Digital tribology and the industry 4.0- A note

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Abstract

Industry 4.0 or the Fourth Industrial Revolution is driven by innovative technologies that have profound effects on production systems. Recent research results and industrial experiments show paradigm shifts in problem solving, which affect many areas, including tribology. Quantitative information obtained through the digital approach of the tribological study in the interface regions of the contact pairs, exhibit a strong potential for the optimization of the productive processes as a whole. In this sense, the concepts of Digital Tribology, presented here, are perfectly aligned with the new technologies in this era of digitalisation and emergence of intelligent, efficient and autonomous solution required by industry 4.0.

Kewords: Digital tribology; Quantitative information; Autonomous analysis; Industry 4.0

1. Introduction

The term "Industry 4.0" was first used in 2011 in industrial trade fair Hannover Messe and originated from a high-tech strategic project of the German Government. Industry 4.0 focuses on the full digitisation of its core activities and its integration into digital ecosystems with the various value chain providers. In this new disruptive reality, the development of innovative technologies, in all areas, requires the valuation of knowledge under the current conditions of an overwhelming digitisation.

Tribology, for example, is a multidisciplinary field that studies wear, friction and lubrication in order to predict the behaviour of tribo-elements used in mechanical systems [1]. This area has sought new approaches to issues of reduction of energy losses and pollution [2,3] mainly by friction, whose most dramatic example is the automotive industry, whose reduction prospects are internationally reiterated.

Among these new approaches, the topographical study of the tribological systems interface exhibit strong potential to find new solutions. In this direction, digitalisation has also introduced new tools for the evaluation of the topography in the area of interfaces. The development of new equipment, such as digital 3D optical microscopes, 2D and 3D optical profilers [4-6], as well as three-dimensional reconstruction techniques [7], have enabled advances in the analysis of pair interfaces in tribo-systems. Currently, several efforts have been made in this direction, such as the case of articles for the detection and evaluation of wear [8,9] and for contact analysis [10] and lubrication conditions [11].

This new wave of modernisation encouraged the introduction of a new expression: Digital Tribology. This is a term which began to be used recently in some articles and research projects. Without calling into question the quality of the work, the various definitions attributed to this expression are often vague, encompassing all sorts of actions related to digitalisation, and often give the main emphasis to the equipment which provides digital answers.

In our understanding, “Digital Tribology is a set of approaches based on digital microscopy (integration of computer control of the microscope with acquisition, processing and digital analysis of images) and statistical criteria, which allow the quantitative and qualitative extraction of topographical/morphological information of the sliding surfaces of tribological pairs and formed surface media, in order to relate the inputs of the tribological system to its outputs”. In this way, the ultimate utility of digital tribology is to serve as a tool to aid decision-making in processes involving tribological activities, perfectly balanced with the emergence of digitalisation, particularly in the field of manufacturing.

Fig.1 shows the key elements of a generic tribo-system. The analysed regions are the sliding surfaces of the tribo-elements, 1 and 2, together with the interfacial media formed, 3, (third body, oxides, etc.).

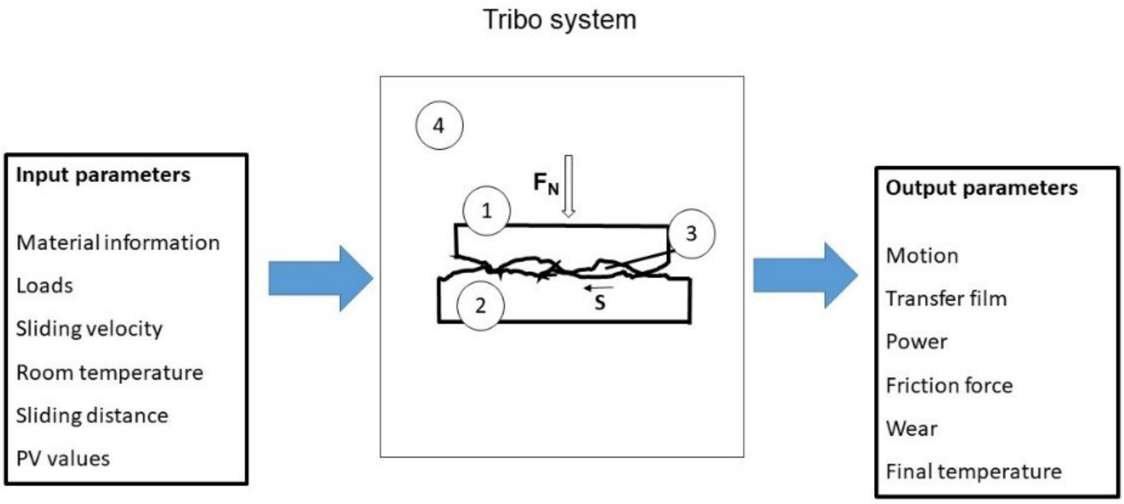

Fig.1 Components of a tribe-system: 1 and 2 represent the body and counter-body of the tribological system; 3 represents the interfacial medium and 4 represents the environment.

