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HTR-M1 Report on specimen fabrication, procurement & testing requirements for the turbine blade material

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HTRM1-High Temperature Reactor Materials

Deliverable D2 (Draft document)

Report on specimen fabrication, procurement & testing requirements for the turbine blade material

1. Objectives

The objective of this document is to give an overview of the turbine blade procurement and testing, including:

- blade alloy selection and test conditions;
- blade composition, fabrication and delivery date.

The blade alloy selection was discussed and approved by the HTR-M1 partners after the meeting held in Jülich (15-17/04/02).
The blade manufacturer was selected by H Rantala (JRC) with the help of BC Friedrich (FRA-Gmbh). The blade alloy test matrix for HTR-M1 presented in this document is the latest version discussed during the mid-term meeting in Paris (28-29/11/02). The blade alloy test matrix for HTR-M is also presented as both HTR-M and HTR-M1 programmes are complementary.

2. Blade alloy selection and test matrix

2.1. Blade alloy selection

The discussions of candidate blade materials for the HTR gas turbine have resulted to the selection of two DS grades for HTR-M&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)

This selection has been made after a discussion of the following options.

A. Single Crystal / Directionally Solidified / Conventionally-Cast 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.

B. 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.

C. Surface coating

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.

2.2. Mechanical test conditions and test matrix

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 in the condition “fully heat treated for service” (standard delivery for reference, “non-damaged condition”) : denoted **“state I”.**

- Material entirely de-carburised: denoted **“state II”.**

- Material heavily carburised: denoted **“state III”.**

- 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: denoted **“state Imod”**).

The following tasks have been split between CEA and JRC.

- The tests will be performed under protective atmosphere (e.g. argon) or under vacuum for states II and III and in the air for I and Imod.

- JRC is responsible for carburising and de-carburising the specimens (blanks) for states II and III.

- The states II and III will be tested by JRC and the states I and Imod by CEA.

- The thermal ageing at 850°C, 10000h can be performed at CEA under Argon atmosphere.

- The heat treatment corresponding to Imod state will be performed at CEA.

The test matrix for HTR-M1 and HTR-M are defined in the following tables which give the number of specimens to be used for each test condition.

A. HTR-M1 Blade alloy Test Matrix

For each grade (CM 247&IN 792):

Test	**T (°C)**	**I**	**I_{mod}**	**II**	**III**
Creep-Mid term x MPa (5-10 khr)	850	2	2	2	2

x : stress level to be defined to attain the desired rupture time.

For IN 792 DS aged at 850°C 10 khr :

Test	T (°C)	I	I_{mod}	II	III
Tensile	20 800 850	1 1 1			
Creep **x MPa (1000h)** **y MPa (3000h)**	850	3		4	4

x and **y**: stress level to be defined to attain the desired rupture time.

B. HTR-M Blade alloy Test Matrix

For each grade :

Test	T (°C)	I	I_{mod}	II	III
Tensile	20 750 800 850	1 1 1 1	<u>1</u> <u>1</u> <u>1</u> <u>1</u>		
Creep **x MPa (1000h)** **y MPa (3000h)**	850	4	4	4	4

x and **y** : stress level to be defined

3. Blade procurement

Some difficulties in the selection of a possible DS grade producer have been faced.

Finally the two grades have been ordered to Doncaster Precision Castin in Germany.

The cost of the blades, which includes specimens from the HTR-M project, has been shared between JRC (responsible for the IN 792 DS procurement) and CEA (CM 247 DS). Both grades have been ordered in January 2003.

3.1 Blade alloy quotation by Doncaster

The quotation sent by Doncaster and displayed below gives the material manufacturing conditions, prices, lead time and chemical composition.

T E L E F A X - M E S S A G E

Verkauf / Sales

An / to:	CEA France Attn. Dr. Raphael Couturier	Datum / Date:	16-1-03
		Absender / From:	Detlef Hermann
		Telefon / Telephone:	0234/622238
		Telefax:	0234/622340
	Copy to Mr. B.C. Friedrich	E-mail:	dhermann@doncasters.com
Fax - No.:		Seiten / Pages:	2
		JRC291002	

Ref.: Your inquiry dated 31.10.02

Dr. Couturier,

We would like to quote according to our general terms and conditions as follows:

Test bars approx. 16 dia x 150 mm length – Our offer no. F 3195 (DS-Version)

Weight per piece approx.. 0,255kg

Quantity	Material “similar to”	Condition	Price total
24 -36	CM 247 LC	Heat treated, FPI, x-rayed	€ 23.130,--
36 -48	IN 792 +Hf	Heat treated, FPI, x-rayed	€ 21.870,--

Remarks:

Prices: The prices are to be understood ex works Bochum, packing included and are valid for the delivery of the above mentioned requested parts respectively quantity.

Terms of payment: 30 days after receipt of the invoice via bank transfer

Lead time: 8 – 11 weeks after receipt of the order

Quantity: We will produce 3 moulds of pos.1 and 4 moulds of pos.2. The yield of this production will be delivered to you.

Alloys: The alloy of pos. 1 is similar to CM 247 LC.
The analysis of this alloy has to be agreed upon

If CEA insists on the original CM 247 LC this alloy has to be bought from Cannon Muskegon and this will have an impact on the above mentioned price and lead time of the requested parts made of this alloy.

Also the composition of the IN 792+Hf has to be agreed upon.

Test scope: We would propose inspections and heat treatment parameters as usual in connection with the above mentioned alloys.

General remarks: The condition of the parts as well as other technical issues have to be agreed in detail between CEA and DPC.

This has to be made because CEA cannot provide DPC with released specifications.

If you have any further questions don’t hesitate to contact us.

Best regards

- Axel Luckow - - Detlef Hermann -

Chemical composition :

Element	Similar to CM 247 LC	IN 792 + Hf
C	0,074	0,079
Cr	8,16	12,63
Co	9,34	9,08
Ni	Rest	Rest
Fe	< 0,10	< 0,10
Al	5,63	3,52
Ti	0,68	3,91
W	9,55	4,25
Mo	0,43	1,82
Nb	< 0,10	< 0,10
Ta	3,21	4,18
V	< 0,10	
B	0,0155	0,017
Hf	1,42	1,34
Zr	0,015	0,020
Mn	< 0,05	< 0,05
Si	< 0,05	< 0,05
S	< 10 ppm	< 0,002
P	< 0,005	< 0,005
Cu	< 0,10	< 0,10
N	< 10 ppm	< 15 ppm
O	< 10 ppm	< 15 ppm

4. Conclusion

The turbine blade material that will be tested in HTR-M1 project has been selected and procurement is in progress. The selected grades are directionally solidified nickel based superalloys with a chemical composition that should be suitable to the specific HTR environment.

The test matrix includes tensile and creep tests up to 850°C, with additional tests after an ageing treatment at 850°C for 10000 hours.

Considering the delays for specimens delivery, the first tests should start in April 2003.