ULTRASONIC THERMOMETRY IN LMFBR SYSTEMS

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SUMMARY

The progress achieved during the fifth quarter may be summarized as follows:

1) Through meetings and consultations with AEC, ORNL, and GE - NMPO personnel, agreement was reached on the location and type of test which would provide the closest available simulation of the operating conditions obtained in LMFBR's, with particular emphasis on fuel temperature determination.

The test location is the Oak Ridge Research Reactor, ORNL, where temperatures up to $\sim 5000^{\circ}\text{F}$ can be obtained in a radiation environment of $\sim 10^{13}\text{ n/cm}^2\text{sec}$ (fast) and $10^{14}\text{ n/cm}^2\text{sec}$ (thermal) integrating in a typical seven-week test to fluencies of $\sim 10^{19}\text{ nvt}$ (fast) and $\sim 10^{20}$ (thermal).

The ultrasonic thermometer will be tested in conjunction with a GE compatibility experiment scheduled for mid-March 1969 to determine the compatibility of W/Re sheaths with $\text{UO}_2\text{-PuO}_2$ mixed oxide fuel. The ultrasonic thermometer will be designed to operate with a W-W/26Re thermocouple as a composite temperature probe.

2) Pre- and post-irradiation test procedures as well as methods of sensor retrieval have been discussed, and a tentative test schedule was drawn up. It appears that post-irradiation tests in the hot cell may be feasible.

3) Continuing efforts to produce nuclear hardened transducers by anodization have succeeded in obtaining fine reproducible layers of oxide insulation on Al. The present plan is to use Al transducers for the Oak Ridge tests.

4) The basic design parameters of the composite ultrasonic/thermocouple temperature probe have been worked out through a series of laboratory tests on four prototype thermocouple samples submitted by GE-NMPO. Alternative designs were submitted to GE for evaluation, and preliminary approval was obtained for one of the geometries (see Fig. 3c). Subsequently a model probe incorporating an anodized Al coil, but not including insulation or electrical connections, was constructed and tested in our laboratory. The probe was housed in clear plastic tubing for ease in visualization, and will be presented at a meeting at GE - Cincinnati on January 7, 1969 with R. L. Shepard (ORNL) and GE-NMPO personnel, for final approval.

5) Room temperature sound velocity measurements were made on three Re-Os alloy samples obtained from GE, viz: Re - 5% Os, Re - 10% Os, and Re - 15% Os. However, further tests involving thermal cycling and annealing need to be made in order to determine the affect of composition on sound velocity.

LABORATORY TEST PROGRAM

Sound velocity measurements were made at room temperature on three samples of Re-Os alloys previously received from GE in sheet metal form 0.022" thick. A strip $\sim 1/16$ " wide was sheared off each of the three samples and flash butt-welded to three separately tagged 0.056" dia remendur wires in the arrangement shown in Fig. 1. The results were as follows:

Alloy	Extensional Wave Velocity
	(in/ μ sec)
Re - 5% Os	0.177
Re - 10% Os	0.181
Re - 15% Os	0.177

The room temperature extensional wave velocity in pure Re is 0.177 in/ μ sec. The $\sim 2\%$ apparent increase in sound velocity was well beyond the experimental uncertainties in the length and transit time measurements, and does not seem to be explicable on the basis of presently available information on the Re-Os equilibrium diagram, the monotonic variation of lattice constants with composition, or the hardness peak observed at a composition of Re - 60% Os^{(1)(2)*}. Therefore, further tests, involving thermal cycling and annealing of all specimens, are clearly needed to explain this behavior which could be due to the specimen history, such as method of fabrication, amount of cold work, etc.

(1) Winkler, Von Otto, "Untersuchungen Über Die Abriefbestigkeit Von Edelmetallen Und Hochschmelzenden Unedelmetallen," Ztschr. Elektrochem., Vol. 49, 221-28 (1943).

(2) Tylkina, Polyakova and Savitskii, Constitution Diagram of Osmium-Rhenium Alloys, NSA 16:30851, June 62, (in Russian).