The Tribology research group (MacTrib) has been dedicated to the development of tools based on digital microscopy for the topographical and morphological study of the sliding surfaces of the tribological pairs, in an effort to consolidate the concept of Digital Tribology. As examples, a set of three distinct approaches for the study of the sliding surface of polymeric composites based on PA66 are presented in the next section:

2. Examples

In these examples, the routines were developed in the NIH Image J [12]. The images were acquired under optical microscopy (OM), which is usually undervalued in topographic inspection of the sliding surfaces of polymeric materials. The limitation most often referred to is the depth-of-field. Nevertheless, topography of the sliding surface can be analysed with OMs with the aid of extended depth from focus reconstruction methods, with several advantages over: confocal scanning microscopy, scanning electron microscopy and atomic-force microscopy [13]. Issues related to image processing and analysis, as well as microscopy parameters, are discussed topics in the three examples presented below:

a) *Effect of glass fiber reinforcement and the addition of MoS_2 on the tribological behavior of PA66 under dry sliding conditions: a study of pixels intensity distribution on the counterface* [14]

It was proposed a new approach of analysis of the uniformity of the transfer film on counterface, in tribological tests, based on a statistical criterion analysis of the pixel intensity distribution. It was analyzed the relationship between the transfer film on counterface and the tribological behavior of the polymeric composites based on polyamide66. The results showed that statistical analysis employed proved to be a useful for the evaluation of the tribological behavior of the polyamide66 composites, at the described conditions. This article was published in [14]. The Fig.2 summarizes the idea of the research work.

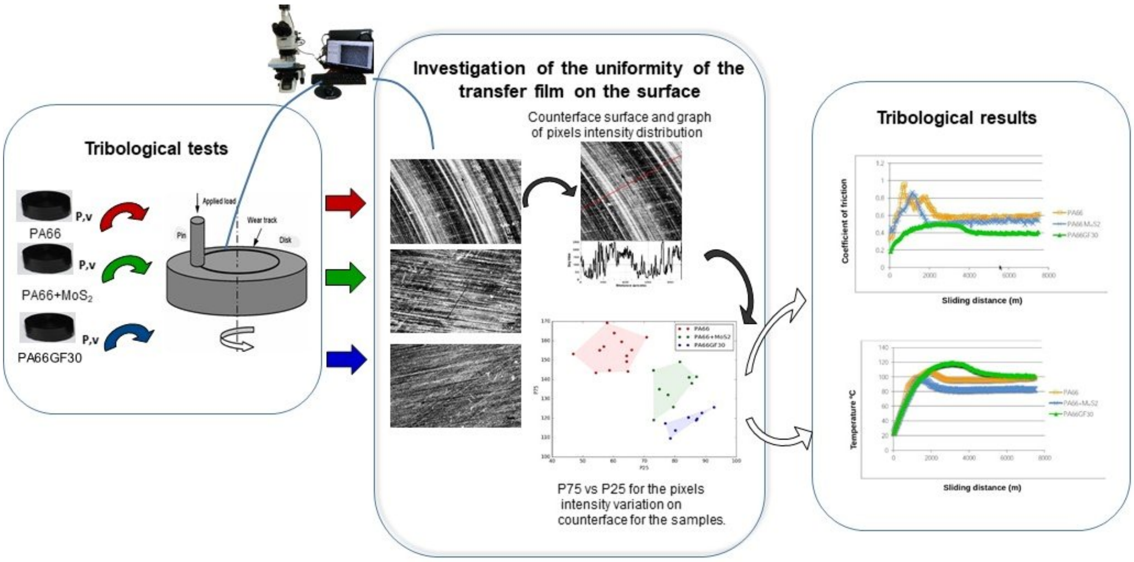

Fig.2 Graphical abstract of example a.

b) ***Influence of sliding velocity on the tribological behavior of PA66GF30 and PA66+MoS$_2$. An analysis of morphology of sliding surface by digital image processing*** **[15]**

A digital image processing methodology was developed to analyze the morphological aspects of sliding surfaces resulting from the evolution of velocities in the following polymeric materials: polyamide66 reinforced with glass filer (30%) and polyamide 66 with MoS$_2$. The overall results allow one to conclude that for these conditions, the increase in sliding velocity improves the friction performance of polyamide66 reinforced with glass filer (30%), since it enables the emergence of a surface rich in glass fibers and clusters glass fibers particles homogeneously dispersed over the polymeric matrix. This article was published in [15]. The Fig.3 summarizes the idea of the research work.

