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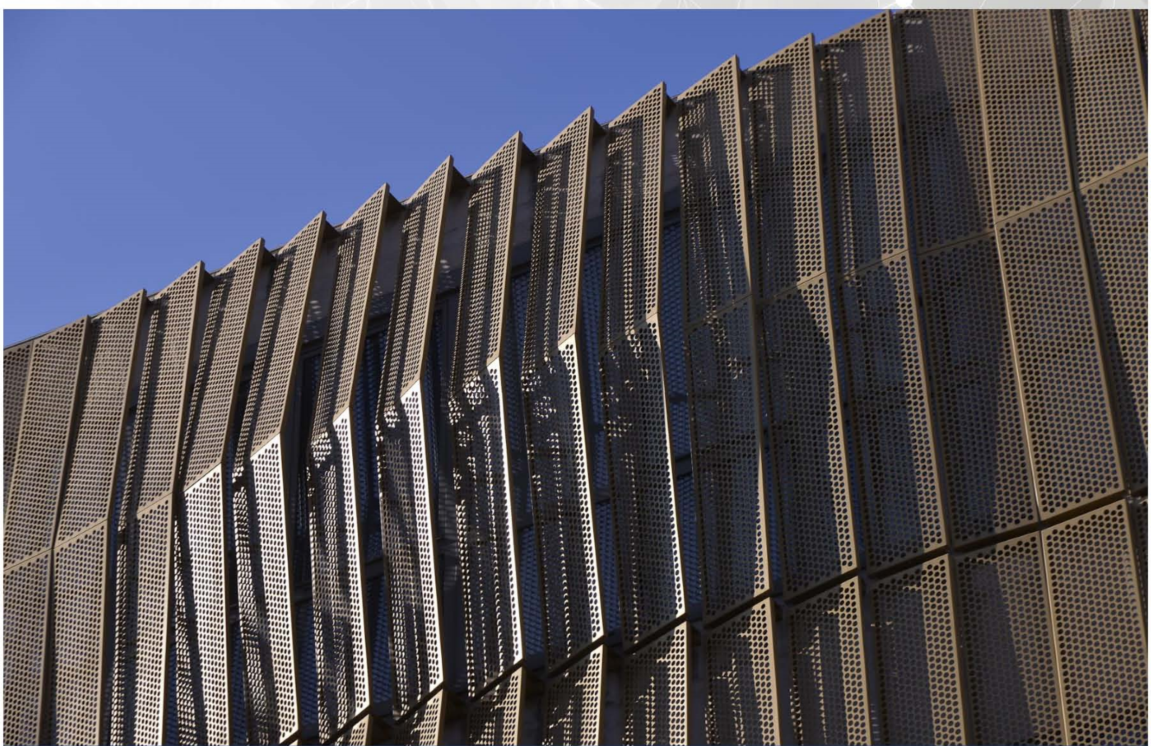

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Issues in characterizing parameters influencing nanometric friction

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1 Introduction

Friction and wear are one of the most challenging problems in many engineering and manufacturing technologies. However, while frictional phenomena on the macro to micro scales are well described and their effects can generally be efficiently compensated, the research on friction in the nanometric domain is still a matter of studies. This work is, thus, aimed at providing a contribution to the study of nanometric friction by characterising the parameters influencing its value and especially the dependence of friction on material properties, loading conditions, velocity of motion and temperature.

2 Experimental Methods and Results

The experimental method employed in this work is based on using the lateral force microscopy mode on a scanning probe microscope (SPM) [1]. The analysed samples, obtained by using either atomic layer or pulsed laser deposition, are: fused silica (FS), HOPG, Al_2O_3, TiO_2, MoS_2, steel, Al and nitinol. To determine the atomic concentrations and the condensed vapour thickness, prior to the measurements the samples are characterized via X-ray photoelectron spectroscopy. To carry out efficiently the experimental measurements, several issues, underlined below, need then to be considered.

