Title: Sustainable components through combining plasticity size effects

Abstract

Plasticity size effects offer opportunities for material engineering to obtain more sustainable/energy efficient industrial components that are lighter, stronger, fatigue and wear resistant. Exploiting plasticity size effects can change the strength of a material by an order of magnitude, but a validated, "joined-up" fundamental understanding of the mechanisms behind "smaller being stronger" is needed. This would enable design rules for combining different methods of yield stress enhancement, would improve calibrations of the Martens Hardness scale, and would enable the use of indentation to probe and map, with high lateral resolution, the local stress-strain properties and/or residual stress of a material.

Conformity with the Work Programme

This Call for JRPs conforms to the EMRP Outline 2008, section on "Grand Challenges" related to Industry & Fundamental Metrology on pages 14 and 38.

Keywords

Size effects, enhanced yield-strength, hardness, toughness, constitutive properties, length-scale engineering

Background to the Metrological Challenges

The strength of a material is a key design parameter for all manufactured components and is size dependent (e.g. component size, grain size, contact size during both manufacture and operation). Current materials models use a continuum mechanics approach that assumes plastic yield is length scale independent. Such models fail to predict the very real material performance improvements available through length scale engineering. This makes virtual prototyping impossible for components that deliberately use length-scale engineering to enhance performance.

Careful materials metrology is required 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. The JRP should provide decisive new knowledge and a core of understanding that would provide a unified description of multiple plasticity size effects. This could be embodied in design rules that would enable users to significantly improve the optimisation of materials and component performance.

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. Instrumented indentation is providing higher resolution information for both elastic and plastic properties of materials, but hardness values can change by over a factor of two over the micro-range of indentation due to the indentation size effect. It is easy to see how this can cause material acceptance disputes (e.g. in 'case-hardened' bolts where the 'case' depth is ~30 µm) if different indent sizes are used to test the same material. Ignoring the indentation size effect and assuming size independent hardness can also cause errors in the indenter calibration/validation. This can easily exceed the 30 % maximum for rejection of the indenter and is a particular problem when using metallic reference blocks. ISO/TC 164/SC 3 has a mandate to revise the instrumented indentation test standard ISO14577 to take account of the indentation size effect on calibration and uncertainty analysis methods. The JRP should aim at better informed acceptance tests and improve the design/specification of metal reference blocks, expanding the range of reference materials available and reducing their calibration uncertainties.

Scientific and Technological 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 JRP-Protocol.

The JRP shall focus on the traceable measurement and characterisation of plasticity size effects in novel materials.

The specific objectives are:

1. To develop validated design rules for combining different size effects to optimise strength and toughness of materials and components (at room temperature).

2. To develop and validate a plasticity size effects model able to provide size-dependent constitutive property relationships for the plastic yield of materials and incorporate it into length-scale enabled models to support experimental constitutive property and/or residual stress mapping by indentation (at room temperature).

3. To develop metrology methods and associated uncertainty budgets to investigate experimentally the length-scale dependence of the strength and toughness of materials with sufficient resolution to distinguish between model predictions. Methods are expected to include:
    a. characterisation methods, such as crystal orientation and crystal rotation
    b. high-resolution indentation into surfaces and compression of micro and nanostructures
    c. systematic quantitative variation or estimation of dislocation density.

4. To develop and evaluate measurement methods and/or models to distinguish between the contributions to the total test response from test-related size effects (Indentation Size Effect) and that from size-related mechanical property of a material or structure.

5. To conduct a feasibility study to determine the capability of the new science understanding and measurement methods to characterise and map previously difficult/impossible-to-measure properties (e.g. material dislocation density and mobility, stacking fault energy, plastic deformation zone size).

Proposers shall give priority to work that meets documented industrial needs and include measures to support transfer into industry by cooperation and by standardisation. A strong industry involvement is expected in order to align the project, prioritise the materials under investigation, and guarantee an efficient knowledge transfer into industry.

Proposers should establish the current state of the art, and explain how their proposed project goes beyond this. Any synergies with project IND05 “Dynamic Mechanical Properties and Long-term Deformation Behaviour of Viscous Materials” should be explained.

The total eligible cost of any proposal received for this SRT is expected to be around the 2.7 M€ guideline for proposals in this call. The available budget for integral Research Excellence Grants is 42 months of effort.

Potential Impact

Proposals must demonstrate adequate and appropriate participation/links to the “end user” community. This may be through the inclusion of unfunded JRP partners or collaborators, or by including links to industrial/policy advisory committees, standards committees or other bodies. Evidence of support from the “end user” community (eg letters of support) is encouraged.

You should detail how your JRP results are going to:

- feed into the development of urgent documentary standards through appropriate standards bodies, especially the revision of ISO 14577.
- transfer knowledge to the surface engineering, manufacturing, semiconductor and transport sectors.

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

You should also detail how your approach to realising the objectives will further the aim of the EMRP to develop a coherent approach at the European level in the field of metrology and includes 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 Member States and countries associated with the Seventh Framework Programme whose metrology programmes are at an early stage of development to be increased
- outside researchers & research organisations other than NMIs and DIs to be involved in the work

Time-scale

The project should be of up to 3 years duration.