Final Publishable JRP Summary for IND11 MADES
Metrology to assess the durability and function of engineered surfaces

Overview

Techniques were developed to more accurately measure friction and wear of engineered surfaces (tribology), including approaches to measure nano-scale wear, the long-term performance of low-friction coatings, real-time temperature and chemical changes at surface contacts, and the mechanical degradation of tools. These techniques will promote the development and adoption of low-wear, low-friction surface in European industries, enhancing industrial competitiveness and reducing environmental impact.

Need for the project

Friction and wear in industrial processes wastes energy and degrades materials. The development and adoption of ‘engineered surfaces’ that reduce friction and wear are important to the development of high-performance products and improved process efficiency in key European sectors including transport, energy generation, manufacturing and mineral extraction. Advances in surface engineering will also allow industry to meet demanding sustainability requirements.

The development and adoption of surface engineering innovations by industry will:

- Improve the efficiency of production through minimising energy lost as friction, and through increasing the longevity of production machinery such as forges, presses and cutting tools; minimising maintenance and replacement costs.
- Support European industry to develop higher performance products. For instance, the downsizing of products, such as car engines, places increased mechanical and thermal stresses on components, demanding the use of lower-friction, lower-wear surfaces.
- Reductions in friction and wear will also help European industry to meet sustainability targets. Reducing friction improves the efficiency of energy use, reducing emissions. The requirement to achieve emissions of 95 g CO_2/km in all road vehicles by 2020 (2008/692/EC) will need significant reductions of friction within engines. Improvements such as dry materials processing may also lead to reductions in the use and disposal of contaminated lubricants and cutting fluids.

To facilitate the development and adoption of lower-friction, lower-wear engineered surfaces, increasingly sophisticated techniques are needed to more accurately assess their properties and performance, specifically to measure:

<u>Nano-scale wear of new, durable engineered surfaces</u>

The development of nano-scale surface coatings has produced durable engineered surfaces with very low-levels of wear but current measurement techniques are not sufficiently accurate to assess their performance.

<u>Friction on low-friction surfaces over extended periods</u>

Similarly, current measurement techniques are insufficient to assess the performance of innovative low-friction coatings, particularly over extended time periods due to issues with drift in the measurement instrumentation.

<u>Temperature, structural and chemical changes at interacting surfaces</u>

Temperature increases and chemical changes at interacting (contacting) surfaces can make them more vulnerable to wear. Real-time and in situ measurements are needed to provide a deeper understanding of the changes taking place, to aid the development of improved coatings and finishes.

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Wear of cutting tool surfaces

The efficient use of cutting tool inserts by industry is currently hampered by an absence of models and techniques to monitor their wear in real-time use, and to predict their wear over time.

Scientific and technical objectives

The overarching project objective was the development of tools and techniques for accurate measurement of friction and wear of engineered surfaces. This included:

1. The development of improved techniques for the measurement of small volumes and material loss from wear (nano-scale), with sensitivity to achieve relative measurements of 0.1 µm or less over a period of several days.
2. The development of traceable, self-calibrating, stable measurement techniques for determination of the long-term friction performance of low-friction coatings.
3. The development of measurement methods for the measurement of the temperature of tribological contacts (i.e. at interacting surface).
4. The development of methods for assessing chemical changes at tribological contacts (i.e. at interacting surfaces).
5. The assessment of methods to monitor the degradation of surfaces due to wear.

Results

This pan-European project explored a range of tools and techniques to more effectively measure the performance of engineered surfaces, to be used primarily by industrial users and industrial researchers. Some techniques made use of instruments, such as atomic force microscopes, used by large industrial research laboratories and other research institutes, whilst others made use of more widespread techniques, such as chromatic aberration probes, that can be adopted by a wide range of industrial users. Significant developments were made to address the project objectives:

1. The development of improved techniques for the measurement of small volumes and material loss from wear (nano-scale) with sensitivity to achieve relative measurements of 0.1 µm or less over a period of several days.

