EMMC case study:

Optimisation of manufacturing conditions for gas turbine rotating components

Interview of Dr Christos Argyrakis, Rolls-Royce

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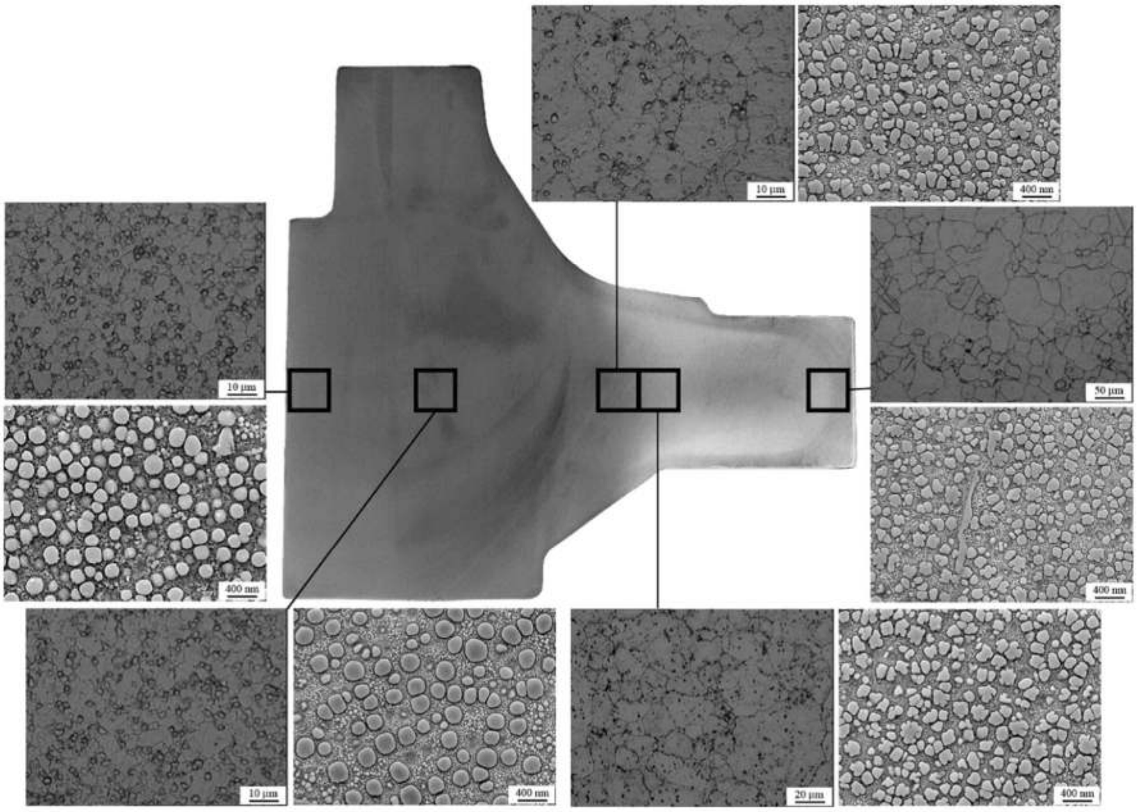


About the Company

Rolls-Royce is a British multinational company which designs, manufactures and distributes power systems for aviation and other industries. The company has 50,000 employees, of which between 100 to 500 work in materials related R&D. Rolls-Royce dedicates up to 20% of their research effort towards developing and applying advanced materials. 40 persons in the company have relevant modelling experience and they typically hold a PhD and enjoy in-house professional development opportunities. According to the Rolls-Royce Holdings plc Annual Report, over £1bn in self-funded R&D was invested in 2017 and a part of it supported the installation of digital engineering tools which lead to their first all-digital engine design. Rolls-Royce have been using materials modelling for 30 years and jobs such as roles for scientific specialists, data scientists, and programmers have been created. Young people find materials modelling an attractive aspect when applying for roles at Rolls-Royce.

About modelling – the nuts and bolts

The modelling team in the UK are familiar with mesoscopic and continuum models and they apply multiscale modelling when looking into the microscale evolution with continuum mechanics models. Rolls-Royce use commercial software, as well as free-ware and in house developed software daily. When doing modelling they aim for always matching the type of modelling to the application/problem at hand. Rolls-Royce have established a wide network of University Technology Centres to facilitate collaborations with academia if they need to improve their expertise in specific topics, would like to explore new ideas/approaches to problems, acquire modelling tools or aim for cost/risk reduction. The company would however not use modelling if the actual experimental testing was quick, accurate and of low cost.

