PROPOSED SPECIFICATIONS FOR CANDIDATE INSULATOR MATERIALS FOR MHD COATINGS -- B. A. Pint and J. R. DiStefano (Oak Ridge National Laboratory)

OBJECTIVE

The objective of these specifications is to identify experimental criteria necessary to (1) select new candidate materials for electrically-insulating, magneto-hydrodynamic (MHD) coating development and (2) evaluate coatings based on processing technique, electrical resistivity, liquid metal compatibility, thermal cycling resistance and self-healing capability. The first section details the recommended performance criteria for evaluation of bulk specimens and the second section details coating performance requirements that need to be met in order to proceed to dynamic loop testing of a coating.

SUMMARY

These specifications provide metrics for evaluating compatibility results in static Li exposures to determine when bulk ceramic candidate materials are ready for coating development and when coatings are ready for dynamic (i.e. loop) testing.

INTRODUCTION

The blanket system in proposed deuterium/tritium-fueled fusion reactors converts the fusion energy into heat and breeds tritium for the fuel cycle. One promising blanket concept is the use of liquid lithium as the breeding medium, where the lithium also self-cools the blanket. However, in magnetic fusion energy systems where a strong magnetic field is used to contain the fusion plasma, a MHD pressure drop is developed when the electrically conductive lithium flows across the magnetic field lines. Accordingly, an insulating barrier is needed to decouple the lithium from the magnetic field in order to have adequate liquid metal flow at acceptable pumping power levels. The best way to achieve such isolation is by creation of an electrically insulating surface layer on the structural alloy containing the lithium. From heat-transfer considerations, this barrier must be relatively thin (<10μm) and integrally bonded to the first-wall containment material, which would likely be a vanadium alloy. The barrier or coating also must be resistant to radiation damage and, based on efficiency considerations, it must be compatible with the lithium and first wall at temperatures up to 700°-750°C.[1]

The materials development goal is to find an insulator material that can be made into a coating with the necessary integrity, compatibility and resistivity to satisfy the system requirements. In order to circumvent the need to select and/or develop a coating process for each new candidate material, one strategy has been to test bulk ceramics to identify the best potential candidates before proceeding with coating development. This allows a wider range of materials to be considered without the cost and time required for an optimized coating fabrication procedure to be completed. The first set of specifications is to clarify when a new candidate material should proceed to coating development and testing, and the second set is to determine when a coating is ready for liquid metal loop experiments. Ultimately, dynamic loop testing will be necessary to determine if a coating is likely to successfully perform in a fusion reactor.

Note: the optimum coating thickness and maximum system operating temperature are not included but MUST be specified before the selection criteria can be satisfied. At this time, those values would be estimated as 10µm and 700°C but could change based on design consideration.

MATERIALS SELECTION SPECIFICATIONS

For any new materials under consideration, the following basic material requirements should be met before coating development of the material occurs:

1-1. Appropriate resistivity measured at 400°-800°C
$\geq 10^5$ Ω-cm

1-2. Appropriate compatibility with liquid lithium:

A. expose a bulk specimen or coating of the pure material to liquid lithium (>90at%Li) at a temperature 50K above the specified maximum temperature.

Note: To eliminate microstructural variables, particularly second phases on grain boundaries that may not be present in a coating, it may be preferable to expose a single crystal of the material.

B. after exposure to lithium as described in (A), based on mass change and/or microstructural analysis, the specimen should show:

- less than an equivalent 3µm loss in specimen thickness after 100h
- less than an equivalent 5µm loss in specimen thickness after 1000h
- less than a 5µm deep reaction zone after 1000h
- the combined thickness loss and reaction zone should not exceed 5µm after 1000h

Note: a reaction zone would include new compound formation, intergranular penetration or intercalation of the material with lithium.

For example, for a specified maximum temperature of 650°C and a bulk specimen of AlN, the testing would be conducted at 700°C. A mass loss of ≈1.6 mg/cm^2 would correspond to an equivalent 5µm material loss using a density of 3.25g/cm^3. Figure 1 shows data obtained for AlN