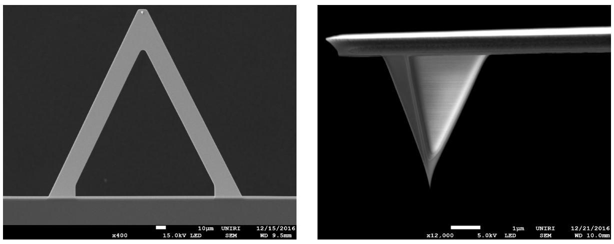

Fig. 1. SEM micrographs of the used probes

To tune the measurement conditions and quantify the obtained results, the experimental methodology involving SPM requires a precise calibration of the lateral and normal stiffness of the used probes. This calibration is performed, based on precisely measured probes' dimensions on a scanning electron microscope (SEM – Fig. 1), by using FEM and the method of parallel beam approximation, as well as by employing subsequently calibration gratings [2]. The thus obtained stiffness allow establishing that the uncertainty of the determined values is significant (up to ± 15 %).

The nanoscale contact between probes' tips and the samples is governed by a variety of other physical phenomena as well. To quantifying these effects, separate experimental

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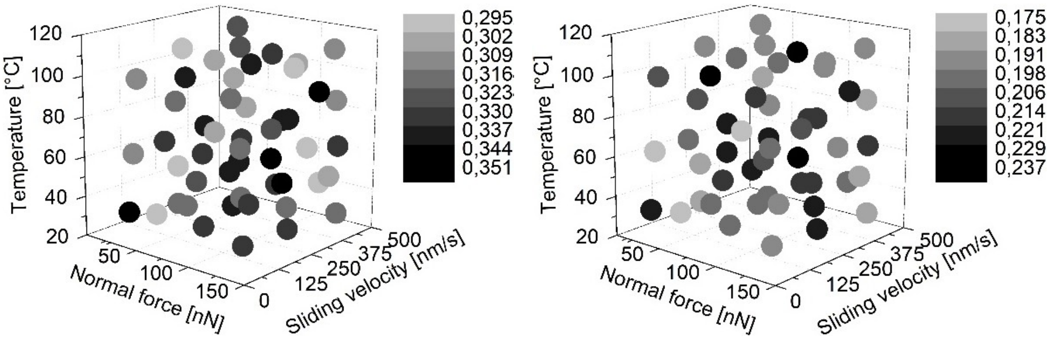
measurements are thus performed to establish the tip wear and to characterize the samples in terms of their Young's modulus, hardness and surface adhesion.

Once this is done, the measurements on the samples can be performed. Standard design of experiments (DoE) methods such as (full) factorial design or Box-Behnken are, however, poorly suited to obtain a detailed insight into the studied multidimensional stochastic phenomenon. DoE is thus conducted in this work by defining the experimental space via sampling methods that enable the development of a meta-model. Since recent studies indicate that among these the centroidal Voronoi tessellation (CVT) [3] has several advantages, CVT is used on each of the sample materials to generate 50 points along each of the studied influencing parameters, i.e., normal force, sliding velocity and temperature.

When experimental data is available, a mathematical expression for the nanoscale friction model should be determined. Due to numerous uncertainties and the highly stochastic dependence of the coefficient of friction on the studied parameters (shown in Fig. 2 for two of the studied materials), this task proves to be very complex. Polynomial fitting of the results via the often-used multidimensional interpolation algorithms yields, however, a very poor fit with the best coefficients of determination limited to $R^2 = 0.1$. The obtained experimental data will thus be rather input into recently developed computational algorithms for nonlinear model representation that enable a simultaneous examination of global uncertainties and contributions of a large number of parameters.



(a) (b)

Fig. 2. Colour-coded experimentally determined values of the coefficient of nanometric friction generated via CVT vs. the influencing parameters for FS (a) and MoS_2 (b) samples

3 Conclusion and Outlook

This work provides an analysis of the numerous difficulties and issues involved in the determination of nanometric friction. The prospected results of the ongoing research will provide a significant scientific contribution to the determination of the basic principles of nanometric friction by characterising the impact of the numerous studied parameters on its value. By obtaining finally multidimensional correlation functions linking the value of nanometric friction to these variables, a possibility to extend the established friction models, so as to broaden their applicability to the nanometric range, should be provided.

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