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Materials for Turbine: Definition of Complementary testing experiments

R. Couturier

CEA

France

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Materials for Turbine: Definition of Complementary testing experiments

Contents

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Summary

This document provides the status of turbine blade and disc material selection and the test matrix for the proposed tests to be carried out within the HTR-M & HTR-M1 projects on turbine materials. It contributes to the 5th FP HTR-M project WP2.2 and the HTR-M1 project WP1, and corresponds to deliverable 2.8 of HTR-M.

The material selected for the turbine disc tests is Udimet 720

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 tensile and creep tests in air and simulated carburising and decarburising atmospheres.

The test matrix will be re-examined if first results indicate differences between material with reference treatment and material heat treated for service.

Part 1

HTR-M&M1 Turbine Blade Material selection

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HTR-M&M1 Turbine Blade Material selection

By R. Couturier
With contribution from P.J. Ennis, H. Rantala, B.C. Friedrich, C. Escaravage, A. Buenaventura

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 summarize 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 oxidizing 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 is 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 oxidizing (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 6^{th} 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 HTRM and M1), we propose IN 792 (Cr-oxide former) and MAR M247 (Al-oxide former) as possible candidates.

Conclusion :

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 carburizing and in Ar + H_2 + H_2O for de-carburizing, to achieve the different conditions to be tested;

- material entirely de-carburized;
- 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 decarburization 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-M&M1 Turbine
Status of Test Matrix for JRC and CEA material tests

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HTR-M&M1 Turbine Materials

Test Matrix for JRC and CEA – 7-3-02

Dispatching and organization

* **CEA** will purchase disc alloy for all tests (CEA + JRC) in relation with A&D
* **JRC** and **CEA** will share the cost of blade alloys (1 for CEA and 1 for JRC)
* **JRC** in charge of blade alloy procurement

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

* Blanks will be machined by **CEA** (1disc +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) and Disc (1 grade) Materials

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

U720

Test	T (°C)	He (JRC)	Air (CEA)
Tensile	20 650 700 750		2 2 2 2
Creep 2σ (500, 2500h)	700 or 750	4	6
LCF (3 $\Delta\varepsilon$)	700 or 750		10
LCF + dwell	700 or 750	10	

CEA : 24 tensile + 18 creep + 10 lcf (air)

JRC : 0 tensile + 16 creep + 10lcf-dwell

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

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- 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)

HTR-M1

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