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FABRICATION OF MTR-SIZED HIGH LOADED U-MO DISPERSION FUEL PLATES

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ABSTRACT

Results of fabricating high loaded ($U_{total} > 8$ g/cm^3) UMo dispersion plates for testing in the AFIP-1 experiment in the Advanced Test Reactor (ATR) at Idaho National Laboratory (INL) are presented. Two different plate types were made. The first plate contains U7Mo powder with a matrix of Al-2Si powder. The second plate has the same U7Mo powder with a matrix of Al-5Si powder. No significant differences in the manufacturing processes were observed that could be attributed to the different matrix powders. Results on fuel homogeneity and ultrasonic evaluation are presented.

1. Introduction

Fabrication of high loaded ($U_{total} >$ g/cm^3) dispersion fuel plates is desirable in order to allow conversion of some high performance research reactors to low enriched uranium (LEU) fuel. Such a high loading density can potentially be achieved with UMo powders, assuming that processing techniques can be adapted to the high fuel loading for Material Test Reactor (MTR) sized plates. With a small matrix volume content of approximately 10%, fabrication of such plates generates new challenges. Conventional dispersion fuel compacting and plate rolling has been limited to U_{total} loading to around 4.3 g/cm^3 for LEU U_3Si_2. Demonstration of the fuel loading and plate fabrication of small miniplates has been proven in past RERTR tests, but MTR sized plates had not previously been attempted in the US. Fabrication of the fuel plates was chosen to be conducted at B&W Lynchburg to enable the use of the standard research reactor fuel plate manufacturing methods used for current MTR type reactors.

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In this paper, we report on results and observations in fabricating two high-loaded MTR sized dispersion U-7Mo LEU fuel plates for the AFIP-1 experiment. Both plates had a target loading $U_{total} > 8$ g/cm3: plate #1 had a matrix comprised of Al + 2% Si; plate #2 had a matrix of Al + 5% Si. No differences in fabrication were noted between the two matrix types.

2. Fabrication Design

Characteristics of the materials comprising the compacts are shown below in Tables 1 and 2. Frames and covers were fabricated from 6061 Al. The compact design for both plate types was the same; the only difference being the matrix powder composition.

The AFIP-1 plates are 22.50” x 2.210” x 0.050” (L x W x T), with a maximum allowed fuel zone of 21.994” x 1.865” (L x W), see Figure 1. The nominal design fuel core thickness is 0.020”.

Table 1 – Plate Composition

Plate ID	Fuel Type	Fuel Phase Composition	Fuel Enrichment (% U-235)	Fuel Zone Thickness (in)	Matrix Phase	Fabrication Technique
1B2	Dispersion	U-7Mo	19.851	0.02	Al-2Si	Roll
1T5	Dispersion	U-7Mo	19.851	0.02	Al-4043 (Al-5Si)	Roll

Table 2 – Powder Characteristics

Mesh Range	U-7Mo	Al-2Si	Al-4043 (Al-5Si)
+120	0.3%	0	not available
-120, +325	72.7%	6.7	not available
-325	27%	93.3	not available

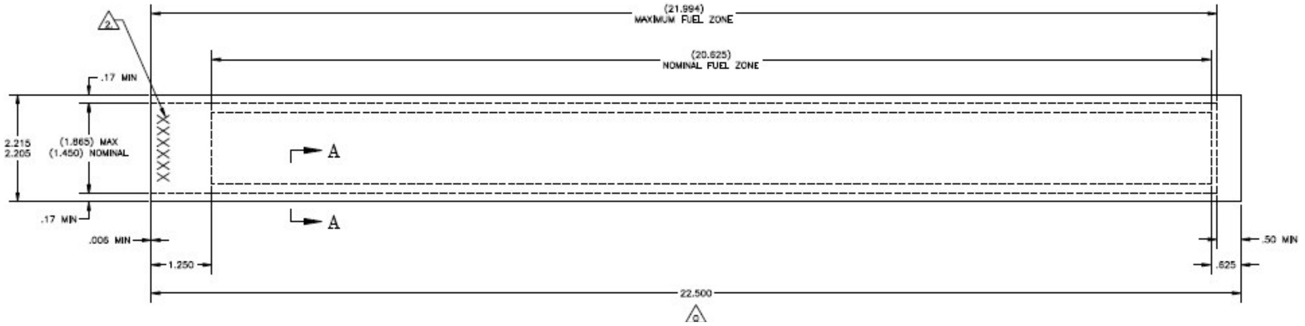

Figure 1. AFIP-1 Fuel Plate Schematic

3. Observations

The high uranium loading of these compacts results from the high density of the U-7Mo and a limited amount of matrix powder (around 10% by volume) that is mixed in with the fuel charge. Consequently, both the compacting characteristics and plate rolling behavior can be affected by this higher fuel loading.