*References (1) and (2) were brought to the author's attention by R. L. Shepard (ORNL).

Continuing efforts to produce nuclear hardened transducers by anodization have succeeded in obtaining fine reproducible layers of oxide insulation on Al. The present plan is to use Al transducers for the Oak Ridge tests. Six Al transducers were constructed and found to give signals of reproducible amplitude and stability after 24 hours continuous operation at room temperature. Further tests up to 500° F are planned for the next month. (NYO-3906-4).

Ultrasonic tests were performed on 4 sample W/W 26% Re thermo-couple geometries to determine the configurations most suited to ultrasonic propagation. The four thermocouples were obtained from GE in the configurations shown in Fig. 2. Thermocouples #1 and #2 were used to determine the effective acoustic impedance discontinuities of the tie-on legs, while thermocouples #3 and #4 were tested for the combined discontinuities of the Re sensors and the tie-on legs. The 0.005" dia tie-on leg (T/C's #2 and 3) yielded a reflection of smaller amplitude than the 0.010" dia. However, the 0.020" dia Re sensors had to be etched down to ~0.015" dia in order to obtain an echo ratio of approximately 2.

There are several ways of introducing ultrasonic pulses into a T/C leg. Examples include: the deposition of a Ni coating on the T/C leg (Fig. 3a); the sandwiching of a Ni extension (Fig. 3b); or the termination of the T/C leg with a Ni wire, the lead-out T/C leg then being joined at a right angle (Fig. 3c). The first method may introduce spurious perturbations of the T/C emf output. In addition, it is too cumbersome for this application. The Ni coating must be carefully blended with a smoothly varying thickness if echoes in the section or resonances are to be eliminated.

In all the T/C tests outlined above, the ultrasonic waves were launched via a magnetostrictive wire flash butt-welded onto the W legs. Since this method involved a modification in the T/C geometry, the question arose as to whether the T/C temperature measurements would be substantially perturbed by the interposition of the magnetostrictive wire (a Ni alloy). For this purpose, the prototype W/W-Re T/C shown in Fig. 4 was heated at the W-Ni and Ni-Cu joints by passing direct current in a fiberfrax insulated copper wire (Fig. 5). Two chromel-alumel T/C's, attached to the joints, were used to determine the temperature at the joints. The T/C outputs were obtained by nulling a standard L&N Potentiometer #8691. The results of these tests indicated an increase of the W/W-Re T/C emf output by several tenths of a mV when the Ni-Cu junction was heated to ~500° F, and a decrease of emf output by a somewhat lesser amount when the W-Ni joint was heated to the same temperature.

In a separate experiment, portions of a 3 ft length of 0.023" dia remendur wire, attached to the T/C posts of the potentiometer, were torch-heated; emf's of +0.5 mV, -0.3 mV were observed depending upon the area being heated. This relatively large Thompson effect in the magnetostrictive wire, therefore, could entail temperature uncertainties on the order of $\sim \pm 1\%$ at $\sim 5000^{\circ}\text{F}$ unless the alloy wire is kept essentially isothermal throughout its length. Based on the above, the design of Fig. 3c was tested in the laboratory and found to be ultrasonically satisfactory. This design, which has been submitted to GE, has the advantage that the Ni alloy is not in the T/C circuit and hence will not perturb the T/C temperature measurement. This design will probably be used in the ORNL tests.

Subsequently, a model probe incorporating an anodized Al coil, but not including insulation and electrical connection, was constructed and tested in the laboratory. The probe was housed in clear plastic for ease in visualization, and will be presented at a meeting at GE - Evandale on Jan. 7, 1969 with R. L. Shepard (ORNL) and GE-NMPO personnel, for final approval.

