360-deg full-field measurement of steel specimens under combined tension/torsion loads

M. Rossi[1a], K. Genovese[2], L. Cortese[3], D. Amodio[1]

[1]Università Politecnica delle Marche, via brecce bianche, 60131 Ancona, Italy, [2] Università degli Studi della Basilicata, viale dell'Ateneo Lucano 10, 85100 Potenza, Italy, [3]Faculty of Science and Technology, Free University of Bozen-Bolzano, Piazza Università 5, 39100 Bolzano, Italy

[a]m.rossi@univpm.it

Abstract. In this work we present a system to perform full-field measurement over the 360 degrees surface of a round specimen during combined tension-torsion tests. Measurements are performed by a camera mounted on a slewing ring bearing that allows to cover the whole surface of the specimen. First, a set of calibration tests is performed to evaluate the metrological performances of the equipment. Afterwards, the system is used to track the deformation of steel specimens under severe plastic deformation until final fracture. Experimental results are compared with those obtained from numerical models of the test, calibrated by a global FEMU approach, in order to assess the feasibility of employing the proposed technique for material characterization.

Introduction

Nowadays, full-field measurement of shape, displacement, and deformation are widespread in many engineering applications, thanks to the advances in techniques and equipment. The use of digital image correlation (DIC [1]), in particular, is becoming increasingly popular and several commercial and academic software are available for both 2D and 3D measurement.

Material testing is one field where such technique can be conveniently used to gather additional local information from experiments. Indeed, most of the standard tests are characterized by simple states of stress, e.g. uniaxial tension, simple shear, usually because of limitations of what can be measured through traditional sensors. On the contrary, the use of full-field measurement allows to exploit also tests on specimens with complex shapes, under complex loading conditions that yield to heterogeneous stress and strain fields. In this way, a lot of information on the mechanical behaviour of materials can be collected from a single test. A typical example of this approach is the virtual fields method (VFM [2]), where the strain field measured during the test is directly used to identify the mechanical properties of materials. Full-field measurement can also be used in conjunction with finite element model updating (FEMU); in this case the strain or displacement maps measured by the experiments are compared with the counterpart obtained from the numerical model [3].

The challenge here is to measure the entire shape and deformation field of a specimen over 360 degrees during a mechanical test. Similar measurement have been already performed for biological applications [4]. However, the 360-deg capability is also valuable to explore the mechanical behaviour of metals in the large strain range, for instance, to study the occurrence of necking [5], or the effect of anisotropy, or fracture initiation.

To this aim, in this paper an experimental system using a camera mounted on a slewing ring bearing is designed, calibrated and applied to the full-field measurement over 360-deg during quasi-static tensile/torsion tests on round steel specimens.

Experiments

A single camera is here used to measure the displacement field over the full 360-deg surface of the specimen thanks to the use of an aluminium round bearing. A scheme of the measurement system is reported in Fig. 1a. System benchmarking is performed on calibration targets following well-established test protocols typical of Computer Vision and DIC. From these preliminary tests, metrological performances of the system are evaluated; additionally an automatic procedure for merging the different views of the cameras is developed and tested.