The most obvious characteristic of the high loaded compacts was their fragile nature. With a minimal amount of aluminum matrix powder, which acts somewhat like a "glue" to hold the fuel particles together, the fuel compacts readily shed particles and had to be handled with extreme care. Losses of 1-2% of the compact mass were typical during each handling and weighing step early in the development program.

Fabrication was completed as a set of four plates per run. The first few fabrication runs resulted in violations of the fuel out of zone (FOZ) requirement due to the loose particles from the compact. Attempts to improve the FOZ by changing the compact design were not successful, while better control of handling of the compacts and assemblies prior to hot rolling made a modest improvement. As can be seen in Figure 2, stray particles or FOZ was fairly considerable in these early runs.

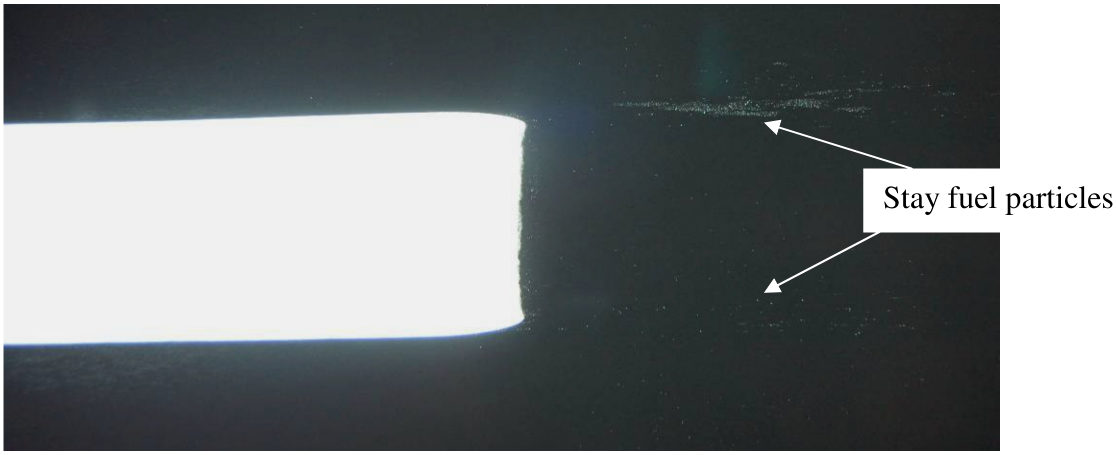

Figure 2. Stray fuel x-ray results from early fabrication trial.

The biggest improvement came from re-seating the compacting die, which gave a significantly more robust compact. There was apparently a small mis-alignment in the earlier set-up to which the high loaded UMo compacts were sensitive. The frame and cover designs were also modified to reduce the potential for FOZ. Careful handling was still critical, because the FOZ requirement for the AFIP test plates was relatively stringent.

Plate lots were rolled using typical BWXT hot and cold rolling schedules. There were no notable differences in how the high loaded UMo plates rolled compared to standard MTR fuel plates. The fuel core was more obvious visually on the surface of the plate, but all other dimensional and handling characteristics were similar.

4. Results

The delivered AFIP-1 test plates were subjected to the usual non destructive testing: Fuel homogeneity and FOZ inspections were evaluated by x-ray; minimum cladding and debonds were evaluated by ultrasonic inspection (UT); bond integrity evaluated by bend testing and void volume was measured.

4.1 Fuel Homogeneity & FOZ

Fuel loading and homogeneity were evaluated by densitometry of the fuel plate x-ray and by immersion density. Table 3 includes the calculated thicknesses of the fuel meat (if one were to assume the fuel core was a solid homogeneous alloy). Also included in Table 3 are the calculated fuel loadings using the immersion density data. The comparative step-tab x-ray standard used by BWXT was fabricated from sheets of .002" thick tungsten foil. This standard was compared to a DU-8Mo monolithic x-ray standard at INL and densitometer readings converted to yield a monolithic equivalent fuel core thickness.