PREPARATIONS FOR IN-PILE TEST AT ORNL

Several meetings were held on September 12, 1968 with members of the ORNL Reactor Division, Operations Division, Metals & Ceramics Division, and Instrumentation and Controls Division. The purpose of these meetings was to generally examine the problems associated with reactor testing, and to submit alternative in-pile test approaches which would achieve the goals of Phase II. The Minutes of this meeting, as summarized by R. L. Shepard, are contained in a distribution memorandum dated September 24, 1968 and include the alternative test approaches discussed during these meetings, and the available test facilities which were later visited.

At the conclusion of a meeting with E. S. Collins (ORNL-GE-NMPO) it appeared by Collins' test would provide the closest simulation of the operating temperature and radiation conditions obtaining in LMFBR's. Consequently, it was decided to further pursue this line of approach by conducting more detailed discussions with the appropriate GE supervisory personnel. This meeting was also organized by R. L. Shepard, and was held at the GE-NMPO facility in Evandale, Ohio on October 17, 1968. The Minutes of this meeting have also been summarized by R. L. Shepard in a memorandum to S. N. Ceja, AEC-DRT dated October 23, 1968.

Some of the highlights of both meetings may be summarized as follows:

(1) The GE test apparently provides the closest available simulation of the operating conditions obtaining in LMFBR's, with particular emphasis on fuel temperature determination. The test reactor facility is expected to provide temperatures up to 5000°F and neutron fluxes of $\sim 10^{13}\text{n/cm}^2\text{sec}$ (fast) and $\sim 10^{14}\text{n/cm}^2\text{sec}$ (thermal) integrating in a typical seven-week test to fluencies of $\sim 10^{19}\text{nvt}$ (fast) and $\sim 10^{20}$ (thermal).

(2) A composite temperature sensor shall be used to obtain independent temperature measurements. The composite sensor consists of a W/W-26 Re thermocouple, one leg of which will be used as a lead-in wire to the ultrasonic sensor. Inclusion of ultrasonics is to be accomplished with a minimum perturbation of the other test considerations.

(3) ORNL shall provide the metals joining facilities and materials (e. g., SS 304 sheaths and/or transducer housings) other than transducers and sensors.

(4) At least two complete composite probes shall be built, one of which shall be proof tested and calibrated at ORNL prior to the in-core tests scheduled for March 1969. The second unirradiated probe could be used to distinguish the effects of irradiation from other effects (e. g., thermal cycling and aging) by duplicating the reactor exposure time vs temperature characteristics in a separate oven experiment, in the absence of radiation.

CONCLUSIONS AND RECOMMENDATIONS

Preliminary agreement with GE-NMPO has been reached on the basic design of the composite ultrasonic/thermocouple temperature probe. A model probe utilizing an anodized Al transducer was constructed and laboratory tested at room temperature.

Agreement was also reached on the pre- and post-irradiation procedures for optimal test data evaluation. The exact procedure for sensor retrieval, however, remains to be fully worked out.

The in-pile test at ORNL is presently scheduled for mid-March, 1969. It is expected that the composite probe configuration shall be finalized at the January 7th meeting or shortly thereafter. A detailed program for fabrication and testing, however, remains to be worked out. Such a program should include ultrasonic testing of the probe in at least two of the intermediate steps in fabrication, viz: (a) at completion of the sub-assembly consisting of the thermocouple wires, ultrasonic transducer and insulation; (b) after housing the sub-assembly in its protective sheath, but prior to final welding.

The first test will be made to determine the soundness of ultrasonic coupling and to ensure that the signals have sufficient amplitude and are in proper relationship to each other. The second test is intended to check for coupling (if any) to the sheating system. A final check will be made after the probe assembly has been completed.

Figure 1. Test configuration for determination of extensional wave velocities in Re-Os samples.

Figure 2. Sample W/W 26% Re thermocouple geometries to obtained from GE.

(a)

(b)

(c)

Figure 3. Alternative methods of ultrasonic coupling. Method (c) is preferred because it does not perturb the T/C emf, and it will probably be used in the ORNL tests.

Figure 4. Test configuration to determine perturbation introduced by remendur wire on T/C temperature measurement.

Figure 5. Photo showing location of insulated heating coils and Type K T/C's.