About the Case Study

The case study is based on a project between Rolls-Royce and the University of Birmingham, "The development and application of a mean field precipitation kinetics model to the optimisation of manufacturing conditions for gas turbine rotating components", which was presented at the 1st Annual Thermodynamics of Materials Symposium 2018 (Sheffield, UK).

Ni-based superalloys are the preferred material to manufacture turbine discs for their high temperature strength, microstructural stability and oxidation/corrosion resistance. However, the size, shape and spatial arrangement of precipitates impact mechanical properties, and thus, influence the component performance. Hence, the development of simulation tools was needed that can be used to predict precipitation kinetics in these in Nickel based superalloys as a function of their location. This can assist in the design of heat treatments and for assessing the component performance.

For this particular case, which were your objectives as an industrial consumer of modelling?

The aim was to reduce testing, increase the fidelity of calculations, and better understand the scatter in properties.

How did materials modelling play a key role in problem solving?

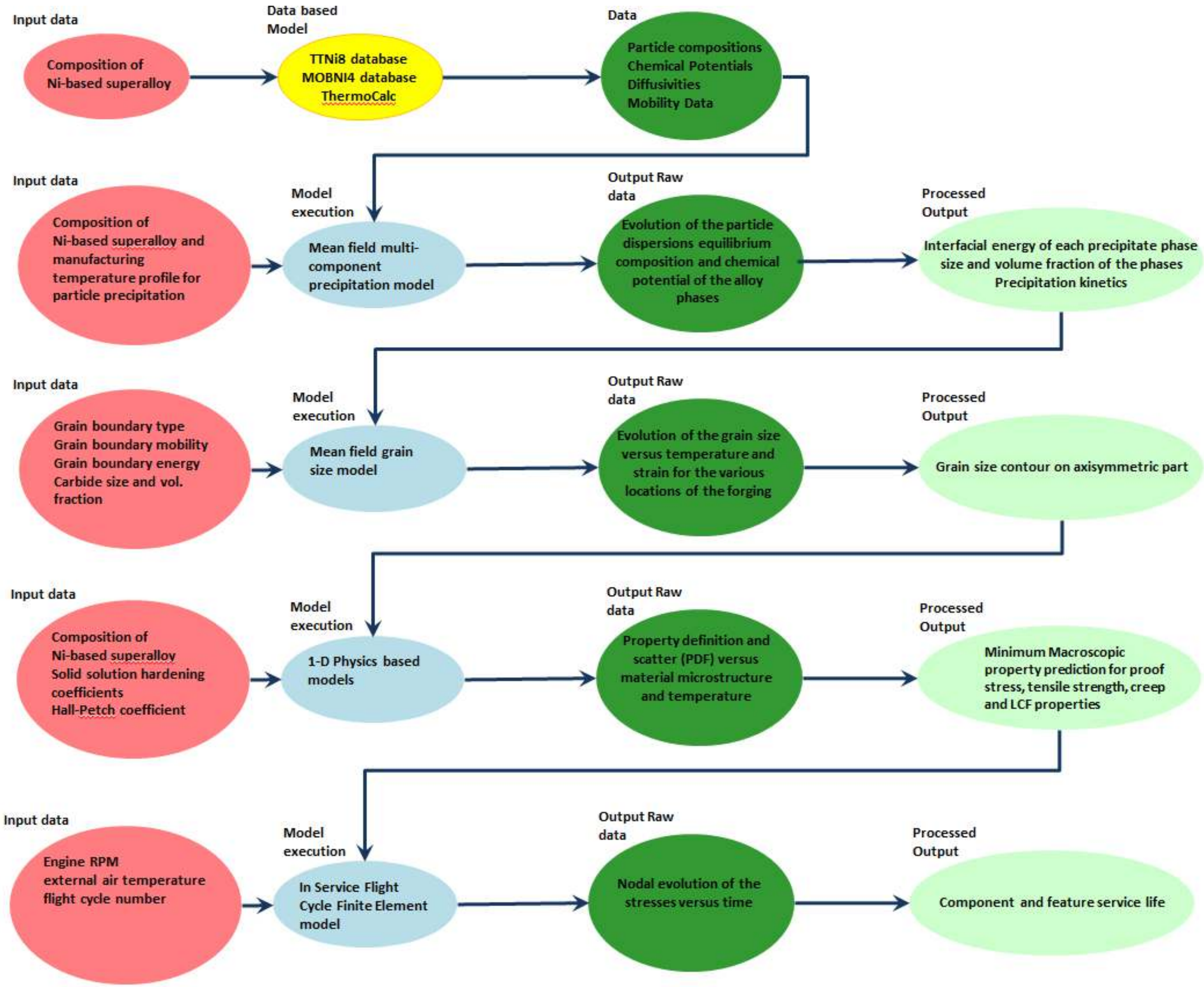
Materials modelling was able to address the above objectives and provided quantitative trends for the manufacturing procedure.