A representative x-ray densitometer shot is shown below in Figure . Some tapering and feathering at this end of the fuel core is evident, but all plates met the requirements for fuel loading and FOZ.

Table 3 – Fuel Core Thickness Results from X-ray Desnsitometry

Maximum Calculated Thickness for fuel plate 1T2	0.0242 in
Average Calculated Thickness for fuel plate 1T2	0.0221 in
Calculated Total Uranium Loading for fuel plate 1T2	8.76 g/cc
Maximum Calculated Thickness for fuel plate 1B5	0.0263 in
Average Calculated Thickness for fuel plate 1B5	0.0227 in
Calculated Total Uranium Loading for fuel plate 1B5	8.69 g/cc

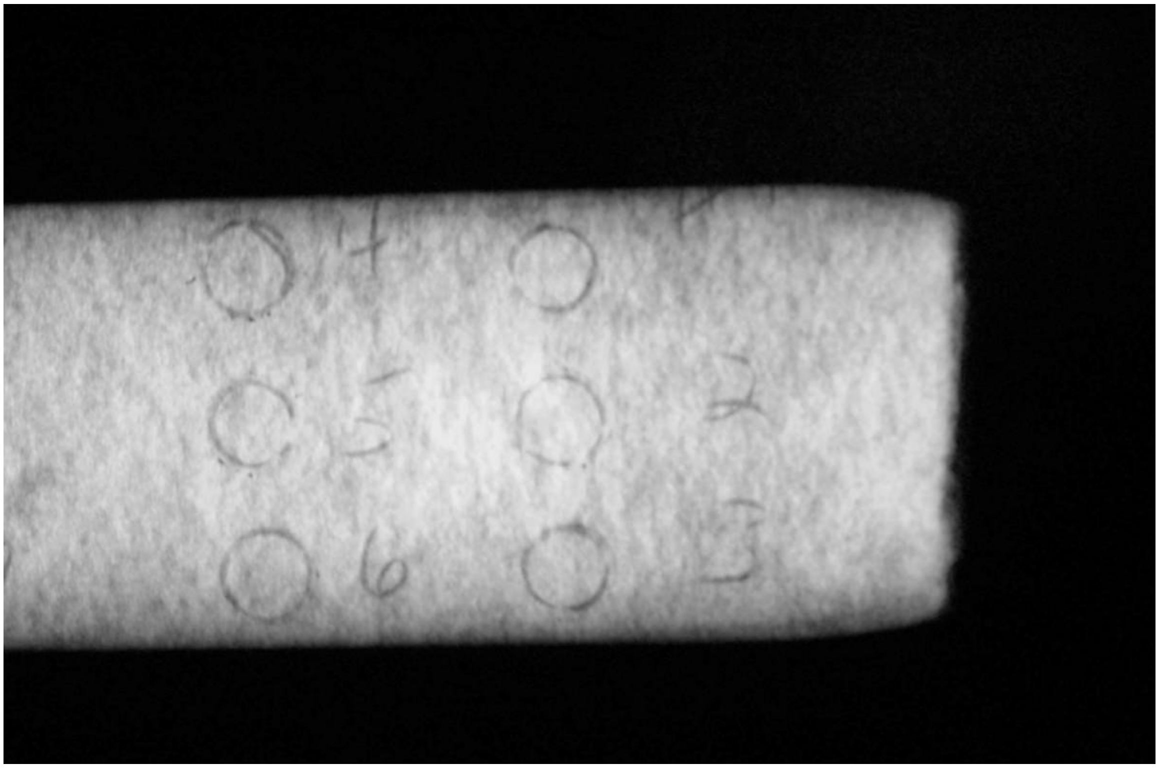

Figure 3. Plate 1B5 X-ray homogeneity result (close up view). Circled areas indicate locations of densitometer readings.

4.2 Minimum Cladding / UT

The next set of figures show results from UT scans to determine the minimum cladding and they also indicate the degree of physical uniformity of the fuel core. Minor dogboning of the fuel core is evident from the UT scans and can be seen in the darker indication at the ends of the fuel core in each scan.

These UT scan images correlate properly with x-ray images as far as features and shape of the overall fuel core.

