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**RECENT BABCOCK & WILCOX UMO PLATE FABRICATION
EXPERIENCE**

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ABSTRACT

Babcock & Wilcox has a long involvement with the Global Threat Reduction Initiative program in supporting the experimental program by fabricating UMo dispersion and monolithic fuel plates. Recent results in fabricating full size UMo monolithic plates are presented. Plates were inspected via radiography and ultrasonic testing and met all quality requirements. Plans for future work are also presented.

1. Introduction

The Babcock & Wilcox Company Nuclear Operations Group in Lynchburg, Virginia (B&W NOG-L) has been providing fabrication services in support of the DOE/NNSA Global Threat Reduction Initiative (GTRI) fuel development program, or the Reduced Enrichment for Research and Test Reactors (RERTR) program for several years. Our primary role in the GTRI program has been the fabricator of fuel plates for irradiation testing. B&W is also the largest domestic supplier of both HEU and LEU aluminum-clad uranium fuel used in Material Test Reactor (MTR) or plate-type research reactors. Customers in the plate-type reactor community include U.S. colleges and universities, and U.S. Department of Energy laboratories.

We have previously reported on fabricating LEU UMo dispersion fuel plates; achieving a total uranium loading of > 8 g/cc [1]. These plates were irradiated successfully,

demonstrating the utility of LEU dispersion UMo for research reactors. Irradiation test results are being presented at this conference [2]. The GTRI program focus has emphasized converting existing high performance research reactors, e.g. the Advanced Test Reactor (ATR), HFIR, MURR, MIT and NIST from dispersion HEU fuel to a suitable LEU fuel. To maintain current performance benchmarks, these reactors need the higher density uranium loading that can only be achieved with monolithic (foil) LEU UMo.

In support of the GTRI program, B&W was contracted to fabricate the AFIP-3 and AFIP-6 test assemblies [3]. These are full-size UMo plates that B&W - because of its unique capabilities, equipment and experience - was able to produce and deliver for subsequent irradiation testing. This paper presents a summary of the fabrication results.

2. Manufacturing Aspects

The baseline plate fabrication process for the GTRI program for monolithic fuel plates is Hot Isostatic Pressing (HIP). A combination of high temperature and high pressure forces the fuel plate piece parts together – aluminum cover plates and UMo foil – and a bond between the components is formed via solid state diffusion. The process does not involve the formation of any molten phases. Cleanliness and process control are both important factors for obtaining adequate bonding and ensuring predictable performance in the reactor.

The two most recent UMo monolithic test assemblies B&W has fabricated are the AFIP-3 and AFIP-6 experiments. A summary description of the plate and frame characteristics for the two experiments is shown below in Table 1.

Table 1 – Comparison of AFIP-3 and AFIP-6 Test Assemblies

Feature	AFIP-3	AFIP-6
No. of Plates / Assembly	2 plates	1 plate
Plate Size (L x W x T)	22.50" x 2.21" x .050"	45.00" x 2.23" x .050"
Foil Enrichment	LEU	HEU
Foil Diffusion Barrier	Plate #1 – Zr cladding on foil Plate #2 – Silicon thermal spray coating on cover pocket	Zr cladding on foil
Frame Size	48.75" x 2.40"	48.75" x 2.40"
Assembly Method	Plates are tack welded to frame rails	Plate is swaged into rails

There are three main differences between the AFIP-3 and AFIP-6 experiments from a fabrication point of view:

- AFIP-3 fuel plates utilized LEU fuel while AFIP-6 plates contained HEU fuel foils
- AFIP-6 fuel plates were designed to be twice the length of AFIP-3 plates
- AFIP-6 fuel plates were designed to be swaged into the frame assembly rather than the previous method of welding the plates into the assembly.

These changes made it necessary to update numerous fabrication and safety documents which required extensive internal reviews and approvals before work could proceed. The increased fuel plate length necessitated the modification of the HIP tooling for a much longer design. Tooling trials were performed and the results evaluated and deemed acceptable for processing of experiment fuel plates.

The AFIP-6 experiment was the first to swage a fuel plate into the rails of the frame assembly. This experiment condition was implemented as a step in the ultimate goal of fabricating fuel elements which have curved plates swaged into side plates. Extensive design and fabrication of new tooling and development of the swaging process was required for the AFIP-6 assembly. In the end, two AFIP-6 assemblies were swaged with no rework required.

Processing of monolithic UMo fuel plates follows the general outline shown below:

- Cover plates and UMo foils are assembled and HIP processed
- Plates are rough sheared to size
- Reference holes are in the ends of the plates to center foil within allowed fuel zone and then they are machined to width
- Plates are UT inspect to verify core and cladding thickness
- Plates are machined to thickness
- Plates are radiographed to locate end of fuel then machine to final length
- Plate NDE inspections performed
- Plates are assembled into the test frame(s)
- Final visual and dimensional inspections are performed

3. Results

Below we discuss the outcome

A number of detailed quality inspections were required, over and above what is normally required for B&W's standard dispersion MTR-type fuel plates for the AFIP-3 and AFIP-6 assemblies, mostly due to inspection requirements needed to support the fuel development effort and to establish a baseline for post irradiation examination of the plates. These include:

The foil thickness was measured at more than 40 locations across the width and length of each foil. Also, the plate thickness was measured at the same locations.

