Prediction of the recrystallisation defect in Nickel-based single-crystal parts following cooling after a casting operation.

Louis Roche*[1,2], Houssem Badreddine[3], Mylène Leduc[2], Ngadia Taha Niane[2], and Carl Labergere[4]

[1]Laboratoire des Systèmes Mécaniques et d'Ingénierie Simultanée – ICD – LASMIS. Université de Technologie de Troyes – France
[2]Safran Tech PFX – Safran SA – France
[3]Laboratoire des Systèmes Mécaniques et d'Ingénierie Simultanée – ICD – LASMIS. Université de Technologie de Troyes – France
[4]Laboratoire des Systèmes Mécaniques et d'Ingénierie Simultanée – ICD – LASMIS. Université de Technologie de Troyes – France

Abstract

Prediction of the recrystallisation defect in Nickel-based single-crystal parts following cooling after a casting operation.
Keywords: Single crystal Ni-based superalloys, Casting, Recrystallization, Cooling simulation

Background

The lost wax casting process is used to manufacture single-crystal nickel-based parts. During solidification and cooling, this process generates a high level of stress, due to the different coefficients of thermal expansion of the various components (mould, alloy and core). This state of stress can lead to the nucleation and germination of highly misorientated grains, resulting in a significant deterioration in the mechanical properties of the part. This recrystallisation defect therefore leads to the part being systematically scrapped, which is why predicting this potential defect upstream of manufacture is becoming crucial, especially with the arrival of increasingly complex geometries and new generations of alloy, which could tend to favour the appearance of this phenomenon.

Procedure

A methodology was set up to predict the potential areas subject to recrystallisation. To do this, a complete numerical model was developed to simulate the cooling of a single-crystal nickel-based part over a temperature range from 1500◦C to 700◦C. This study presents the general methodology (1), which can be subdivided into 3 major stages. The first one consists of simulating the casting operation in a purely thermal manner on ProCAST. The resolution of the mechanical equilibrium is then decoupled from the resolution of the heat equation.

*Speaker

A spatial and temporal distribution of the temperature at each point of the structure is extracted, serving as input data for the mechanical calculation. The second stage simulates and predicts the mechanical behaviour of the part at the end of the cooling process. A classical behaviour model was developed, taking into account Voce isotropic hardening and a modified Norton-Hoff potential. During solidification, there is a transition between the liquid and solid phases, in which stresses and strains are generated. This phase, which is often neglected due to a lack of information and data, has been considered by introducing the 1st stress invariant in the construction of the equivalent stress, as well as transition function from the work of (2,3). The last stage uses recrystallisation criteria to determine the zones that are potentially sensitive to recrystallisation. Using various tests, Safran has developed recrystallisation charts (4) to establish whether or not recrystallisation is present by means of two physical quantities determined by mechanical calculation: cumulative viscoplastic deformation and viscoplastic dissipation energies. This methodology is applied to an industrial case involving recrystallisation.

Key findings

- Formulation and identification of a macroscopic behaviour model taking into account the liquid-solid transition state
- Good correlation between experimental and numerical results on a cast test piece

References

(1) C. Labergère, M. Long, H. Badreddine, N-T. Niane, D. Grange, K. Saanouni, Thermomechanical model for solidification and cooling simulation of Ni-based superalloy components. International Journal of Solids and Structures 212 (2021). https://doi.org/10.1016/j.ijsolstr.2020.12.009

(2) Cocks, A.C.F., 1989. Inelastic deformation of porous materials. J. Mech. Phys. Solids 37 (6), 693–715.

(3) Galles, D., Beckermann, C., 2016. In situ measurement and prediction of stresses and strains during casting of steel. Metall. Mat. Trans. A 47, 811–829.

(4) M. Long, N. Leriche, H. Badreddine, N-T. Niane, D. Grange, C. Labergère, A new experimental and simulation methodology for prediction of recrystallization in Ni-based. Journal of Materials Processing Tech. 306 (2022). https://doi.org/10.1016/j.jmatprotec.2022.117624