EUROPEAN COMMISSION
5th EURATOM FRAMEWORK PROGRAMME 1998-2002
KEY ACTION : NUCLEAR FISSION

HTR-M1

European Project for the development of HTR Technology - Materials for the HTR

CONTRACT N°
FIKI-CT-2000-00032
&
FIKI-CT-2001-00135

HTR-M1: Report on selection of materials & testing requirements for the Turbine

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Dissemination level : CO
Document Number: HTR-M1-02/9-D-1.1.7
Deliverable D1

Selection of materials & testing requirements for the Turbine

Contents

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Summary

This document reviews materials selection and testing requirements for the turbine blade tests performed within the HTR-M1 Project. The status of the test matrix for the medium term turbine blade creep tests is given along with information on other turbine blade tests performed within HTR-M & M1. The report contributes to WP1 of the 5th FP HTR-M1 project and corresponds to deliverable D1 of HTR-M1.

The materials selected for the turbine blade tests are:

- IN 792 DS (Ni-13Cr-9Co-4.2Ti-3.2Al-2Mo-4W-2Nb);
- CM 247 LC DS (Ni-8Cr-9Co-0.7Ti-5.6Al-0.5Mo-10W-3.2Ta-1.4Hf).

The tests involve medium term creep tests in air and simulated He carburising and decarburising atmospheres.

The test matrix will be reviewed following an interrogation of the first results from the HTR-M short term tensile and creep test programme.

Part 1

HTR-M &M1 Turbine Blade Material selection

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HTR-M& M1 Turbine Blade Material selection

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Introduction

During the HTR-M progress meeting in Jülich (15-17/04/02), the selection of two blade alloys for the HTR gas turbine was discussed. The aim of this document is to summarise the different options that were raised and to discuss the reasons that have led to the final selection, CM 247 LC DS and IN 792 DS.

Coatings

A general agreement was obtained on this point. A coating should be applied to the blades to protect the base metal from corrosion effects. Al or Cr-based oxide coatings are candidates for protection of alloys that naturally form oxide scales based on Al_2O_3 or Cr_2O_3 in oxidising environments.

Since it cannot be assumed that the coating will remain undamaged during the lifetime of the blades, the selection of base metal still needs to be discussed with regard to the possible corrosion effects at the metallic surface.

It seems that the decision to coat the blades enables the selection of superalloy grades with a significant content of cobalt (~10%). Co is not incorporated into the oxide scales and so no contamination and activation due to oxide spallation are anticipated.

Cr-oxide former / Al-oxide former

The environment in a HTR is composed of helium with impurities as CH_4, CO, H_2O and H_2 at μbar levels. Depending on the partial pressure of the impurities, the atmosphere can be either oxidising (high P_{O2}, low a_c) or carburising (low P_{O2}, high a_c) for the alloys selected. The carburisation can be limited by a protective Cr-oxide layer, provided that the oxygen partial pressure is sufficiently high for a stable Cr oxide scale to be formed (see Ellingham diagram). The experience gained in the past German projects has shown that the oxygen partial pressure may not in all cases be high enough for the formation of a stable Cr-oxide scale. For this case, Al-oxide formers should be considered in the selection of blade alloys because Al-oxide forms even at extremely low oxygen partial pressures.

As specifications on the content of CO, O_2, CH_4, H_2O in the future HTRs are not precisely known, it was suggested that one Al_2O_3 forming alloy and one Cr_2O_3 forming alloy should be selected.

Conventionally Cast / Directionally Solidified / Single Crystal grades

SC grades offer the highest possible creep properties at 850°C. However, the selection of SC grades for the HTR turbine leads to the following problems.

- Cost is very high and procurement may be difficult as there are licensing agreements between turbine manufacturers and SC producers.
- Properties are not isotropic.

- SC alloys are not easily repaired if damaged during their lifetime.

Nevertheless, if SC grades were to be selected (for example in the 6th FP projects with a turbine manufacturer as a partner), it is likely that PWA 1483 and CMSX4 would be the best candidates. PWA 1483 is a Cr-oxide former and CMSX4 is an Al-oxide former.