Shown below in Figure 1 is a photograph of a Zr clad UMo foil. The foil was clad and rolled to size by INL. The foil is flat and uniform in thickness and width. The Zr cladding gives the foil a matte, silver appearance. The nominal thickness is 0.015”.



Figure 1. Zr Clad UMo foil, approximate size is 22.5” length x 2.2” width

Foils are plates undergo radiographic examination to verify alloy homogeneity, foil thickness and edge clad location. A sample foil radiograph is shown in Figure 2. This image is a composite of two separate radiographs. The even shading within the foil indicates good homogeneity. Densitometer readings are taken and compared against a known standard to verify radiographic thickness determinations.



Figure 2. Zr clad UMo Foil Radiograph

Ultrasonic testing (UT) of the plates is used to evaluate both the minimum plate cladding requirement and the presence of any unbond indications in the bonded plate. Shown in Figure 2 is an example of the min clad examination. The small black dots in the middle of the figure are the first indications of the UMo foil. The timing gate in this image is equivalent to a depth of 0.017”. The min-clad requirement for these plates is 0.010”.

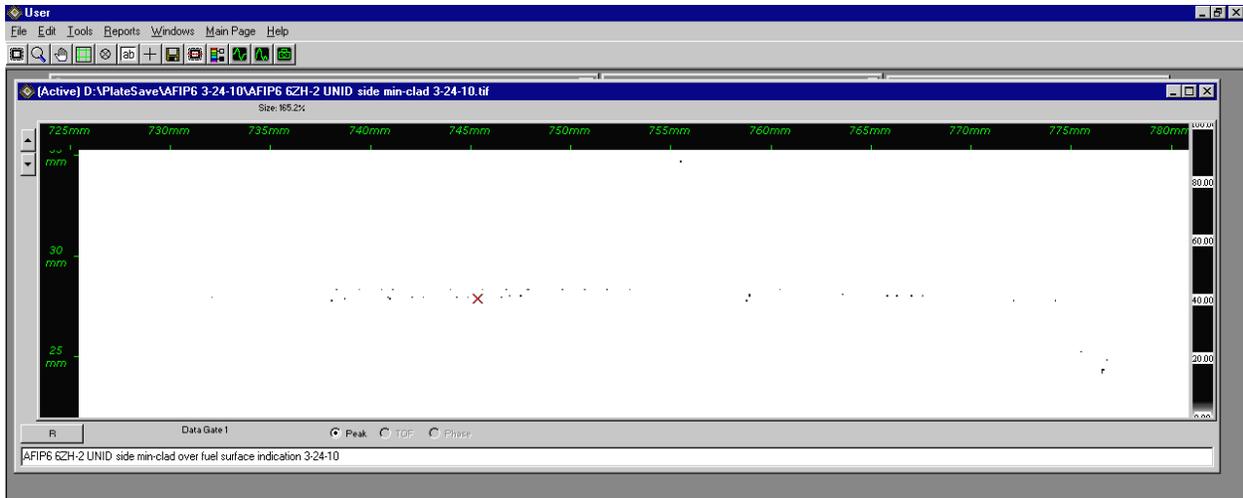


Figure 2. UT Cladding Inspection, Plate AFIP-6 ZH-2 Non-ID side

A second, and more important UT inspection is that for debond indications over the fuel zone. A representative result is shown in Figure 3 for AFIP-6 plate 6ZH-1. The good news is there are no debond indications. This was the case for the AFIP-6 plates. The bad news is the image is rather boring, there being nothing of note in the debond image.