Established techniques are either not precise enough to measure nano-scale wear, or can only measure such wear in unrepresentative conditions, such as placing the surfaces under unrealistic loads. Whilst more precise techniques are available, they use radioactive tracers and their adoption was limited by safety concerns. This project met this objective by developing a range of techniques to assess wear. Novel techniques were developed to validate the relocation profilometry approach to wear measurement using optical microscopes and atomic force microscopes (AFM). The use of chromatic aberration probes for the non-contact in-situ measurement of wear was achieved and validated at NPL and MIKES for the in-line measurement of wear and the assessment of accumulation of damage. New mathematical descriptions of the interaction of electrons with materials have been developed that were intended for fast accurate simulation of images. Their use in tribological applications was found to be limited, due to unresolved issues with the simulations that limit their accuracy and additional work is required to further develop the technique. Finally, the relevance of integral light scattering for the rapid evaluation of wear damage has been demonstrated and shown to give new information on the progression of wear damage.

2. The development of traceable, self-calibrating, stable measurement techniques for determination of the long term friction performance of low friction coatings

A better understanding of sources of uncertainty will aid in the development of more accurate measures of friction, and the development of self-calibrating (self-correcting) techniques are needed to provide stable long-term measures. The objective was met through the development of two different approaches to eliminate drift in friction measurements: NPL developed, manufactured and validated a self-zeroing friction measurement device based on periodic lift-off of the friction load from the load cells that is now being used routinely in the provision of research consultancy at NPL. BAM developed a system using their Homat high-speed reciprocating tribometer, which combines a stiff test element with an accurate high-resolution interferometric displacement measurement for the assessment of friction. The Homat test system is being used by BAM to deliver research services for industry.

3. The development of measurement methods for the measurement of the temperature of tribological contacts (i.e. at interacting surface)

Current techniques cannot measure temperatures whilst surfaces are in contact. Temperature measurement techniques that can access contact interfaces and provide real-time temperature measurements are needed to more effectively manage and develop engineered surfaces. The objective was met through the development of three new techniques to measure interface temperatures whilst surfaces are in contact. Improved fibre-based temperature measurement techniques based on the transmission of infrared radiation through an optical fibre were developed by INRIM for the measurement of the temperature of wear scars, and have been built into a self-contained measurement system that was validated in tribological tests at NPL. Techniques have also been developed by NPL for the ex-situ and in-situ measurement of the temperature of wear interfaces based on thermal imaging cameras to measure the infrared radiation emitted by the areas of interest on the worn surface. Finally, novel thin film sensors based on platinum resistance thermometry were developed by DTI and validated in tribological tests at NPL. Consistent results between the three different test methods were achieved demonstrating that in situ temperature measurement is possible in this challenging area, and these important developments were shared with industrial users and the research community through dedicated workshops.

4. The development of methods for assessing chemical changes at tribological contacts (i.e. at interacting surfaces)

As with the measurement of temperature, techniques are required that can identify real-time chemical changes in contact interfaces. This objective was partially met. Both Raman Spectroscopy and Thermal Desorption Mass Spectrometry (TDS) / Laser TDS (LTDS) were shown to provide information on ex-situ (after the surfaces were separated) wear interface chemistry. Although the development of the TDS/LTDS technique was successful, the information obtained is overly technical and not yet applicable to tribological testing in industry. The in-situ Raman measurements attempted in the project were not successful although this is believed to be due to the choice of materials examined. Results have been published in the literature which show that the TDS/LTDS technique can be applied successfully, and research on the application of Raman spectroscopy to the analysis of chemical changes at wear surfaces is expected to continue in other projects.

5. The assessment of methods to monitor the degradation of surfaces due to wear

Manufacturing efficiency can be improved by the creation of approaches that can predict and monitor insert degradation in real-time – particularly in widely used cutting tools. This objective was met through the development of new measurement methods for the real-time monitoring of the degradation of surfaces due to wear. These include a novel linescan camera sensor system which produces images and videos of the wear surface, with a lateral resolution of 2 µm, providing a record of the evolution of the wear interface. This can be combined with use of a chromatic aberration displacement probe and Linear Voltage Differential Transformer (LVDT) to provide real time measures of the quantitative wear of the two components of the wear couple. A programme of testing was carried out that provided novel results showing details of the degradation of wear surfaces.

