Title: Industrial process optimisation through improved metrology of thermophysical properties

Abstract

Many industries use materials at very high temperatures (up to 3000°C) and in harsh conditions such as shuttle re-entry, gas turbines, aircraft engines and processing of refractory materials. Therefore, accurate knowledge of the thermophysical properties of such materials is needed to ensure optimised processes and to develop new materials. However, for solid materials currently the traceability of these measurements is only possible for temperatures below 1500 °C for emissivity and specific heat, and below 2000 °C for thermal diffusivity. Proposals in response to this SRT should therefore, develop new methods and infrastructure to extend traceability of measurements of spectral emissivity, specific heat and thermal conductivity, temperature of fusion and mechanical adhesion to temperatures up to 3000°C.

Keywords

Heat transfer, calorimetry, thermophysical properties, gas turbines, aerospace industry

Background to the Metrological Challenges

Although it is possible to measure the thermal diffusivity and specific heat of solid materials at very high temperatures up to 3000 °C, the specific apparatus for these measurements must be calibrated in their operating temperature range, and the traceability of these measurements to the SI cannot currently be assured by European NMIs at temperatures above 1500 °C for emissivity and specific heat, and above 2000 °C for thermal diffusivity.

The behaviour of a material submitted to thermal fluxes in e.g. glass furnaces, space launchers and gas turbines, depends on properties such as specific heat, thermal conductivity and emissivity, which describe the temporal and spatial temperature distribution inside the material. Moreover, knowing the temperature of fusion/adhesion of the material, it is possible to determine the thermal limit of the material. For example in the glass industry, refractories are operated up to 1800 °C and the development of new materials that can withstand such aggressive environment requires the measurement of thermal conductivity. In gas turbines, the materials are used close to their thermal limit and a discrepancy of only a few degrees can change the operability of the gas turbine.

Currently, data on the temperature of fusion of materials is scarce. Pulse and inductive heating techniques can be used for measurements over a broad range of temperatures with reasonably short times, but for high-speed and high-temperature measurements radiation thermometry is often the only viable option although this requires knowledge of the emissivity of the sample. In-situ measurements can also be performed by ellipsometry, reflectometry or direct comparison with blackbody sources, but again the short measurement times and high temperatures present a challenge.

Over recent years, the operational temperatures of gas turbine engines have been increased to reach temperatures above 1500 °C in order to significantly to optimise their efficiency. To protect the metallic blades from these high temperatures, thermal barrier coatings are applied onto the turbine blades. However, these layers must have adhered well to the supporting turbine blade and therefore it is necessary to check the quality of the layer adhesion regularly during service or preferably during operation. Existing approaches for non-contact and non-destructive techniques by using optical or infrared radiation are not fully adequate, therefore, improved optical or infrared-optical methods are needed.

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 protocol.

The JRP shall focus on the traceable measurement and characterisation of the thermophysical properties of materials used in high temperature industrial processes.

The specific objectives are

1. To establish a reference facility for the traceable measurement of the thermal diffusivity of solid materials at temperatures between 1500 °C and 3000 °C and to determine an uncertainty budget for the measurements at highest temperatures.
2. To develop validated methods and establish a metrological reference facility for the traceable measurement of the specific heat of solid materials between 1500 °C and 3000 °C. The target uncertainty is 0.5 % below 1000 °C and 1.5 % above.
3. To establish a reference facility for the traceable measurement of the emissivity of solid materials above 1500 °C based on radiometric or calorimetric methods using pulse or induction heating. The target uncertainty is 0.5 % below 1000 °C and 1.5 % above. In addition to use measurements from this new facility to (i) to compare results of total hemispherical and normal spectral emissivity measurements obtained with existing facilities, and (ii) develop validated methods for the measurement of the temperature of fusion of refractory materials up to 3000 °C.
4. To develop validated methods to quantify the mechanical adhesion of solid materials, in particular functional layers, for thermal or corrosion protection above 1000°C.
5. To facilitate the take up of the technology and measurement infrastructure developed in the project by the measurement supply chain, standards developing organisations (e.g. those associated with the Registration, Evaluation, Authorisation & restriction of CHemicals (REACH) Directive EC1907/2006) and end users.

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. In particular, proposers should outline the achievements of the EMRP project ENG08 and how their proposal will build on those.

EURAMET expects the average EU Contribution for the selected JRPs in this TP to be 1.5 M€, and has defined an upper limit of 1.8 M€ for this 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 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,
- Feed into the development of urgent documentary standards through appropriate standards bodies,
- Transfer knowledge to the aerospace and glass production sectors.

You should detail other impacts of your proposed JRP as specified in the document "Guide 4: Writing Joint Research Projects (JRPs)"

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.