Selection and Evaluation of Magnetic Flowmeter Liner Material for Nuclear Power Plants

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1. Introduction

Nuclear power plants are licensed to operate at power levels up to a specified thermal power rating. Safety analyses and evaluations are performed at conditions selected to account for uncertainties in determining thermal power. The NRC in Regulatory Guide 1.49, Rev. 1, December 1973 provides guidance regarding the amount of margin needed to account for uncertainties. Guidance provided in Regulatory Guide 1.49 recommends that analyses and evaluations be made by assuming the thermal power is equal to 1.02 times the licensed thermal power. The reason that analyses should be performed at two percent above the licensed thermal power is to allow for possible instrument errors. A 1% error in a primary loop flow can result in a 1% reduction in the unit net load if the error is in the high direction. In order to avoid errors in the low direction (and exceeding the licensed plant thermal power) a margin is built into the control system. Improved accuracy of the primary flow measurement allows for a reduction of this margin. EPRI has reported that the typical power plant primary flow measurement errors are 3 5% [1].

Primary loop flow measurements are used to determine the core heat rate in PWRs and as such are a basic safety indication. These measurements are conventionally made using flowmeters based on the differential pressure. Differential pressure based on flowmeters have significant, fundamental accuracy limitations as well as having failure modes difficult to diagnose while in service. Magnetic flowmeters offer a potential solution to these limitations. Magnetic flowmeters are highly accurate, respond linearly, and are obstructionless (no fouling; consume no pumping power). Also, the transmitter for magnetic flowmeters can be located remotely (up to hundreds of feet) from the point of the measurement, thus reducing the environmental exposure. The major limitation to the immediate application of magnetic flowmeters to nuclear power plants is the radiation sensitivity of the non-conductive inner pipe liner. Ceramic pipe liners are currently available for pipe diameters up to 30 cm. However, for larger pipes only radiation sensitive materials such as Teflon™ or rubber are available. Ceramic pipe liners are not currently available for larger diameter pipes due to manufacturing and material limitations.

2. Methods and Results

2.1 Preparation of test components

ORNL has produced a series of magnetic flowmeter ceramic liner test components and supplied them to both KAERI and OSU for testing. Figure1 shows the samples that ORNL has prepared.

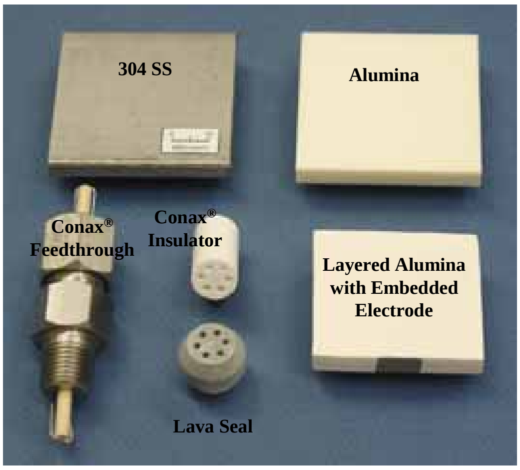

Fig.1 Test samples used for radiation exposure testing at KAERI and OSURR

2.2 Evaluation of the components after gamma irradiation

The test pieces have been irradiated to 1.77 MGy (equivalent to 15 full power years) and their mechanical performance has been evaluated. Evaluation of the samples after a completion of the radiation exposure showed no significant changes in the dimensions or weights of the samples.

The flexure strength of the alumina ceramic was compared for samples before and after a radiation exposure. Five samples were tested for each radiation exposure level: 0, 0.88, and 1.77 MGy. The strength tests were performed at KAERI using a universal material testing machine Instron 4465. The test has been done according to a four-point flexural strength test method at an ordinary temperature of the criteria JIS R1601:1995 [2]. The results were that there was no degradation of the material strength after an exposure to a gamma radiation that was an equivalent of 15 years service in the reactor environment.

The thermal expansion coefficients of the alumina material were measured in the same temperature range of the primary coolant of NPP - 25 ℃～350 ℃ with a dilatometer - Setaram TMA92 according to the method of the criteria ASTM E831 [3]. The results of the thermal expansion coefficient (α) measurements conducted at KAERI were that there was no discernable change in α for the three different levels of radiation exposure. When the dilatometer data was averaged for all of the samples in each group and plotted simultaneously (Fig.2), the traces were virtually overlapping.

The test components show no evidence of degradation in material strength or mechanical integrity after an irradiation.