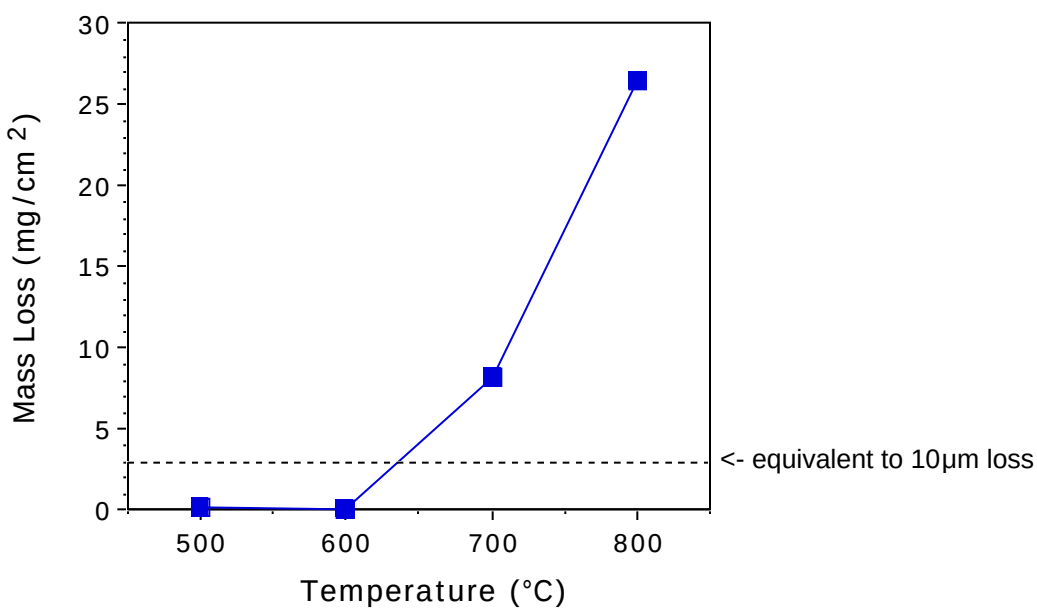

Figure 1. Mass losses for AlN (Shapal SH-50 from Tokuyama Corp, 0.04wt%Y, 0.9%O) after 1000h exposures in undoped Li at each temperature in a V alloy capsule. The dissolution of AlN becomes rapid above 600°C. [2]

exposed to undoped Li in a V alloy capsule for 1000h at several test temperatures. According to the above criteria, these data would indicate a maximum use temperature for AlN in undoped Li of <650°C. (These results are provided as an example, mass losses were lower at 700°C when a Mo capsule was used for the test.)

COATING PERFORMANCE CRITERION

For an actual coating, these criteria would need to be satisfied before proceeding with a dynamic lithium loop testing.

2-1. Demonstrate a reasonable and reproducible coating technique for this application:

A. uniform microstructure and coating thickness (deviations less than 25% of total thickness) confirmed by multiple characterization techniques including transmission electron microscopy as appropriate.

B. ability to coat complex geometries

2-2. Demonstrate sufficient electrical resistivity from 25°C to specified maximum temperature:

A. measure values of ≥1000 Ω-cm^2 on a coating with appropriate thickness (50%-150% of specified thickness) and fabricated using a process which satisfies requirements in section 2-1.

Note: the resistance should be measured through the coating thickness, NOT by a 4-pt probe method which measures properties in the plane of the coating.

2-3. Demonstrate compatibility with liquid lithium:

A. expose coating with appropriate thickness (50%-150% of specified thickness) and fabricated using a process which satisfies requirements in section 2-1 to liquid lithium (>90at%Li) at a temperature 50K above the specified maximum temperature.

B. after exposure to lithium as described in (A), based on mass change and/or microstructural analysis, the coating specimen should show:

- less than 5% loss in coating thickness after 100h
- less than 10vol% of coating reacted after 100h
- less than 10% loss in coating thickness after 1000h
- less than 20vol% of coating reacted after 1000h
- resistivity measured from 400° to test temperature maintained above 500 Ω-cm^2

For example, using specifications of 700°C and 10µm, a 5-15µm thick coating would be exposed at 750°C and thickness losses of <0.5µm after 100h or <1µm after 1000h would be required.

Note: percentage thickness losses were selected based on a minimum reactor operating time of 25,000h; significant mass losses measured in short-term static tests are unlikely to significantly decrease in longer-term dynamic exposures.

Note: compound conversion limitations are specified because the coating may not dissolve but rather convert to a different compound such as has been reported for AlN forming $LiAlO_2$ [3] or Y_2O_3 forming $LiYO_2$ [4]

2-4. Demonstrate thermal cycling capability

A. use a coating with appropriate thickness (50%-150% of specified thickness) and fabricated using a process which satisfies requirements in section 2-1

B. expose the coating to a minimum of 3 thermal cycles from room temperature to a temperature 50K above the specified maximum temperature in liquid lithium (>90at%Li). Each cycle should consist of 10-100h at the high temperature and >0.5h at room temperature.

C. after exposure described in (B), examine to determine that the coating meets the requirements in section 2-3-B.

2-5. Demonstrate possibility of self healing

A. experimentally confirm the viability and reproducibility of the self healing process and specify the conditions under which the self-healing will be performed.

Note: for a coating system which demonstrates exceptional Li compatibility, adhesion and resistance to thermal cycling, this requirement may be waived.

REFERENCES

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