Advanced Methods for the Mechanical and Topographical Characterization of Technological Surfaces

Abstract

Doctoral Program in Management, Production and Design (33rd Cycle)

Advanced Methods for Technological Surfaces Characterisation

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Manufacturing is currently facing the challenging development of novel processes, e.g., additive manufacturing, and advanced materials, e.g., innovative composites and coatings, to cope with the more stringent customer demands for enhanced performances and customization and more sustainable use of resources. This requires flexible and fast quality inspections that rely on thorough, accurate, and precise characterization methods to cope with big data and interconnected cyber-physical systems within Industry 4.0.

Amongst several product properties, the characterization of technological surfaces is core to control the manufacturing process and engineer the product. In fact, it has long since it has been demonstrated processing conditions and process parameters induce a typical surface texture, i.e., the manufacturing signature. Therefore, characterizing the surface topography is essential to understand and qualify manufacturing processes and support process optimization and quality control. As the dependence of technological surface topographies on processing conditions has long been proved, also the fact that topographies can control a wide range of functional properties is well established. Consequently, the industry has targeted surface topographies' design to engineer products' functionality and increase their quality and performance. Thus, in the last decades, the increasing demand for enhanced performances pulled fundamental research in several fields, e.g., electronics, energy, IT, optics, tribology, to enable surface functionalization by surface technology.

The characterization is core to ensure the achievement of the modification goal and enable quality control. A complex set of characterization techniques must be adopted to achieve thorough characterization, considering complex interactions between surface topography and properties.

However, this set of complex characterization requires a continuous investigation and development to cope with new manufacturing challenges, such as miniaturization, nanotechnologies, innovative processes, and materials. It is core to have precise and accurate characterization methods, to provide process engineers to exploit them with confidence and enable reliable and robust statistical process control of geometrical and technological properties of surfaces. Thus, a rigorous metrological framework is necessary to guarantee the measurements' traceability to enable their implementation for quality controls, results' comparability, and adoption for design specification within a sound and rigorous framework to enable total quality management. Therefore, this work aims to develop advancements for surface topographical and mechanical characterization by instrumented indentation test, as far as the methodological and metrological aspects are concerned, and apply them to interesting practical case studies.

Provided the massive attention received surface topography characterization in the last decades, this thesis will tackle two very specific aspects within this field. They are: (i) Assessing the effect of augmentation of conventional measurement techniques' informativeness on topography characterization to provide SMEs with tools to improve old-fashioned characterization methods' informativeness and increase their competitiveness in Industry 4.0; (ii) Evaluating measurement uncertainty of wear volume measurement methods based on topographical measurement, which is essential to enable comparability of results and improve the development of innovative material designed for wear reduction.

Instrumented indentation test is one of the most flexible mechanical characterization methods, enabling thorough multiscale characterization. It is widely exploited in industry and academia, in several sectors spanning from technological to life science. This notwithstanding and quite surprisingly, little research has been conducted on its metrological performances. Additionally, related standard shows some shortcomings in prescribing calibration procedures, thus hindering traceability and the exploitation of this technique to specify product requirement and statistical process control. Accordingly, this thesis tackles two main aspects pertaining to the metrological assessment: (i) Reducing measurement uncertainty, and (ii) Improving calibration procedure for testing machines. These two are strictly intertwined and aim to establish traceability for this technique and highlight potential impact factors in the calibration and characterization operations.