Cladding materials performance and the safety of HLM cooled systems

C. Fazio, G. Müller, D. Struwe, A. Weisenburger

Forschungszentrum Karlsruhe, P.O. Box 3640, Karlsruhe, Germany, 76021 - concetta.fazio@nuklear.fzk.de

INTRODUCTION

Heavy Liquid Metals (HLM) as Pb and Lead Bismuth Eutectic (LBE) alloys are considered as coolant options for fast neutron reactors in GEN-IV concepts [1] and for Accelerator-Driven Systems (ADS), proposed for high-level radioactive waste incineration [2]. Heavy liquid metals are also being proposed as target materials for high power neutron spallation sources [3]. The thermal and physical properties as well as the advantages to use HLM coolant in fast neutron systems have been discussed elsewhere [4]. Of particular importance for these systems are the materials performances in presence of HLM. Several studies have been conducted and are still ongoing in order to select and assess suitable structural materials which should show corrosion and mechanical resistance under a large variety of load conditions during power operation and transients. The objective of this work is to discuss the safety issues related to fuel pin integrity and the link to the materials selection and assessment.

SAFETY CONSIDERATIONS

In operation, the cladding material is subject to corrosion and neutron irradiation, fretting due to flow induced vibrations as well as to several types of stresses which can induce creep, fuel-clad mechanical interaction, hoop stress due to the fission gas plenum pressure etc. However, a stringent requirement on the integrity of the cladding material has been put for design basis operating conditions and design extension conditions (table 1).

Present designs of HLM cooled systems, either critical or sub-critical [1, 2] foresee a maximum HLM core inlet and outlet temperature in normal operating conditions of 400°C and 480°C respectively . The average temperature of the clad material has been evaluated to be about 10% higher with respect to HLM core outlet temperature. For this temperature regime the selected cladding material should withstand the combined effect of neutron irradiation, corrosion and mechanical stresses in order to comply with the safety requirements given in table 1.

Table 1: Clad limits for normal operating, Design Extension Condition (DEC) and Design Basis Condition (DBC)

Category of operating conditions	**Safety Target**	**Clad limit**
Normal operating conditions	Radiological release ALARA	No clad failure
2	Radiological release lower than target	No clad failure except due to random effect for experimental pins
3	Radiological release lower than target	No systematic (i.e. large number of) pin failures
4	Maintaining of the core coolability and limitation of core geometrical modifications	No systematic clad melting. No simultaneous and coincident clad failure and fuel melting
Complex sequences and limiting events	Controlled radiological releases below admissible limits	No severe core damage
Severe accident	No off-site emergency procedures necessary	Cooling ability of the damaged core to be demonstrated

CORROSION RESISTANCE IMPROVEMENT OF CLAD MATERIALS

Envisaged reference materials for the HLM fuel pin clad are the Ferritic – Martensitic (F/M) steels of the 9Cr class [5].

The corrosion resistance of the 9Cr F/M steel has been studied thoroughly and it results that this steel is oxidized in HLM having appropriate oxygen potential [6, 7]. However, just above 500°C the required slow oxidation seems to fail and sever oxidation and at higher temperatures corrosive attack can be observed [8, 9]. Similar results have been obtained also with austenitic steels [10] . This effect can then affect the admissible temperature limit of the cladding (~ 530°C) as indicated above. An alternative protection method has been developed. This method consists in alloying a FeCrAlY coating at the steel surface applying a pulsed electron beam facility (GESA, Gepulste ElektronenStrahl Anlage) [11]. First requirement for such protection is sufficiently high Al content to develop thin alumina scales in HLM. Second the deposited coating has to be melted together with the upper layer of the bulk to create a metallic bonding between the coating and the substrate to overcome any adhesion problems. Both needs can be fulfilled with the GESA treatment of FeCrAlY coatings. Corrosion experiments performed on such FeCrAlY alloyed steel did show that the resistance can be improved up to 600 °C. (see fig. 1)

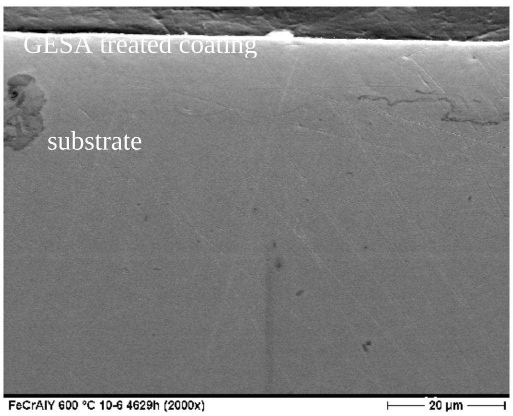

Fig. 1. Cross section of 1,4970 GESA [12] alloyed steel tested in flowing HLM at 600°C for 5000h.

SUMMARY

The safety requirements on fuel pin clad for HLM cooled systems are related to the corrosion resistance, the mechanical strength and the thermal creep resistance of the materials. It has been shown that the corrosion resistance of cladding materials can be enhanced with an appropriate surface treatment. First results from corrosion experiments in flowing liquid metal have shown that GESA alloyed FeCrAlY resists in HLM environment up to 600°C. Further experimental activities are going on in order to evaluate the resistance of these barriers under neutron irradiation in a fast spectrum [5].

Moreover an experimental program is underway to assess the mechanical properties of the structural materials in terms of e.g. thermal creep resistance in HLM [5].

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