E&I Research Studentship project proposal form 2019

Project title: Single crystal mechanics at high temperature: measurement and validation

Supervisory team:
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Project Highlights:

- Novel imaging techniques will be used to characterise the creep behaviour of Ni base single crystals.
- Data will be generated to validate a multiscale material model predicting creep behaviour of materials
- Project outcomes will contribute new material development for high temperature applications

Project Description:

The creep resistance of materials is one of the limiting factors for the development of more efficient turbine engines, such as power generators and aircraft engines. Continuous research is undertaken in alloy development by modifying composition and/or microstructure to improve creep resistance. The Ni-base single crystals, which were developed for use in jet engines, show superior creep resistance over polycrystalline superalloys. It is desirable to develop a material modelling procedure to estimate mechanical properties, including creep resistance, from chemical composition and heat treatment. Initial attempts of predicting creep behaviour use regression analysis or neural networks, but these are not as effective as a physics based material modelling, which requires a better understanding of material behaviour at microstructural scale.

Creep behaviour of single crystals is highly dependent on the interaction of dislocations with microstructural features, such as solute atoms, second phase particles, etc. [1, 2]. This dependence is further complicated by the anisotropy of the single crystals, and hence the modelling of creep resistance requires an accurate prediction of accumulated creep strain in all crystallographic directions with respect to primary loading direction [3]. The experimental verification of current theories of creep behaviour are predominantly performed by the measurement of creep strain in loading direction only. The accumulation of strain in other directions are estimated by crystallographic calculations [3]. Ideally the accumulation of creep strain should be measured in all directions since the estimations based on crystallographic calculations are not reliable as the microstructural variability is not factored in.

The aim of the proposed project involves the use of the full field measurement of long term creep strain developed at Materials Engineering group in The Open University [4] to determine deformation characteristics at high temperature under quasi-static and creep loading conditions (Figure 1). The method will be applied for the systematic study of full field deformation behaviour of single crystals when loaded at various crystallographic directions. As part of the project, in order to simulate materials deformation at microscale, a crystal plasticity finite element method (CPFEM) will be built with the data obtained in the experimental programme as its parameter matrix. This will provide a more reliable creep resistance characterisation of anisotropic materials.

Figure 1: *Creep testing facility at OU*

Research Methods:

Three sets of single crystal test specimens with primary loading directions corresponding to three different crystallographic directions will be machined and tested under quasi-static and creep conditions. Full field deformation behaviour of the specimens will be measured using High Resolution Digital Image

Correlation (HR-DIC). This is a state-of the art strain measurement technique that allows mapping strain distribution at a microstructural scale (Figure 2).

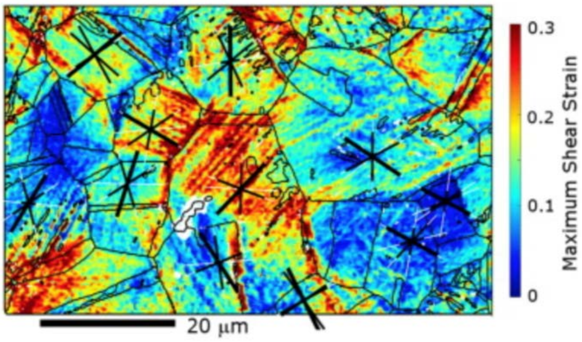

Figure 2: *Strain distribution within crystals as a result of martensitic transformation [5].*

Modelling creep resistance of polycrystalline materials is more challenging because of the interaction of each grain with its neighbours. The experimental method developed for the study of single crystals will be extended to study the interaction of grains in a polycrystalline environment. For this purpose, model materials containing two large grains at various crystallographic directions and relative orientations will be produced and tested at high temperature. The data obtained will be compared to that obtained using a multiscale modelling.

References

[1] Reed, R.C., Tao, T. and Warnken, N. (2009) Alloys-By-Design: Application to nickel-based single crystal superalloys, Acta Mater., v.57, p5898.

[2] Bande G. and Nemes, J.A. (2005) A New Approach for Single Crystal Materials Analysis: Theory and Application to Initial Yielding, J.Eng.Mater.Tech, v.127, p119.

[3] Wen, Z. et al. (2017) Anisotropic creep damage and fracture mechanism of nickel-base single crystal superalloy under multiaxial stress, J. Alloys. Comp., v.692, p301.

[4] Sakanashi, Y., Gungor, S., Forsey, A.N. and Bouchard, P.J. (2017) “Measurement of creep deformation across welds in 316H stainless steel using digital image correlation”, Experimental Mechanics, 57 (2), pp 231–244.

[5] Y. B. Das, A.N. Forsey, T.H. Simm, K.M. Perkins, M.E. Fitzpatrick, S. Gungor, R.J. Moat, In situ observation of strain and phase transformation in plastically deformed 301 austenitic stainless steel, In Materials & Design, Volume 112, 2016, Pages 107-116

Candidate Applications

Students should have a strong background in materials/metallurgy/physics, an interest it state-of-the-art materials characterisation techniques and a willingness to learn basic programming techniques. Experience of research in mechanics of materials is desirable. The student will join a well-established research group at the Open University, with a world class reputation in strain measurement.

Applicant must be willing to travel occasionally to attended international conferences or to use international research facilities when/if required.

Please contact Salih Gungor for further information (Salih.gungor@open.ac.uk)

Applications should include:

- 1000 word cover letter outlining how they are equipped in their educational background and expertise to conduct the research project,
- a CV including contact details of two academic references
- An Open University application form, downloadable from: http://www.open.ac.uk/postgraduate/research-degrees/how-to-apply/mphil-and-phd-application-process (Note: This is an Advertised studentship and you do not need to submit a proposal).
- IELTs English Language test scores on application. An average of 6.5 and no less than 6 in anyone of the four components. Applicant should have these results when applying.

Applications should be sent to STEM-EI-Research@open.ac.uk by 28 February 2019