What tools and methodologies have been applied?

The precipitation kinetics mean-field methodology has been published in "Mean-field modelling of the intermetallic precipitate phases during heat treatment and additive manufacture of Inconel 718" M.J. Anderson, C. Panwisawas, Y. Sovani, R.P. Turner, J.W. Brooks, H.C. Basoalto; Acta Materialia 156 (2018) 432-445. (https://doi.org/10.1016/j.actamat.2018.07.002) and "A Multi-Scale Multi-Physics Approach to Modelling of Additive Manufacturing in Nickel-Based Superalloys." C. Panwisawas, Y. Sovani, M. Anderson, R. Turner, N. Palumbo, B. Saunders, I. Choquet, J. Brooks, and H. Basoalto

(2016). In Superalloys 2016 (eds M. Hardy, E. Huron, U. Glatzel, B. Griffin, B. Lewis, C. Rae, V. Seetharaman and S. Tin (doi:10.1002/9781119075646.ch108)

Continuum mean-field models have been developed to simulate the nucleation, growth, coarsening and dissolution of Ni superalloy precipitates during complicated thermal cycles. The models apply a multi-component and multi-phase description of the alloys, utilising a thermodynamic and mobility database to determine chemistries, chemical driving forces and diffusivities.


Input data
Composition of
Ni-based superalloy
Data based
Model
TTNi8 database
MOBNI4 database
ThermoCalc
Data
Particle compositions
Chemical Potentials
Diffusivities
Mobility Data
Input data
Composition of
Ni-based superalloy and
manufacturing
temperature profile for
particle precipitation
Model
execution
Mean field multi-
component
precipitation model
Output Raw
data
Evolution of the particle
dispersions equilibrium
composition and chemical
potential of the alloy
phases
Processed
Output
Interfacial energy of each precipitate phase
size and volume fraction of the phases
Precipitation kinetics
Input data
Grain boundary type
Grain boundary mobility
Grain boundary energy
Carbide size and vol.
fraction
Model
execution
Mean field grain
size model
Output Raw
data
Evolution of the grain size
versus temperature and
strain for the various
locations of the forging
Processed
Output
Grain size contour on axisymmetric part
Input data
Composition of
Ni-based superalloy
Solid solution hardening
coefficients
Hall-Petch coefficient
Model
execution
1-D Physics based
models
Output Raw
data
Property definition and
scatter (PDF) versus
material microstructure
and temperature
Processed
Output
Minimum Macroscopic
property prediction for proof
stress, tensile strength, creep
and LCF properties
Input data
Engine RPM
external air temperature
flight cycle number
Model
execution
In Service Flight
Cycle Finite Element
model
Output Raw
data
Nodal evolution of the
stresses versus time
Processed
Output
Component and feature service life

What were the expected improvements of the material behaviour simulation?

Rolls-Royce were able to predict location specific properties, gain information on scatter thereof, and finally, to perform a more accurate Uncertainty Quantification (UQ).

For this particular case, did modelling affect your value chain?

Their method could generate a digital twin and models how it evolves during disc manufacturing. It led to better understanding of phases in a known Ni superalloy and its formulation could be better understood. This workflow could also be used to screen new materials (new alloy designs) and predict their behaviour during conventional and additive manufacturing.

For this particular case, what was the quantitative value of materials modelling?

Materials modelling saved multiple person time in the region of 6-12 months and a new alloy design was sped up by 5 years. Overall, Rolls-Royce would estimate a financial saving in the order of millions of pounds.

What investments were made during the project?

They had to acquire a thermodynamic database, invest in PhD's and post-doc's time at their University Technology Centres, and engage dedicated materials modelling personnel.

What were the economic benefits/impacts when you did use modelling?

The R&D process had a faster cycle, so Rolls-Royce could reduce testing, perform UQ, and come up with a better digital product definition.

What was the business impact versus previous approach?

Modelling leads to more accurate results as opposed to when Finite Elements Methods are used only with experimental data to solve physics equations in continuum models, and to better understanding of scatter. Thus, Rolls-Royce could design their end product (turbine) using better limits.

Did modelling improve your competitiveness/innovation power?

The research results by Rolls-Royce have been patented, for example: US10138534B2 Nickel-base alloy for gas turbine applications

What sort of obstacles or barriers did you have to overcome to use modelling?

They had to alter their current approach and thinking on materials validation. By using modelling, testing can be reduced dramatically and previous work practices need to be challenged.