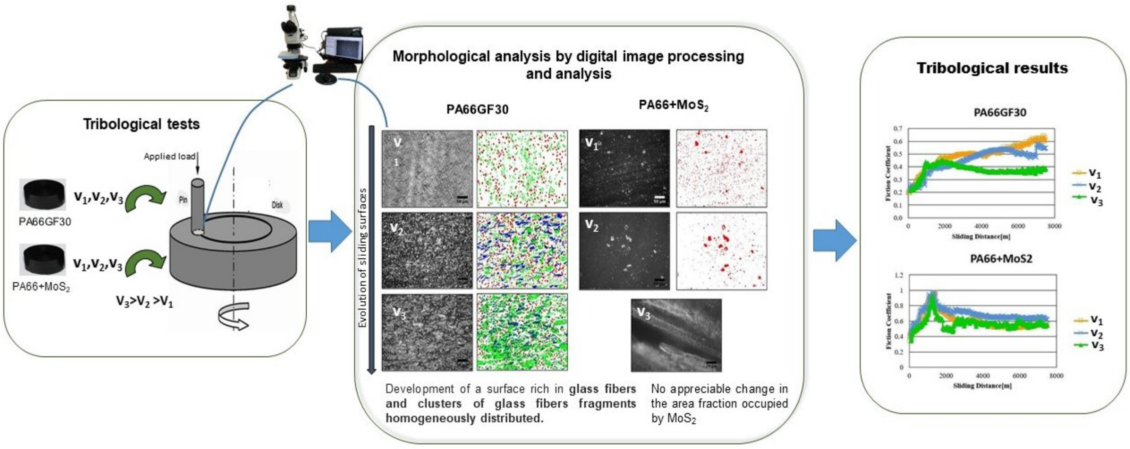

Fig.3 Graphical abstract of example b.

c) ***3-D reconstruction by extended depth-of-field in tribological analysis: Fractal approach of sliding surface in Polyamide66 with glass fiber reinforcement*** [16]

The polyamide66 reinforced with glass filer (30%) was analyzed in terms of fractal behavior. A set of tribological tests was conducted and the resulting fractal values were correlated with surface morphology and tribological parameters. Images from optical microscopy of the sliding surfaces were converted in elevation maps which were investigated with the extended depth-of-field method. A robust methodology is proposed to calculate the micro- macro-scale threshold of multi-fractal behavior. The technique allows the comparison between the mono-fractal behavior and the structural and textural (micro- and macro-scale) mixed fractal components. This work obtained a dependency between the fractal dimension and the tribological conditions and positions along sliding surfaces. This article was published in [16]. Fig.4 summarizes the idea of the research work.

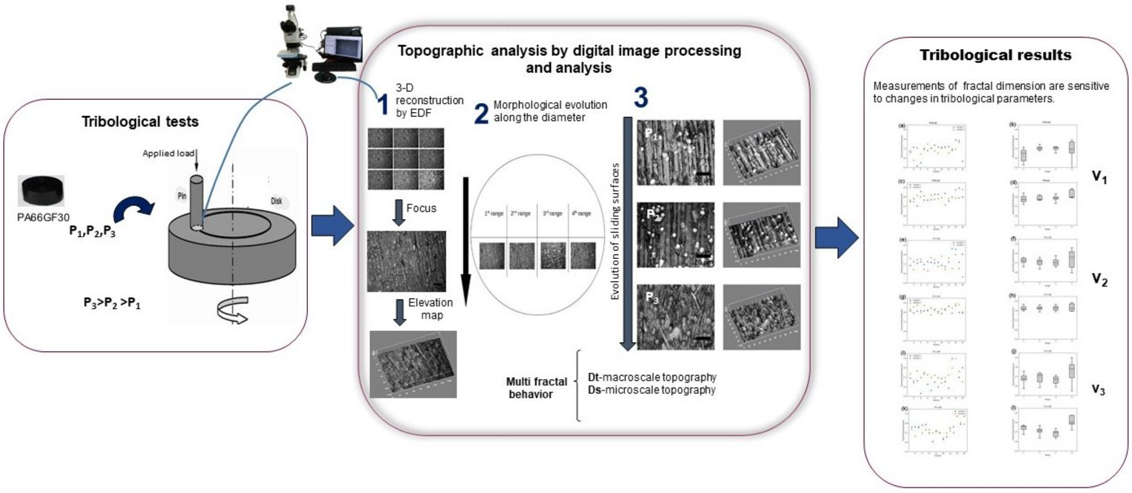

Fig.4 Graphical abstract of example c.

3.Main remarks

-To be useful to industry 4.0 the tribology has to be capable to give accurate, autonomous and customized answers. These requirements will only be met by the digitalisation of the tribology.

-Digital microscopy reveals a series of possibilities in the analysis of the tribological parameters, paving the way for increased automation and for the emergence of Digital Tribology.

-The consolidation of the Digital Tribology field still requires the exploration of several researches related to the repeatability of tribological tests, the diversification of equipment (profilometers, microscopes...) and the development of routines in digital image processing with the ability to inspect the complex topographical aspects of the most diverse materials (e.g. preferential alignments). These approaches should be robust, both for *post mortem* monitoring of sliding surfaces and online (with real-time micrographs).

-The improvement of the Digital Tribology approach should lead to a complete package of identification and measurement of the parameters of interest, replacing human observation.

-The three examples presented are an indication that Digital Tribology has great potential for relating the inputs of the tribological systems with their outputs.

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