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Reduced Shape-space Approach to Material Characterization Instrumented Indentation Test Case

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This work lies at the intersection of three disciplines: numerical methods, experimental techniques, and machine learning. The primary aim of this work is to develop a group of algorithms for characterization by inverse analysis of a material's constitutive law.

In the field of material characterization, indentation test is especially attractive since it is considered non-destructive. The test, similar to a hardness test, consists in penetrating an indenter into the surface of the material. The force exerted on the indenter is recorded against the penetration depth over a series of time instants, leading to a force-displacement (P-h) curve, which is the most frequently used source of information for the identification of material properties. However, the inverse problem based solely on this curve tends to be ill-posed, leading to non-unique identification solution, i.e., the "mystical material pair", for whom the corresponding force-displacement curves are almost identical despite the very different material properties.

The basic idea is then to complete the identification process with innovative experimental measurements, such as the laser microscope, which allows measuring the 3D residual imprint after the withdrawal of the indenter. To address the advantage of this measured over P-h curve, we propose to construct, within a reduced affine space, a manifold of shapes admissible to the postulated constitutive law, experimental and simulation setups, based on synthetic data. The intrinsic dimensionality of the manifold limits the number of identifiable parameters allowing to validate numerically experimental procedures.

Considering both the model and measurement errors, we develop a series of local manifold learning algorithms to solve the inverse problem iteratively for experimental results obtained in cooperation with INSA de Rennes. This approach allows us to characterize diverse metallic materials of increasing complexity, based on actual experimental measurements. For example, for the Hollomon's law, the mystical pair is alleviated in using a single imprint, while for the Voce law, a multi-depth experimental protocol is proposed to differentiate mystical siblings.

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