



Preface – Virtual Special Issue on nanomechanical testing in materials research and development



It is our pleasure to present this virtual special issue (VSI) on nanomechanical testing that is built up from contributions made to the 2019 Nanomechanical Testing in Materials Research and Development VII meeting in Malaga, Spain (https://dc.engconfintl.org/nanochemtest_vii/, Fig. 1). In the meeting, more than 160 delegates from 20 different countries across Europe, America and Asia had the opportunity to report on and learn about the advances in the field of nanomechanical testing through 62 oral presentations and 81 poster contributions. The event helped foster scientific discussion and exchange of ideas through numerous networking activities, and was supported by the active participation and sponsorship of a large number of companies that presented their latest developments in the field, including Alemnis AG, Bruker, FemtoTools AG, Fisher Instruments S.A.U., KLA Corporation, Micromaterials, NanoMEGAS SPRL, Synton_MDP Inc., Surface, Tescan and ZwickRoell GmbH.

Since the development of the instrumented nanoindentation technique, micro- and nano-mechanical testing has become an important research field providing new insights into the deformation behaviour of materials. There has been a rapid expansion of available testing strategies in recent years to examine elastic, plastic, fracture and fatigue properties at small scales, with control of the loading mode, temperature and environment. Reflecting the popular saying “*seeing is believing*”, recent years have witnessed an enormous effort to combine these techniques with high-resolution imaging and spectroscopy in real time, which has led to cutting-edge *in situ* and *operando* testing strategies that contributed to establishing new theories of the small scale deformation of materials. Last but not least, interdisciplinary approaches combining small-scale mechanical testing with data-driven mechanics, advanced multi-scale modelling and artificial intelligence algorithms are becoming more and more widespread, serving to connect observations across multiple length scales and/or facilitate the analysis of large volumes of data.

All these areas are covered in the articles collected in the current Virtual Special Issue, including the latest developments in the application of micromechanical testing to determine fracture [1,2] and fatigue properties [3] at the micrometre scale, as well as their *operando* use to extract relevant information under service conditions, such as elevated temperature [4–6], high strain rates [7–9], and hydrogen embrittlement conditions [10]. Further refinements in testing protocols are reported, e.g. the advancements in the continuous stiffness measurement (CSM) methods [11,12], as well as better strategies to determine the strain rate sensitivity of materials [13]. Other contributions include the application of nanomechanical testing techniques for improving our understanding of the process-structure-property relationships in thin films

and nanostructured materials [14–16], ceramics [17,18] and metallic alloys, including high entropy alloys [19,20], refractory metals [21], light alloys [22], shape-memory alloys [23] and steels [24,25]. Another area of increasing interest is the use of nanomechanical testing techniques as a high-throughput methodology to produce material property libraries from specimens produced by combinatorial synthesis, so that a vast range of compositions can be tested in a single specimen. Good examples of this strategy found in this VSI include, for instance, binary metallic alloys [26] and thin films [27]. Finally, as testing instruments and protocols become faster, larger and more statistically representative volumes of data can be generated, e.g. by sampling mechanical properties over large areas. More efficient, faster and better automated data processing strategies are needed, such as those based on artificial intelligence algorithms, with a few examples found in this collection [28–30].

The Nanomechanical Testing conference series begun in 2005 with the first meeting in Crete, Greece, and continued in 2009 in Barga, Italy; 2011 at Canary Islands, Spain; 2013 and 2015 in Olhao and Albufeira, Portugal, respectively; and 2017 in Dubrovnik, Croatia. The Editors express their gratitude to the Steering Committee members: G. Pharr, Texas A&M, USA; M. Göken, FAU Erlangen-Nürnberg, Germany; G. Dehm, MPIE Düsseldorf, Germany; J. Michler, EMPA Thun, Switzerland; M. Legros, CEMES-CNRS, France; K. Durst, TU Darmstadt, Germany; J.M. Molina-Aldareguia, IMDEA Materials Institute, Spain. The Editors are also grateful to publishers at Elsevier, the editorial teams of *Materials & Design* and *Materials Science and Engineering A*, and all reviewers and contributors for creating this body of published work.

With the outburst of the Covid19 pandemic in 2020, the meeting in Malaga, Spain, in October 2019 was one of the latest face-to-face meetings that the nanomechanical testing community has enjoyed to date. If one can extract some positive learning from the challenging times that the world is grappling with right now, then perhaps it is the fact that online meetings can be run efficiently in ways that minimise losses, and bring the experience as close as possible to face-to-face encounters. The organisers of the Nanomechanical Testing series, however, feel that for scientific meetings like this one, personal interactions remain the key to exchanging and generating new ideas, opening new research directions and fostering stronger collaborations. With that in mind, and the next meeting in the series planned for 2022 (<http://engconf.us/conferences/materials-science-including-nanotechnology/nanomechanical-testing-in-materials-research-and-development-viii/>), the organisers hope that by then the harsher restrictions brought about by the pandemic



Fig. 1. Group photograph from the Nanomechanical Testing VII meeting (2019).

will become part of the past, and that participants will be able to enjoy a safe, fruitful and exciting face-to-face meeting experience.

The two collections of papers included in this Virtual Special Issue are found at <https://www.sciencedirect.com/journal/materials-and-design/special-issue/10XJLR32DR> and <https://www.sciencedirect.com/journal/materials-science-and-engineering-a/special-issue/10T86SLJCST>.

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