8th. World Congress on Computational Mechanics (WCCM8)
5th. European Congress on Computational Methods in Applied Sciences and Engineering (ECCOMAS 2008)
June 30 – July 5, 2008
Venice, Italy

AN INTERGRATED EXPERIMENTAL-NUMERICAL METHOD APPLIED TO THERMO-MECHANICAL CHARACTERISATION OF STEEL AT HIGH STRAIN RATES

***Ben Elliott[1], Stefan Schwindt[1], Clive Siviour[1] and Nik Petrinic[1]**

[1] Impact Engineering Team,
Solid Mechanics and Materials Engineering Group,
Department of Engineering Science
Parks Road, Oxford, OX1 3PJ, UK
http://www.eng.ox.ac.uk/solidmech

Ben.Elliott@eng.ox.ac.uk
Stefan.Schwindt@eng.ox.ac.uk
Clive.Siviour@eng.ox.ac.uk
Nik.Petrinic@eng.ox.ac.uk

Key Words: *FE Modeling, Inverse Modelling, High Strain Rate Characterisation, Hopkinson Bar, Ballistic Impact.*

ABSTRACT

There is a strong industrial and scientific push for increasing the use of combined experimental-numerical material characterisation programmes to calibrate, validate, improve and compare numerical models for real industrial situations. The full cycle could involve: experimental determination of physical material behaviour; development of an appropriate material model; calibration of model parameters against bespoke characterisation experiments; predictive modelling of validation experiments; comparison of prediction against further experimental results; and updating of material model (*not* material parameters) where required to better represent the physical system.

Two important steps in this routine are to calibrate the model (that is, to find the material parameters) and to identify which of its features are responsible for observed weaknesses in predictive capability. This is complicated when model parameters do not have a direct manifestation in the phenomenological material behaviour or are not separable experimentally. In these cases, inverse modelling [1,2] may be used as a robust, objective method for linking observed behaviour to model parameters.

This paper will describe characterisation of a steel for high temperature applications in aeroengines and subsequent assessment of the selected material model. The material was characterised using experimental data obtained using small specimen tests. A modified version of the Bammann Damage material model [3] was calibrated using an inverse method and validated against plate impact experiments. This approach has also been successfully applied to titanium alloys [4].

The calibration experiments consisted of uniaxial tensile specimen tests between room temperature and 700°C, and at strain rates of between $1e^{-4}$ and $1e^{3}$ s^{-1}. The tests at quasi-static rate were undertaken on a screw-driven Hounsfield tensometer, those at medium strain rate using an in-house hydraulic device and those at high strain rates

using a split-Hopkinson-bar. Heating was achieved using a high-speed induction heating coil.

Stress-strain curves are not evaluated directly in order to avoid a number of unrealistic assumptions, including mechanical equilibrium, thermal homogeneity, deformation of specimen shoulders, geometrical uniformity approaching failure and the absence of heat generation due to plastic work. Furthermore, it is clear that the various regions of the specimen will experience different strain rates, final strains and temperature histories, whilst the stress-strain analysis gives only an average curve. Instead, the specimens are modelled fully using an in-house finite element code, *DEST*.

In the model identification step, the material parameters are optimised such that the numerical simulations of all the calibration tests match the experimental results as closely as possible. The inverse problem thus formed is solved iteratively, due to its ill-posed nature, which arises from non-linearity and non-uniqueness in the material model and evolving geometry. The key steps in the inverse model are: to define a good objective function that accurately reflects both the quality of available experimental data and the importance of different parameters to the end user's application; to solve the forward problem accurately and appropriately; and to have a robust automated scheme for optimising material parameters efficiently whilst avoiding local minima in the objective function.

The predictive accuracy obtainable in realistic situations using this model and parameters is assessed by comparing a multi-stress state validation experiment to a corresponding finite element model. The validation experiment was designed so that the boundary conditions were simple and accurately measurable but the material response generated was representative of practical problems. The experiments involved firing a 1 inch steel ball-bearing at velocities up to 150 m/s at steel plates heated to temperatures up to 700°C, which were filmed at 11,000 fps with a high-speed camera. Large amounts of plastic deformation were generated around the impact site and the supports, in some cases leading to failure. Good agreement was found between the model and experiment, thus suggesting that confidence can be placed in results obtained when this material model and parameters are used to solve industrial problems.

REFERENCES

[1] Elliott, B., "Inverse Identification of Constitutive Parameters for Simulation of Impact on Rate-Dependent Media" D.Phil. Thesis, University of Oxford, 2007.

[2] Mahnken, R. and Stein, E., "Concepts and Computational Methods for Parameter Identification of Inelastic Material Models" in editors, Computational Plasticity, 1997 (D. R. J. Owen, P. Oñate and E. Hinton, eds.) proceedings for COMPLAS 5, Barcelona, Spain.

[3] Bammann, D. J. et al., "Failure in ductile materials using finite element methods" in Structural Crashworthiness and Failure, 1993 (J. Norman and W. Tomasz, eds.), Elsevier Applied Science, London.

[4] Petrinic, N. et al., "On competing volumetric and deviatoric damage mechanisms in simulation of ductile fracture in Ti64 alloy at high rates of strain" in Proceedings of EMMC-10 Conference, pp. 467-478, Kazimierz Dolny, Poland, June 2007.