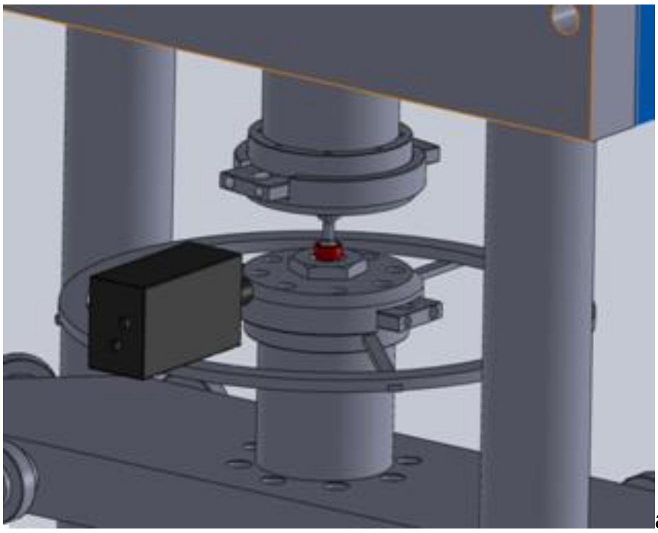
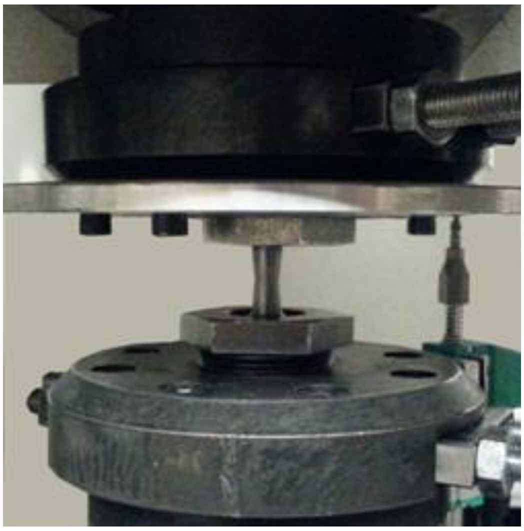

a)

b)

Fig 1: Scheme of the 360-deg measurement system (a) and testing machine used to perform tensile/torsion tests (b).

After calibration, the system is used along with a tension-torsion machine, illustrated in Fig. 2b. The machine allows to apply, independently, both tensile and torsion loads, on cylindrical, hollow and full specimens. A series of tests is here performed on steel samples. Three types of load are applied: simple tension, simple torsion and combined tension-torsion. The investigated materials are steel grades for pipeline applications [6]. The developed system aimed to measuring specimen shape and deformation evolution due to the induced severe plastic deformation.

Comparison with FE models

A comparison of the experimental results with FE models of the tests is performed. In the numerical models, a plasticity model using a specific function that keeps into account the Lode angle dependency is used as constitutive law, to properly describe the elasto-plastic behaviour [6-7], particularly at large strain. The parameters of the constitutive model are first calibrated by FEMU from the global behaviour of the test, i.e. force vs load and torsion moment vs rotation angle. No information is given about the local deformation field. A minimization algorithm varies the parameters, in order to find out the best fit between numerical and experimental curves.
The shape and deformation of the specimen obtained with the numerical models are then compared with the experimental counterparts, in order to assess the effectiveness of the FEMU approach.
In future work, the full-field information can be included in the minimization procedure in order to improve the material characterization. Moreover, the shape and the deformation field can be used to infer the volume displacement of the specimen (as done for instance in [8]), and other identification methods such as VFM on volume data [5] could be used to identify the parameters.

Conclusion

This paper presents an experimental protocol to measure shape and strain field evolution of specimens that undergo severe deformation. The measurement over the full 360-deg is obtained using a single camera mounted on a slewing ring bearing. Experimental results are compared with those obtained from FE models calibrated with a FEMU approach, based on global variables (force/torque vs. displacement/rotation). The comparison allows to validate the accuracy of the FEMU identification and evaluate whether the proposed measurement technique could be used to verify and improve the characterization of plasticity models in metals.

References

[1] M. Sutton, J.-J- Orteu, H.W. Schreier: *Image correlation for shape, motion and deformation measurements,* edited by Springer, New York (2009).
[2] F. Pierron, M. Grédiac: *The Virtual Fields Method*, edited by Springer, New York (2012).
[3] M. Grédiac, F. Hild: *Full-field measurements and Identification in Solids Mechanics*, edited by Wiley (2012).
[4] K. Genovese, L. Casaletto, J. Humphrey, J. Lu (2014). Proc. R. Soc. A, 470: 20140152.
[5] M. Rossi, F. Pierron: Comp. Mech. Vol. 49 (2012), p. 53-71
[6] L. Cortese, T. Coppola, F. Campanelli, F. Campana, M. Sasso: Int. J. Damage Mech. Vol 23 (2014), p. 104-123
[7] L. Cortese, T. Coppola, G.B. Broggiato, F. Campanelli, Proceedings of the Soc.for Exp. Mech. Series (2014), p. 287-294
[8] M. Rossi, F. Pierron: Key Engineering Materials. Vol. 504.506 (2012), p. 703-708