DEFORMATION MICROMECHANISMS AND TENSILE PROPERTIES OF ADVANCED SINGLE CRYSTAL NICKEL-BASED SUPERALLOYS

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Subject and challenge of the project: Single crystal nickel-based superalloys are widely used for aero-engines components, more particularly high-pressure turbine blades and vanes. The use of these materials is required because of the range of stresses applied to the turbine blades, going from intermediate temperatures (700 - 800 °C) and high stresses in the blade root to high temperatures (1000 – 1200 °C) and low stresses. The superior high temperature mechanical resistance of such alloys over other metallic alloys is ensured by a high volume fraction (~70 pct) of regularly arranged cubical strengthening γ' precipitates coherently embedded in the γ matrix and the absence of grain boundaries. Advanced single crystal Ni-based superalloys are necessary to achieve higher operating temperatures [1–3]. A series of nickel-based experimental alloys was defined by varying the content of different alloying elements, particularly the refractory elements Mo, W, Re, Ru, and Ta, in order to fulfill several requirements: i) a high γ' solvus temperature; ii) a high amplitude of γ/γ' mismatch; iii) a density as low as possible and iv) a good phase stability. The continuous demand of the gas turbine engine manufacturers for an increasing turbine inlet temperature have pushed the alloy designers to develop nickel-based superalloy chemistries with high rhenium (Re) contents. Re was indeed shown to have a strong beneficial effect on the high temperature mechanical properties. This leads to different generations of single crystal nickel-based superalloys (SXs) depending of the Re-content. For example, CMSX-4 Plus is an improved 3rd generation SX and TMS-238 is a 6th generation SX with 4.8 wt. % Re and 6.4 wt. % Re respectively [4, 5]. More recently TROPEA, a completely different and new-generation Pt-containing superalloy has been developed between ISAE-ENSMA/Institut Pprime and SAFRAN in France [6, 7]. This new alloy is considered as a potential alloy for future airfoils.

The general context of this PhD work is to give some fundamental grounds to better understand the fatigue properties of these three SXs (CMSX-4 Plus, TMS-238 and TROPEA) and more generally of the SXs. Fatigue is responsible for most of the crack initiation events and failure of internally cooled turbines blades and vanes. The fatigue life durability is thus of great interest. A recent study in the group of J. Cormier performed on nine different SXs has pointed out that the yield strength (YS) is the main parameter controlling the low cycle fatigue. The chemical composition was confirmed to be a crucial parameter controlling directly the YS at 650°C [8]. This effect on the YS and on the hardening behavior was already suggested by Caron in other SXs [9]. In order to validate the major role of the chemical composition, the physical parameters controlling the deformation micromechanisms (i.e. the dislocation mobility, nature of deformation mechanisms, elemental segregation at plasticity defects) need to be identified and quantified.

The aim of this study is thus to concentrate the efforts on the tensile behavior understanding. Tensile tests will be performed at a given temperature (in the range 500 °C – 800 °C) for the three SXs (CMSX-4 Plus, TMS-238 and TROPEA), which differ in chemical composition. The final goal will be to confirm the effect of the chemical composition and to understand how it influences the controlling deformation parameters.

The experimental approach will consist in the realization of the tensile tests at ISAE-ENSMA/Institut Pprime (Poitiers) during the first year. A complete analysis of the microstructure and the deformation micromechanisms will be carried out at CEMES using Transmission Electron Microscopy (conventional TEM, in situ TEM tensile tests, TEM spectroscopies: EELS and EDX), during the next two years. The final goal is to identify and quantify the physical parameters controlling the tensile properties at temperature lower than 800 °C for different SXs.

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Profile:

Education: Master degree in Material Science or in Physics with very good grades.

Competencies: Good knowledge on mechanical properties and/or mechanical properties and/or microstructure, and/or metallic alloys, and/or plasticity.

Language: French or English.

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