DS grades appear to be good candidates for the HTR turbine. Procurement of large DS non-cooled blades seems possible and these grades have shown highly reliable properties in aeronautical gas turbines. DS grades offer improved creep properties when compared to conventionally cast grades, and a better repair possibility during operation compared with SC grades. Also the experience of DS blades for industrial land-based gas turbine is more extensive than for SC grades.

IN 792 LC DS (Cr-oxide former) and CM 247 LC DS (Al-oxide former) are the two alloys that were selected. Conventionally **Cast grades** are easy to procure, industrial experience is extensive and the fabrication of HTR blades should be possible. However, the major limitation of such alloys is the modest creep strength at 850°C. In the case of a future design with cooled blades (this option is not considered for HTR-M and M1), we propose IN 792 (Cr-oxide former) and MAR M247 (Al-oxide former) as possible candidates.

<u>Conclusion</u>

The discussions of candidate blade materials for the HTR gas turbine have resulted in the selection of two DS grades for HTRM&M1 projects.

- IN 792 DS (Ni-13Cr-9Co-4.2Ti-3.2Al-2Mo-4W-2Nb).
- CM 247 LC DS (Ni-8Cr-9Co-0.7Ti-5.6Al-0.5Mo-10W-3.2Ta-1.4Hf).

Material will be delivered in the HIPed and solution heat treated condition. Specimens will be machined from the cast and heat treated bars and then “pre-treated” (temperature 950°C or 850°C) in Ar + methane for carburising and in Ar + H_2 + H_2O for de-carburising, to achieve the different conditions to be tested.

- Material entirely de-carburised.
- Material heavily carburised.
- Material with reference treatment (heat treated at 950°C or 850° depending on pre-treatment, in He, time same as pre-treatment, to separate thermal ageing effects from the effects of decarburisation or carburisation.
- Material in the condition “fully heat treated for service” (standard delivery for reference, “non-damaged condition”).

The tests will be performed under protective atmosphere (e.g. argon) or under vacuum.

It is clear that the test matrix should be discussed again if first results indicate differences between material with reference treatment and material heat treated for service.

Part 2

HTR- M1 Turbine blade tests
Status of Test Matrix for JRC and CEA material tests

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HTR-M&M1 Turbine Blade Materials

Test Matrix for JRC and CEA – 7-3-02

Dispatching and organisation

* **JRC** and **CEA** will share the cost of blade alloys (1 for CEA and 1 for JRC)

* **JRC** is in charge of blade alloy procurement

* Heat treatments have to be performed by **CEA** (1 blade alloy) and **JRC** (1 blade alloy)

* Blanks will be machined by **CEA** (1 blade alloy) and **JRC** (1 blade alloy)

* **CEA** and **JRC** have to perform the final machining of their specimens

* Blade alloys are the same for HTR-M and HTR-M1.

HTR-M – Blade (2 grades)

Grade 1
Grade 2

Test	T (°C)	He (JRC)	Air (CEA)
Tensile	20 750 800 850		2 2 2 2
Creep 3σ (500, 1500, ≤5000h)	850	6	6

HTR-M1 – Blade (2 grades) Materials

Grades 1 & 2, Unaged

Test	T (°C)	He (JRC)	Air (CEA)
Creep 2σ (t_r = 5-10 khr)	850	2	2
Creep-damage 3 notch radii 1σ (~1500 hrs)	850	4	4

Grades 1 or 2, Aged **at 850°C (?)**

Test	T (°C)	He (JRC)	Air (CEA)
Tensile	20 800 850		2 2 2
Creep 2σ (500, 1500h)	850	4	4

Summary :

CEA : 4 creep (long time) + 6 tensile + 4 creep (aged material) + 8 creep (notched samples)

JRC : 4 creep (long time) + 0 tensile + 4 creep (aged material) + 8 creep (notched samples)

HTR-M&M1 Turbine Materials

Test Matrix : Remaining questions

HTR-M

- Representative environment (impure He, carburized samples…)
- Tests on coated blades ?
- Relation Creep-fatigue (JRC) / Fatigue (CEA)
- Test temperatures for discs and blades to be discussed (? Disc temperature in specifications)

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- JRC creep-fatigue tests to be added ?
- Ageing temperature and grade ?