# AMPM-ÜBUNG

## ADVANCED HEAT-TREATMENTS OF TURBINE BLADE MATERIALS.

Dr.-Ing. Inmaculada López Galilea

### 1. DESCRIPTION

In gas turbines used in power engineering and aviation, the aim is to sustainably optimize thermal efficiency by raising the combustion temperature. The highly stressed turbine blades behind the combustion chamber are made of single-crystal Ni-based superalloys (SX superalloys). These have to withstand mechanical stress under extreme conditions of temperature (above 1000°C) and corrosion (fuel gases in a gas turbine). On an industrial scale, the blades are cast as single crystals (without grain boundaries) via the Bridgman technique. The (mechanical) properties of materials depend on their microstructure, and often the potential of a material in terms of its properties remains unfold after casting. In this context, the outstanding high-temperature properties of SX superalloys are adjusted "post-cast" by a complex heat treatment. The design of the temperature - time profiles for these heat treatments is derived from arduous characterization of the microstructures of the as-cast state as well as those derived from isothermal heat treatments, among other experimental investigations.

This tedious experimental characterization can be combined or, in the best cases, replaced by simple and fast thermodynamic calculations using the CALPHAD method. The CALPHAD method, can be used to determine the predicted phases and segregation levels in the as-cast condition, as well as the phase transformation temperatures and phase amount evolution with temperature under equilibrium conditions. This information can be used to design the homogenization-solution heat treatment.

Other relevant information that can be extracted from the CALPHAD method is the value of the interdiffusion coefficient of the different alloying element in each phase. This information helps to identify the alloying element that will control the diffusion processes in term of the time required to achieve homogenization.

The Dictra software coupled with the TCNi10 thermodynamic database and MOBNi5 mobility databases, can be used to study the homogenization processes that take place during homogenization-solution annealing reduced to a one-dimensional scale. These calculations result in the temperatures and time required to achieve homogenization and can therefore be used to define the experimental heat treatment of the material. However, the restriction to 1D has to be kept in mind, as it differs from the real process.

### 2. Teaching objectives

The focus is on the heat treatment of SX superalloys because this thermal treatment is one of the most complex in materials science and technology. A heat-treatment is not just a furnace where the part is subjected to temperature over a certain time. A heat-treatment governs the final properties of more or less expensive parts. Therefore, special emphasis must be placed on the microstructural features present in the as-cast condition and, consequently on heating rates, holding times, and cooling rates. This training addresses the guidelines for the design of such a heat treatment. The attendees learn what (microstructural) features present in the as-cast condition have to be taken into account by the help of different characterization techniques and define objectives from a scientific and economic standpoint for the heat-treatment schedule of SX blade material for turbine blades.

Through independent use of Thermo-Calc software, thermodynamic calculations and kinetic simulation will allow the student to better understand the provided experimental data and the design of a suitable homogenization heat treatment.

## 3. Learning objectives

In this session, the attendees will learn:

- Qualitative and quantitative identification of microstructural inhomogeneities in the as-cast state of the CMSX-4 turbine blade material from given characterization techniques.
- Assessment of datasets. Processing, visualization and interpretation of the data.
- Independent use of the ThermoCalc and Dictra via the console mode.
- Understanding of the effect of temperature on interdiffusion coefficients. Determination of the slowest diffusing element for a given alloy composition using the ThermoCalc software.
- Development and understanding of isothermal homogenization simulations for a given segregation profile, using Dictra.
- Development of the student's ability to compare and analyse results that come from different methodologies.
- Layout and understanding of complex heat-treatment schedules for SX blades material.

## 4. TASKS

In order to design a heat-treatment for a single-crystalline Ni-base superalloy, it is mandatory to investigate the present microstructural features via different analytical techniques briefly.

**Task 1: Description of the as-cast single-crystalline microstructure**

In Task 1 a SEM micrograph is provided, where an as-cast single-crystalline microstructure can be seen. The nominal chemical composition of the ERBO/1 superalloy is given in *Table 1*. Please assign the following terms to what you see in *Figure 1*: (1) dendrite, (2) interdendritic area, (3) porosity, (04) eutectic, (5) TCP-phase.

Please use the micrograph ERBO/1 in order to measure and calculate the average dendrite arm spacing via the Fiji ImageJ software. What type of information can you extract?

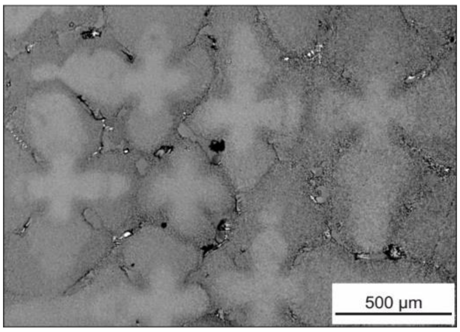


Figure 1. As-cast ERBO/1

*Table 1*. Nominal chemical compositions in wt.% of the two alloys used in the exercise: a complex single crystal Ni base superalloy, ERBO/1 (CMSX-4), and a simplified alloy, S4_alloy.

| | Cr | Co | Mo | W | Ta | Ti | Al | Hf | Re | Ni |
|---|---|---|---|---|---|---|---|---|---|---|
| **ERBO/1** | 6.4 | 9.7 | 0.6 | 6.4 | 6.5 | 1 | 5.6 | 0.1 | 3 | Bal |
| **S4_alloy** | 6.5 | 9 | - | - | - | - | 5.6 | - | - | Bal |

**Task 2: Chemical analysis of the as-cast material**

In *Figure 2* you can see so-called element mappings obtained from SEM analysis. Please describe in your own words which microstructural features you identify.

In *Table 2* are quantitative results from different local chemical analysis listed. Please calculate the average chemical composition in accordance to the location. Furthermore, please calculate the element-specific coefficient *k* and classify / sort the value of k in a meaningful manner. The dataset “linescan” contains raw data from a so-called quantitative line-scan or concentration profile along a certain distance obtained at the SEM. Please use the data to visualize the results. Taking everything so far into account, what conclusion can be drawn with respect to a possible heat-treatment?

**Task 3: Equilibrium calculations: Property diagrams**

Determination of the main transformation temperatures of the different phases that coexist in equilibrium conditions for the nominal composition as well as for the compositions measured at dendrite core and at the interdendritic regions. List the obtained main transformation temperatures in a table. Represent the evolution of volume fraction of phases with temperature. Discuss the main differences within the obtained results. Calculation of the processing-window temperature for this alloy.

**Task 4: Interdiffusion coefficients in γ phase.**

Calculation of interdiffusion coefficients of the alloying elements in the γ - phase at 1200°C and 1300°C. Which alloying element determines the duration of the solution annealing heat treatment? Which alloying element will be the first to homogenize?

**Task 5: Simulation of the solution annealing heat treatment by using Dictra.**

For this task, the composition of the simplified alloy, *S4_alloy*, listed in *Table 1* will be used. The provided file “segregation_profile.TXT” contains the segregation profile that will be homogenized by different isothermal heat treatments. - Isothermal homogenization heat treatments at 1200°C and 1400°C. Homogenization time = 1h; For each isothermal heat treatment, graphical representation of the homogenization profiles for the different homogenization steps.

**Task 6 Draft of a potential heat-treatment**

A conventional layout of a heat-treatment consists of one or more defined heating and holding segments and a final cooling segment that terminates the overall heat-treatment procedure. -Please describe how a heat-treatment for a superalloy could be defined taking all the above gained results into account? You can use the excel or origin software package and plot a schematic temperature vs. time diagram. What are your conclusions from a technological and economic viewpoint?