Optimization of an image-based experimental setup for the dynamic behaviour characterization of materials

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Abstract The present work aims at identifying an elastic-viscoplastic material constitutive model over a wide strain and strain-rate range (up to 0.1 and $1000\,\mathrm{s}^{-1}$ respectively), using the so-called Virtual Fields Method. To define the experimental campaign, a design process has been set. It relies on the numerical optimization of the setup – notably the specimen shape, the impact conditions and the measurement resolution (time and space) – with respects to user-defined criteria. Finally, the selected configuration ensures an accurate and robust identification.

Keywords Virtual Fields Method · Impact · Optimization · Viscoplasticity · Johnson-Cook

28.1 Introduction

As optical devices are continuously being improved (notably in terms of spatial/temporal resolution and interframe rate), their combination with a full-field measurement technique is more and more suitable for high strain-rate testing. Among the available inverse methods, the Dynamic Virtual Fields Method (DVFM) enables the identification of material parameters with the sole knowledge of the strain and the acceleration fields (Eq. 28.1). In particular, the DVFM does not require the knowledge of any external loads, thus avoiding the use of an intrusive sensor (e.g. load cell).

$$\underbrace{-\int_V \boldsymbol{\sigma} : \boldsymbol{\varepsilon}^* \, dV}_{W^*_{int}} = \underbrace{\int_V \rho \boldsymbol{\gamma}.\mathbf{u}^* \, dV}_{W^*_{acc}} \tag{28.1}$$

Inertial impact tests have been recently proposed to take advantage of the DVFM for material behaviour characterization under high strain rate [1]. However, the application has not concerned up to now rate-dependent material behaviour. As the latter are generally more complex and therefore requires several tests to proceed, it is necessary to explore extensively the design space of the testing procedures to improve the identification process, in particular with a reduced number of optimized tests with an efficient exploitation of the available data.

The present work aims at optimizing the aforementioned impact test to characterize the rate-dependent hardening law of a metallic material over a wide strain and strain-rate range, using the Johnson-Cook model [2] at room temperature (Eq. 28.2). Two criteria govern the selection of an optimized test configuration: (1) – the strain and the strain-rate range (2) – the identifiability of the parameters.

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$$\sigma_y = \left[\sigma_0 + K p^n\right]\left[1 + M \ln\left(\frac{\dot{p}}{\dot{\varepsilon}_{eq,0}}\right)\right] \tag{28.2}$$

28.2 Optimization of a Test Configuration

In this work, Finite Element Analysis (FEA) is used as a basis to assess the two selected criteria. Contrary to an approach with real tests, the numerical models enable to analyze of the test parameters influence by an iterative procedure. Thus, the viscoplastic spectrum (cumulated plastic strain, p, vs. equivalent plastic strain rate, $\dot{p}$) is plotted in a bidimensionnal histogram (Fig. 28.1) to analyze its expansion.

To take experimental biases (full-field measurement features, digitization process, camera noise, dynamic range,. . .) into account in the identification toolchain, virtual images are generated using a new gradient-based algorithm. This has already been addressed for other cases under quasi-static [3] and dynamic [4] loading but the proposed methods suffered from critical drawbacks – as the overlooking of the camera fill factor for instance – which could have jeopardized their application in ultra high-speed imaging. Finally, the simulated images are input in the DVFM toolchain by processing them with the grid method. The latter has been recently defined as a good compromise for full-field measurements with a low-resolution camera [5].

This enhancement process notably relies on the topological optimization of the specimen inner geometry. For given impact conditions, it has to promote the development of viscoplasticity over the whole targeted spectrum. To do so, geometric singularities (e.g. holes, notches) with various parameters (e.g. position, diameter, spacing,. . .) are manufactured at different locations in the specimen to enhance stress concentrations. However, this shrinking process may jeopardize the identification insofar as it decreases the specimen surface area for a given field-of-view. To restrict the optimization problem, the specimen inner geometry is driven by an evolution law for the geometric singularities. Figure 28.2 shows an example of a strain field extracted with the grid method. As a starting geometry, a circular hole was considered in the vicinity of the impact zone. Whereas the accumulation of geometric singularities may jeopardize the identification, it also strengthens the stress concentrations owing to a wider viscoplastic spectrum.

28.3 Conclusion

In this study, new tests configurations were introduced to characterize viscoplastic behaviours at high strain rate. This was based on the Dynamic Virtual Fields Method (DFVM) which is input with full-field kinematic maps (strains and

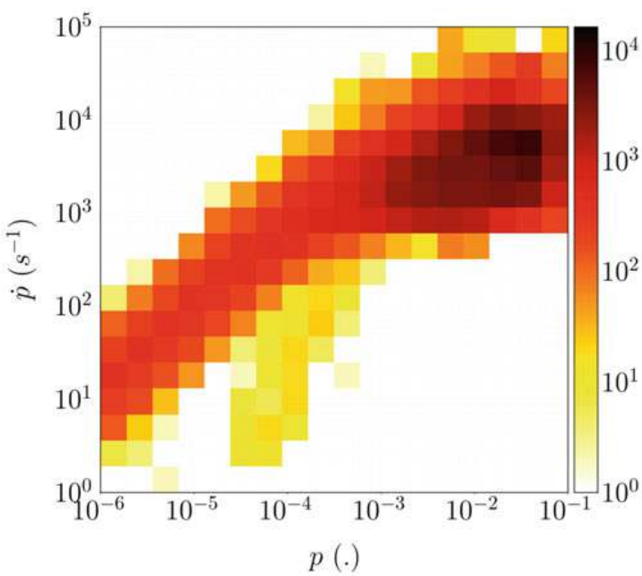

Fig. 28.1 Example of a viscoplasticity histogram

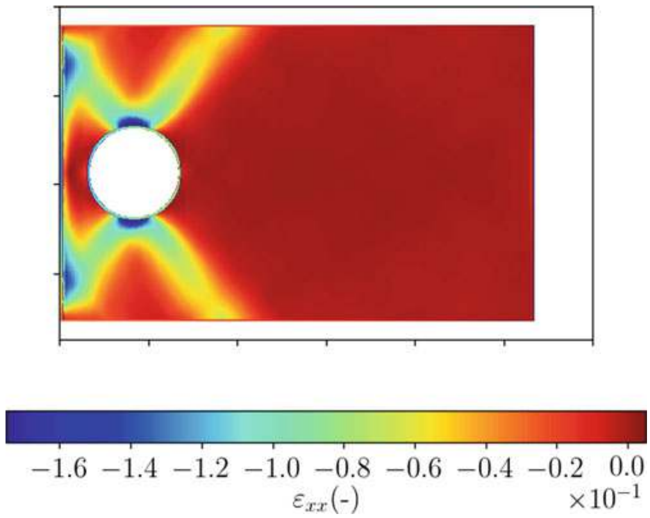

Fig. 28.2 Longitudinal strain extracted from simulated images with the grid method

accelerations) to extract the material parameters. As no standards have been defined, a fully computational approach was addressed to improve the test features. The final configuration ensured a robust and stable identification of the Johnson-Cook flow rule parameters.

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