Actual and potential impact

Dissemination of results

To ensure uptake of project results a variety of channels was used to disseminate the findings to the research and industrial communities. In addition to peer-reviewed scientific papers (listed below) presentations at international scientific meetings and conferences, the project held international workshops and webinars with the end-user community and developed a series of good practice guides for industrial users:

- Good practice guide on the assessment of chemical changes at the wear interface
- Good practice guide on assessment of small wear volumes
- Good practice guide on the assessment of wear to tools
- Good practice guide on the assessment of “zero wear”
- Good practice guide on on-line assessment of temperature (to be finalised)

These will be available shortly on the EURAMET website.

Impact on standardisation:

The research consortium worked closely with standards organisations and it is anticipated that new procedures for assessing wear and friction will be developed and adopted by the relevant technical committees within CEN, ISO and ASTM. Partners are active in these committees, thus giving a straightforward route to standardisation. Already project results have been used to contribute to:

- The development of a new standard for wear testing of diamond-like carbon coating in ISO standard *TC 107 Metallic and other inorganic coatings.*
- The development of a new ASTM standard *G211-14 Test Method for Conducting Erosion Tests by Solid Particle Impingement Using Gas Jets* published in 2014
- As the basis for work to develop a new standard on nano-scratch testing, initially within *CEN 352 Nanotechnologies* and eventually through *ISO 229 Nanotechnologies*. This work was approved and started in November 2015.

Early impact on industry:

A number of project outputs have already been adopted by industry including:

- Use of the new measurement technology developed in the MADES project in core NPL project work including consultancy work for industry.
- Techniques developed in the project have inspired an SME instrument manufacturer to develop low-wear volume measurement devices. The development of these devices has been greatly enhanced by the knowledge they gained during the MADES project.
- The new measurement technology is being used in collaborative work within Annex IX of the Implementing Agreement for Advanced Materials for Transport of the International Energy Agency which is concerned with the development of better surface engineering for internal combustion engine components.

Over the longer term it is expected that the techniques developed will be adopted by industry and used to develop further advances in low-friction, low-wear surfaces; leading to improvements in process efficiency, in the performance of products and components, and reductions in the environmental impact of European industry.

List of publications

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3. D. García-Jurado, J.M.Mainé, M.Batista, L. Shaw, M.Marcos, T. Hausotte, *Metrological Evaluation of Secondary Adhesion Wear Effects in the Dry Turning of UNS-A92024-T3 Alloy through Focus-variation Microscopy (FVM)*, Procedia Engineering, Volume 63 (2013), pp. 804–811
4. A. Kovalev, M. Hartelt, D. Spaltmann, R. Wäsche, M. Woydt, *Zero wear (Null Verschleiß)*, Tribologie und Schmierungstechnik, Vol. 60 (2013) pp. 5-12
5. N. Myshkin, A. Kovalev, D. Spaltman , M. Woydt, *Contact mechanics and tribology of polymer composites*, Journal of Applied Polymer Science, Vol. 131 (2014), pp. 39870(1)-39870 (9)
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7. Julian Le Rouzic, Tom Reddyhoff, *Spatially resolved triboemission imaging*, Tribology Letters, January 2014
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11. *B. Hemming, P. Andersson, The determination of wear volumes by chromatic confocal measurements during twin-disc tests with cast iron and steel, Wear 338 (2015) pp 95-104*
12. *K Holmberg, A Laukkanen, H Roikainen, R Waudby, G Stachowiak, M Wolski, P Podsiadlo, M Gee, J Nunn, C Gachot, L Li, Topographical orientation effects on friction and wear in sliding DLC and steel contacts, Part 1: Experimental, Wear 330-331(2015)3–22*
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14. *W Hartmann, A Loderer , Automated Extraction and Assessment of Functional Features of Areal Measured Microstructures Using a Segmentation-Based Evaluation Method, Surface Topography: Metrology and Properties, 2 (2014)*
15. *P Cizmar, CG Frase, H Bosse Novel super-fast three-dimensional SEM image simulation Microscopy and Microanalysis, 19 (2013),pp 796 - 797*

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