Title: Metrology for length-scale engineering of materials

Abstract

Plasticity size effects offer both measurement challenges and opportunities to engineer materials into more sustainable/energy efficient industrial components that are lighter, stronger, fatigue and wear resistant. Size effects can change the strength of a material by an order of magnitude. A validated, "joined-up" understanding (vs. temperature) of the mechanisms behind "smaller being stronger" is needed. This would enable design rules to combine different strength enhancement methods, improve Martens Hardness calibration, and enable new indentation methods to probe small volumes of material (e.g. drug particles) and generate high resolution maps of stress-strain properties or residual stress of alloys, welds, inclusions, and interfaces.

Keywords

Size effects and temperature dependent enhanced yield-strength; fracture; hardness; toughness; constitutive properties; length-scale engineering; small volume / particle properties.

Background to the Metrological Challenges

The strength of a material is a key design parameter for all manufactured components and is size and temperature dependent. FEA models fail to predict the very real material performance improvements available through length scale engineering and virtual prototyping is impossible without length-scale-enabled models for components that deliberately use length-scale engineering to enhance performance. Design rules and measurement methods are needed to enable and control the manufacture of innovative components and thermal management devices, manufactured via sustainable, low-energy routes (electrochemical additive manufacturing).

Industrial use of instrumented indentation is being hindered by plasticity size effects causing failures in hardness-based quality control and acceptance, and calibration failure in the Martens Hardness scale. Innovative new indentation-based measurement methods are continually being developed but quantitative results are hindered because the indentation response is dominated by unquantifiable plasticity size effects. Metrology to validate understanding of the mechanisms behind plasticity size effects, including valid measurement of force, structure size (film/layer thickness), local strain, indent/contact sizes, microstructure and orientations would enable users to significantly improve the optimisation of materials and component performance.

The existence of several plasticity size effects is well-established but industry has made do with empirical relationships relating to individual length-scales. Current state of the art understanding of size effects is fragmented, and it is now increasingly important to know the interactions between different strengthening strategies for applications in metals and powder metallurgy and coatings and surface engineering sectors. The increasing range of length scales being made available through nanotechnology makes the consideration of length-scale effects unavoidable

Objectives

Proposers should address the objectives stated below, which are based on the PRT submissions. Proposers may identify amendments to the objectives or choose to address a subset of them in order to maximise the overall impact, or address budgetary or scientific / technical constraints, but the reasons for this should be clearly stated in the proposal.

The JRP shall focus on the traceable measurement and characterisation of size effects for length-scale engineering.

The specific objectives are

1. To develop validated design rules for combining different size effects to the optimise strength and toughness of materials and components over a range of temperatures. In addition to develop a validated plasticity size effects algorithm able to provide size-dependent constitutive property relationships for the plastic yield of materials. This algorithm should be incorporated into length-scale enabled models to support experimental constitutive property and/or residual stress mapping (by indentation) of surfaces and small volumes of material.
2. To develop a MEMS-based instrumented indentation system to bridge the length and force-scale between AFM and Nanoindentation and allow the use of better defined probe shapes with lower uncertainty contact sizes. In addition to improve AFM-based property measurements.
3. To develop methods and associated uncertainty budgets for the length-scale dependence of the strength and toughness of materials vs. temperature. The methods should have sufficient resolution to distinguish between model predictions and include:
   - Characterisation methods, such as for dimension of a particle, structure or layer, grain size, crystal orientation and crystal rotation,
   - High-resolution indentation and compression (vs.T) of surfaces, micro /nanostructures.
   - Systematic quantitative variation or estimation of dislocation density.
4. To develop and evaluate measurement methods to distinguish between the contribution(s) to the total test response from test-related size effects (Indentation Size Effect) and that from size-related strength or plastic deformation properties of a particle, volume, or structure. A feasibility study to determine the capability of the measurement methods to characterise and map measure properties such as material dislocation density and mobility, stacking fault energy and plastic deformation zone size, should also be conducted.
5. To engage with industry, that exploits manufacturing technologies and process control, to facilitate the take up of the technology and measurement infrastructure developed by the project, to support the development of new, innovative products, thereby enhancing the competitiveness of EU industry.

Proposers shall give priority to work that meets documented industrial needs and include measures to support transfer into industry by cooperation and by standardisation. An active involvement of industrial stakeholders is expected in order to align the project with their needs – both through project steering boards and participation in the research activities.

Proposers should establish the current state of the art, and explain how their proposed project goes beyond this and JRP IND05 MEPROVISC.

EURAMET expects the average EU Contribution for the selected JRPs to be 1.5 M€, and has defined an upper limit of 1.8 M€ for any project.

EURAMET also expects the EU Contribution to the external funded partners to not exceed 30 % of the total EU Contribution to the project. Any deviation from this must be justified.

Any industrial partners that will receive significant benefit from the results of the proposed project are expected to be unfunded partners.

Potential Impact

Proposals must demonstrate adequate and appropriate participation/links to the “end user” community, describing how the project partners will engage with relevant communities during the project to facilitate knowledge transfer and accelerate the uptake of project outputs. Evidence of support from the “end user” community (e.g. letters of support) is also encouraged.

You should detail how your JRP results are going to:

- Address the SRT objectives and deliver solutions to the documented needs,
- Drive innovation in industrial production and facilitate new or significantly improved products through exploiting top-level metrological technology,
- Improve the competitiveness of EU industry,
- Feed into the development of urgent documentary standards through appropriate standards bodies,
- Transfer knowledge to the manufacturing sector.

You should detail other impacts of your proposed JRP as specified in the document “Guide 4: Writing a Joint Research Projects”

You should also detail how your approach to realising the objectives will further the aim of EMPIR to develop a coherent approach at the European level in the field of metrology and include the best available contributions from across the metrology community. Specifically the opportunities for:

- improvement of the efficiency of use of available resources to better meet metrological needs and to assure the traceability of national standards
- the metrology capacity of EURAMET Member States whose metrology programmes are at an early stage of development to be increased
- organisations other than NMIs and DIs to be involved in the work

Time-scale

The project should be of up to 3 years duration.