# Engineering and Innovation Research Studentship 2023/2024

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| **Project title:** | **A New Approach for Mapping of Residual Stress in Complex Structures** |
| **Discipline** | Mechanical Engineering, Materials Engineering, Physics |
| **Key words:** | Residual stress, Contour method, Grain scale stresses |
| **Supervisory team:** | Foroogh Hosseinzadeh, Ho Kyeom Kim |
| **URL for lead supervisor's OU profile** | http://stem.open.ac.uk/people/fht7 |

## Project Highlights:

- Advancing the Eigenstrain Reconstruction Method for 2D characterisation of multiple stress components in complex structures;
- Developing an uncertainly evaluation tool for the 2D Eigenstrain Reconstruction Method;
- Project outputs will be influential in improving structural integrity assessment method of safety critical components.

## Overview:

The manufacturing processes used to make high performance parts for high integrity structures for nuclear power systems inherently introduce locked-in residual stresses at both the macro-scale and micro-scale. These stresses can cause distortion and cracking, induce damage, influence function, and potentially reduce a product's lifetime through premature failure. In particular surface machining and modification operations invariably introduce near-to-surface residual stresses that often have high gradients. Surface machining also plastically deforms material close to the surface which can result in excessive work hardening and/or local phase transformation effects.

It is well known that the condition of material close to the surface of a component, and the associated local residual stress field, can affect both low and high cycle fatigue crack initiation life of engineering components as well as increasing susceptibility of nuclear materials to initiation of stress corrosion cracking. Indeed surface and bulk treatments are frequently used to modify the residual stress distribution and thereby improve the functional performance of critical components. However, there remains concern as to whether the residual stresses interact with in-service duty loadings to such an extent that the lifetime and integrity of the component is jeopardised.

Thus, there is a driver for modelling manufacturing and surface treatment processes to predict the surface state of material including the residual stress field.

Prediction of residual stresses requires sophisticated and time-consuming computer modelling, extensive and expensive characterisation of material properties and the use of appropriate validation procedures. The reliability of such predictions depends on the expertise of the modeller and quality of the input data.

Experimental characterisation of residual stresses often requires multiple measurement techniques to unlock useful information. In addition, most measurement techniques are limited to pointwise determination of residual stress hence providing incomplete characterisation of the stress state in the manufactured part.

One approach to overcome the inadequacy of measurement techniques is to implement reconstruction methods. These methods are based on utilising limited measurement data to reconstruct the complete residual stress field that are compatible with both measurements and elasticity theory [1-3]. A variant of the reconstruction method known as Eigenstrain Reconstruction Method has been proved to be a powerful technique applied to a number of manufacturing processes such as shot peening, laser forming and welding. The method is developed further to complex geometries relevant to engineering components [2]. The first step in implementing this technique is to determine the source of eigenstrain distribution. Eigenstrains represent incompatible strains within a body produced via inelastic processes often during manufacturing and give rise to generating residual stress state in the body. This can be obtained from experimental results for residual elastic lattice strains measured by diffraction techniques or data obtained for change in strain or displacement during material removal for example via implementing hole drilling, slitting or the contour method. The residual stresses can be reconstructed by introducing the eigenstrain distribution in a linear elastic finite element (FE) model of the part. Once the eigenstrain distribution has been determined, the entire full-field residual stress state can be found at every point within the structure. One important aspect of implementing the ERM is to consider dimensionality of different stages of the analysis; that is dimensionality of the FE model, non-zero eigenstrain components and the eigenstrain variation directions. Ideally, a choice of 3D for the different stages of the analysis is desirable to represent a reconstruction of multi-axial residual stress distribution variation in real engineering structures. The ERM methodology however has been focused on 1-dimensional eigenstrain spatial variation (representing a line plot). In addition, there is lack of uncertainty evaluation for the results generated using the ERM and hence its use in structural integrity assessment of safety-critical components has not been adopted.

The research question to address is whether the dimensionality of the ERM approach could be advanced to provide 2D maps of multiple components of the stress tensor.

## Aim and objectives:

The main aim of the proposed project is to advance the Eigenstrain Reconstruction Method to provide 2D maps of multiple components of the stress tensor.

Specific PhD research objectives include:

- To Develop the most suitable eigenstrain analysis that can deal with 2D sample geometry, 2D eigenstrain components and 2D eigenstrain distribution.
- To perform a sensitivity analysis to determine the amount of experimental data required for the proposed 2D ERM approach.
- To develop an uncertainty evaluation tool for the outputs of the 2D ERM approach.
- To validate the developed method using other techniques for example, neutron or synchrotron diffraction and the contour method.

## References & Further reading:

[1] Faghidina, S.A., et al., Measurement, Analysis and Reconstruction of Residual Stress, Strain Anal. Eng. Des., 2012, vol. 47, no. 4, pp. 254–264.

[2] Jun, S., Korunsky, A., Evaluation of Residual Stresses and Strains using the Eigenstrain Reconstruction Method, 2010, 47, 1678-1686.

[3] Salvati, E., Korunsky, A., A simplified FEM eigenstrain residual stress reconstruction for surface treatments in arbitrary 3D geometries, International Journal of Mechanical Sciences, 2018, 138-139, 457-466.

## Further details:

Students should have a strong background in Solid Mechanics, Materials Engineering, Mechanical Engineering or physics and enthusiasm for laboratory experimental work and have experience of finite element modelling and programming in Matlab, Python or similar platform.

Please contact Dr Forooh Hosseinzadeh (foroogh.hosseinzadeh@open.ac.uk) for further information.

Applications should include:

- A 1000 word cover letter outlining why the project is of interest to you and how your skills match those required
- an academic CV containing contact details of three 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
- IELTS test scores where English is an additional language

Applications should be sent to **STEM-EI-PhD@open.ac.uk by 15.02.2023**