Methodology for the Automated Spatial Mapping of Heterogeneous Elastoplastic Properties of Welded Joints

R. Hamill[1a], A. Marek[1], A. Harte[2] and F. Pierron[1]

[1]Faculty of Engineering and Physical Sciences, University of Southampton, UK, [2] UKAEA, Culham Science Centre, Oxfordshire, UK

[a]r.hamill@soton.ac.uk

Abstract. A methodology to map the heterogeneous elastoplastic mechanical properties of welded joint geometries is presented. The approach and results of the proposed methodology will be demonstrated using numerical data representing an off-axis butt-weld. This work extends the Virtual Fields Method (VFM) by introducing automated spatial parameterisation of the constitutive parameters. This extension enables the novel characterisation of welds with more tests to be performed.

Introduction

Inverse identification methods have been previously developed to take advantage of the rich data provided through full-field measurements. The VFM is one such method which uses full-field strain measurements to determine constitutive parameters, and benefits from computational efficiency compared to other methods as no resolution of the direct problem is required [1,2]. The VFM has previously been used to determine the constitutive parameters of welded joints with simple butt-joint geometry, however existing work requires *a priori* spatial parameterisation of constitutive parameters [3,4]. Automated spatial parameterisation removes the necessity of *a priori* knowledge, hence enabling more complex geometries and loading conditions to be characterised.

Methods

Fig. 1 shows the data generation and identification toolchain which has been developed to verify the proposed approach. Finite Element (FE) analysis is used to generate deformation data for a specified geometry and boundary conditions. The FE deformation data is then embedded into a set of synthetic images through the process of numerical image deformation. This process deforms a selected reference image (of user-defined speckle pattern) using FE deformation data. The resultant images are the synthetic equivalent of those obtained experimentally using optical measurements, however the kinematic fields they encode are known and controlled. Digital Image Correlation (DIC) can then be used to obtain strain fields for each load step from the set of deformed images. Finally, an algorithm based on the VFM is used to perform the parameterisation and identification of constitutive parameters. This toolchain allows the errors introduced at each stage to be investigated, and a direct comparison of the defined and identified parameter maps.

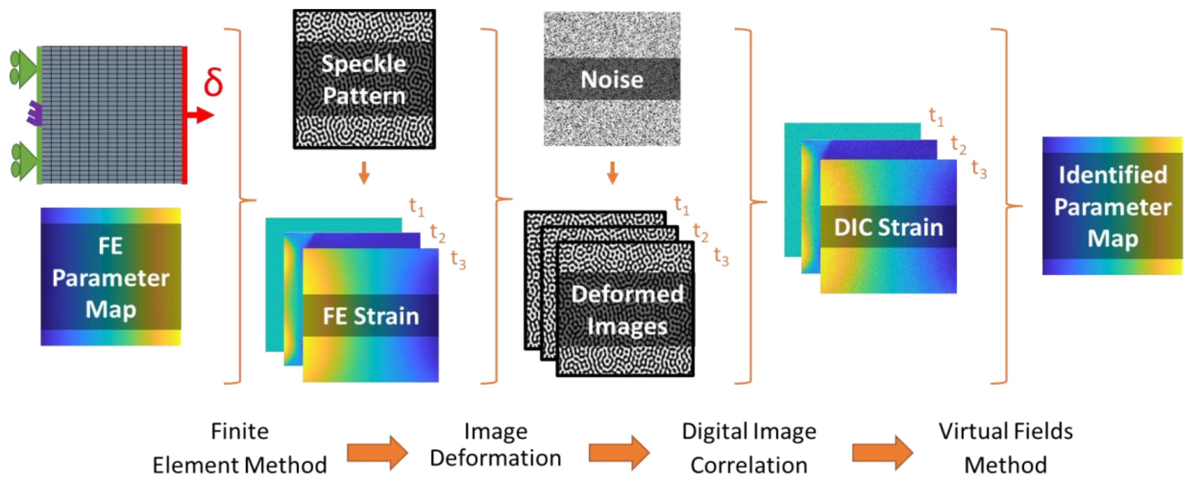

Figure 1. Toolchain showing numerical data generation

Fig 2. shows the core components of the VFM enclosed in the dashed box. The measured strains are used in conjunction with an initial guess of the constitutive parameter map to reconstruct stress. The principle of virtual work is then used to check if the stress field satisfies global equilibrium. The parameter map is iterated until global equilibrium is satisfied, at which point the parameter map is said to be identified.