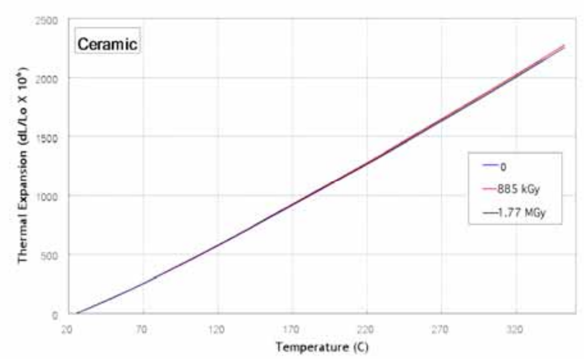

Fig.2 Dilatometer plot showing the thermal expansion of alumina samples before and after radiation exposure. For each exposure level the line represents the average value of six tests

2.3 Fabrication method of flowmeter liner

The flowmeter liner consists of an alumina tube having an embedded electrode layer near the inside diameter surface shrink-fitted into stainless steel primary piping. Platinum ink is used to form the internal electrode in the alumina tube. This is accomplished by using a two-step gelcasting procedure to form the tube. A thin-walled tube is first gelcast and electroded onto the outer diameter surface. A second, thicker tube is then gelcast against the electroded surface of the first tube resulting in an embedded electrode. The Pt electrode is an interconnected, but discontinuous layer in the laminated structure. The sintering process used to densify the alumina ceramic hermetically seals the electrode inside the tube wall. The strength tests combined with the examination of the laminated alumina samples with embedded electrodes confirm that the concept of a gelcast laminated alumina ceramic liner is a feasible approach to producing a large-scale, ceramic-lined magnetic flowmeter.

2.4 Examination of the internal electrode layer

One of the laminated specimens that had undergone an irradiation exposure was cross-sectioned at ORNL to examine the internal electrode layer and the interface where the two alumina layers were joined. Optical micrographs of the sample cross-section are shown in figure3. The measured thickness of the Pt electrode seen in the micrographs is between 5 and 10 microns. Examination of the electrode and the interface region shows no indication of a degradation of the irradiated material. The images show no structural difference between the alumina in the interface region and in the bulk of the material. There is no evidence of any damage to the interface bond due to the radiation exposure.

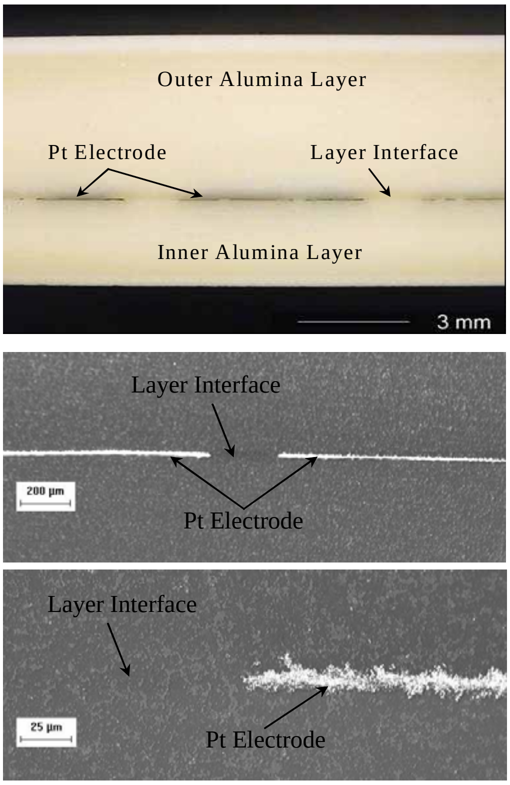

Fig.3 Optical microscope image of the cross-section of the laminated alumina sample and high magnification optical images of the Pt electrode and layer interface

3. Conclusion

Two candidate ceramic materials were identified that appear to have the needed properties for this application, aluminum oxide (Al_2O_3) and zirconium oxide (ZrO_2). These ceramics can be formed by several different processing methods and can be sintered to a full density. No degradation of the materials was detected in the property evaluation tests conducted after the exposure.

Fabrication of the ceramic cylinder liner could be accomplished by using a two-step gelcasting procedure.

The test results confirm that the concept of a gelcast laminated alumina ceramic liner having an embedded electrode is a feasible approach for producing a large-scale, ceramic-lined magnetic flowmeter.

REFERENCES

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[2] JIS R1601, Testing Method for Flexural Strength of High Performance Ceramics, 1995.

[3] ASTM E831, Linear Thermal Expansion of Solid Material by Thermomechanical Analysis.