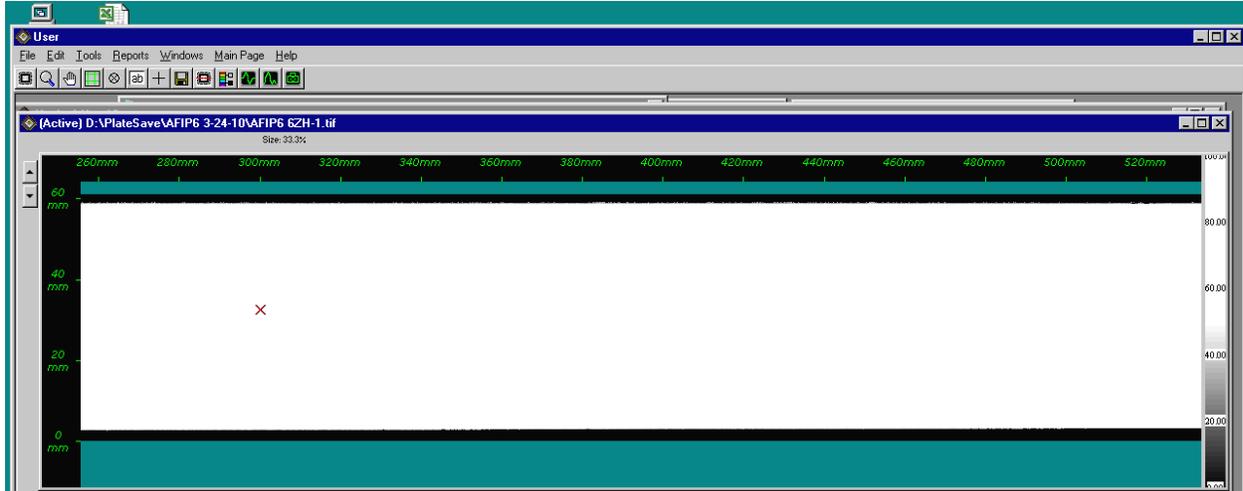


Figure 3. Plate AFIP-6 6ZH-1 Debond Image

After the plates pass all QA inspection requirements, they are then assembled into their respective test frames. As discussed above, the AFIP-3 test assembly consisted of two smaller monolithic LEU plates that were tack welded into the frames. One AFIP-3 assembly is shown below in Figure 4. The plates slid into grooves that were milled on the inside edge of the side rails.



Figure 4. Tack Welded AFIP-3 Test Assembly

In Figure 5 is shown one of the swaged AFIP-6 assemblies. The small top and bottom end plates, as well as the fuel plate, are all swaged in same operation and is not the usual configuration for our typical MTR type fuel element assemblies. A few swage trials were needed to work through some challenges with this configuration. Two AFIP-6 fuel assemblies were successfully swaged and met all requirements.

Each assembly underwent a final cleaning and dimensional inspection. These were then boehmite filmed prior to shipping to INL for testing in the ATR.



Figure 5. Swaged AFIP-6 Test Assembly

4. Future Work

B&W is to fabricate and assemble the next experiment in the AFIP test series, the AFIP-7 test element. This assembly consists of four LEU UMo plates, formed into curved plates and then swaged into an element. A rough sketch of the proposed assembly is shown in Figure 6.

This will be the next step in complexity for UMo irradiation testing. Forming UMo monolithic plates will require some tooling modifications. One unknown is the formed plate curvature stability. The UMo foil is likely much stiffer from a mechanical standpoint than the conventional dispersion fuel plates. There is potential for the plates to creep after forming.

Earlier forming testing and UT inspection have demonstrated that forming HIP bonded plates to a curvature does not result in any cracking or debonding of the foil and the cladding.

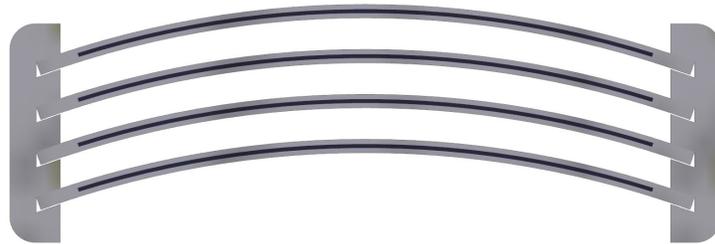


Figure 6. Cross-Sectional Illustration of the AFIP-7 Test Element

5. Summary

Babcock & Wilcox has a long record as a supplier of quality MTR type research reactor fuel assemblies. We have successfully fabricated several challenging and unique UMo experimental assemblies in support of the GTRI program. This paper describes the two latest assemblies.

These efforts have required significant support from the B&W Safety organization, as well as the UPRR Operations group. Without their timely cooperation, the assemblies would not have been delivered on time, adversely impacting the overall RERTR/GTRI program. We look forward to continued opportunities to provide fabrication support to the DOE/NNSA GTRI program.

6. References

- [1] M. J. Nilles and J. M. Wight, "Fabrication of MTR-Sized High Loaded U-Mo Dispersion Fuel Plates", Proceedings of the 30th International Meeting on Reduced Enrichment for Research and Test Reactors, Washington, D.C., October 5-9, 2008.
- [2] D. Keiser, Jr., J-F Jue, A. Robinson, "Microstructural Development During Irradiation of AFIP-1 Fuel Plates", 32nd International Meeting on Reduced Enrichment for Research and Test Reactors, Lisbon, Portugal, October 10-14, 2010.
- [3] A.B. Robinson, D.M. Wachs, G.S. Chang, M.A. Lillo, "Summary of 'AFIP' Full Sized Plate Irradiation in the Advanced Test Reactor", Transactions Research Reactor and Fuel Management, Marrakech, Morocco, March 21-25, 2010.