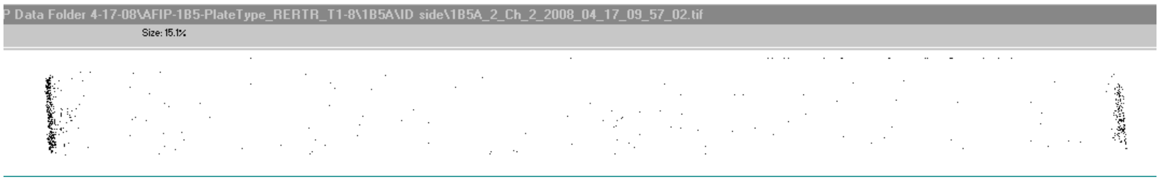

Figure 4. Plate 1B5, ID Side, UT scan depth is .008”.

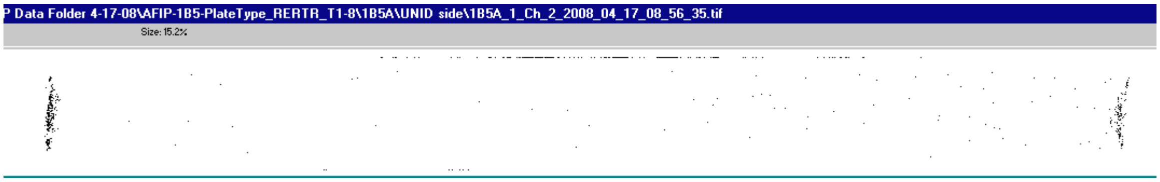

Figure 5. Plate 1B5, UNID Side, UT scan depth is .008”.

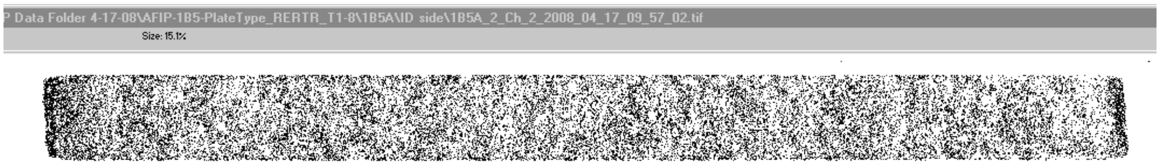

Figure 6. Plate 1B5, ID Side, UT scan depth is .009”.

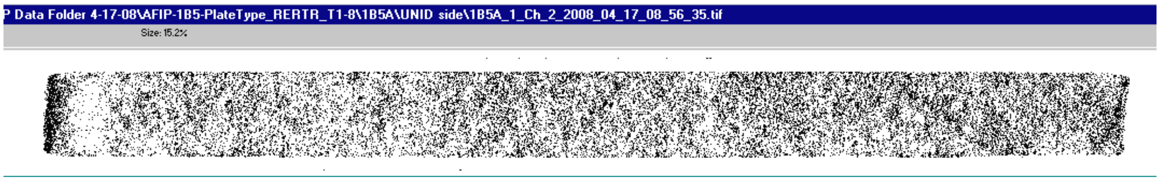

Figure 7. Plate 1B5, UNID Side, UT scan depth is 009”.

4.3 Bend Testing

Narrow pieces of the plate assembly were sheared off adjacent to the final edges of the finished plate. The pieces were subjected to bend testing, which consists of clamping the piece between two radiused steel platens, bending the section 90º in one direction, bending it back vertically, bending it 90° in the opposite direction and finally, bending to its original orientation. If bonding is inadequate, the piece will delaminate, as shown in Figure 2. All samples evaluated met the bend test requirement.

Bend test sample without delamination

Bend test sample with delamination

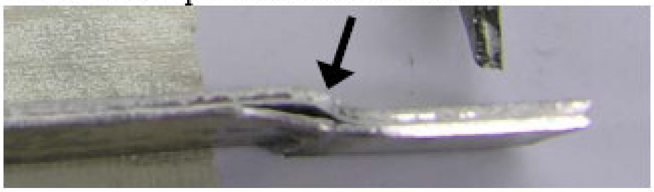

Figure 8. Bend Testing.

5. Summary

BWXT has successfully fabricated LEU UMo dispersion fuel plates with a $U_{tot} > 8$ g/cm^3. Our experience indicates the quality of the compacting operation has the biggest impact on final quality of the fuel plate. With further optimization of the die design, we believe that commercial fabrication of high loaded UMo fuel plates is practical and can realize high plate yields.

Two of the fabricated plates are undergoing irradiation testing the ATR. The plates are being UT scanned between cycles to monitor fuel swelling. After the first cycle of irradiation the plates are behaving as expected. Post-irradiation test results will be presented at a future conference.