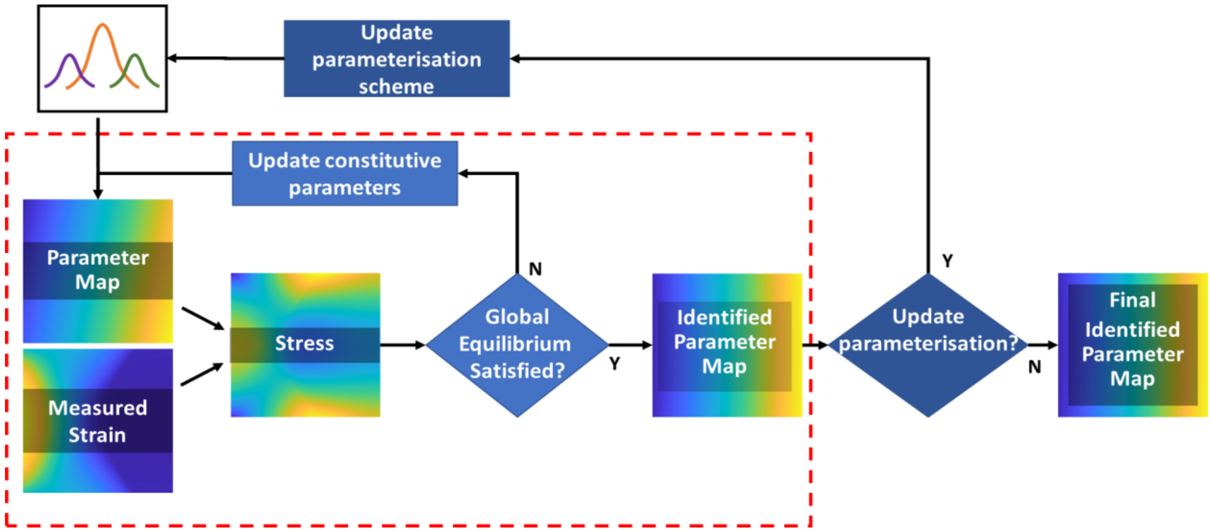

Figure 2. The Virtual Fields Method with automated parameterisation

When identifying heterogeneous properties, parameterisation is required to assign a value of the constitutive parameters to each datapoint. In this work, a combination of discrete and continuous parameterisation is used to keep the number of degrees of freedom to a computationally efficient level. Initially, a coarse finite element mesh is used to determine an approximate map of the target parameter. This initial identified result is used to discretise the specimen geometry into homogeneous and heterogeneous regions. A secondary parameterisation is then performed for which the homogeneous regions have a single degree of freedom each, whilst the heterogeneous regions are parameterised using radial basis function (RBF) interpolation. Throughout each stage of identification, a variety of virtual fields are used to construct cost functions to assess stress equilibrium across different length-scales. The 'equilibrium gap indicator' and 'force reconstruction error' virtual fields are used to assess and update the parameterisation scheme. Sensitivity-based virtual fields are also used to fine-tune the identification for noisy data.

Discussion

This methodology shows promise in its ability to characterise the heterogeneous elastoplastic properties of various welded joint configurations. Fig 3. shows an example target map of yield strength (left) next to the resulting identified map (right). In this case, no image deformation was performed, however, investigation into the method's robustness to noise is ongoing.

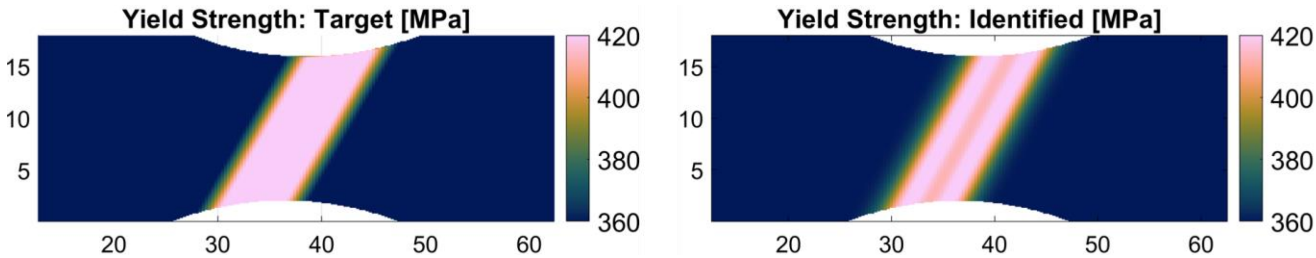

Figure 3. Target map of yield strength (Left). Identified map of yield strength (right).

References

[1] F. Pierron and M. Grédiac, The Virtual Fields Method, Springer, 2012.

[2] J. Martins, A. Andrade-Campos, and S. Thuillier, "Comparison of inverse identification strategies for constitutive mechanical models using full-field measurements," International Journal of Mechanical Sciences, vol. 145, pp. 330–345, 2018.

[3] M. A. Sutton, J. H. Yan, S. Avril, F. Pierron, and S. M. Adeeb, "Identification of heterogeneous constitutive parameters in a welded specimen: Uniform stress and virtual fields methods for material property estimation," Experimental Mechanics, vol. 48, no. 4, pp. 451–464, 2008.

[4] G. L. Louedec, F. Pierron, M. A. Sutton, and A. P. Reynolds, "Identification of the local elasto-plastic behavior of FSW welds using the virtual fields method," Experimental Mechanics, vol. 53, no. 5, pp. 849–859, 2013.