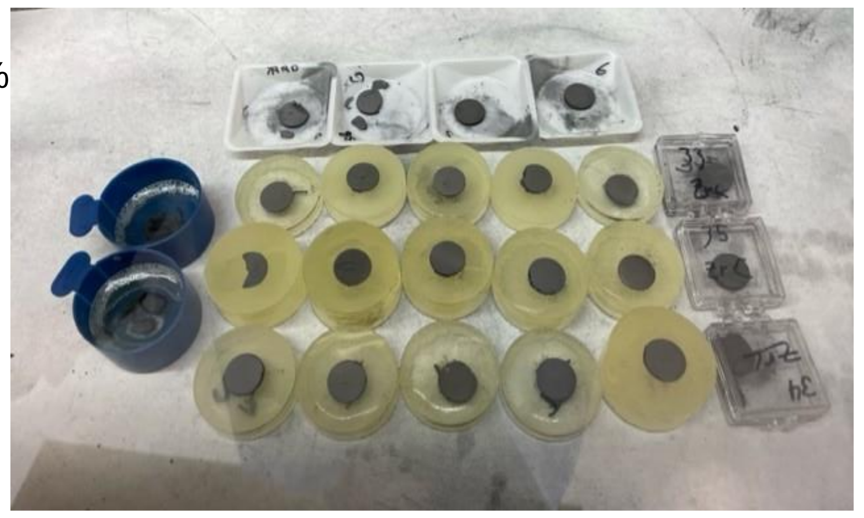

Figure 15: ZrC pellets mounted in epoxy have been sintered

Future Work

We will be investigating higher sintering temperatures as well as different sintering times for pellets that contain EBS. We will also be putting the ZrC + EBS powder in the ball mill to reduce powder size.

CAES Center for Advanced Energy Studies · NASA · NSF · AML Advanced Materials Laboratory

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