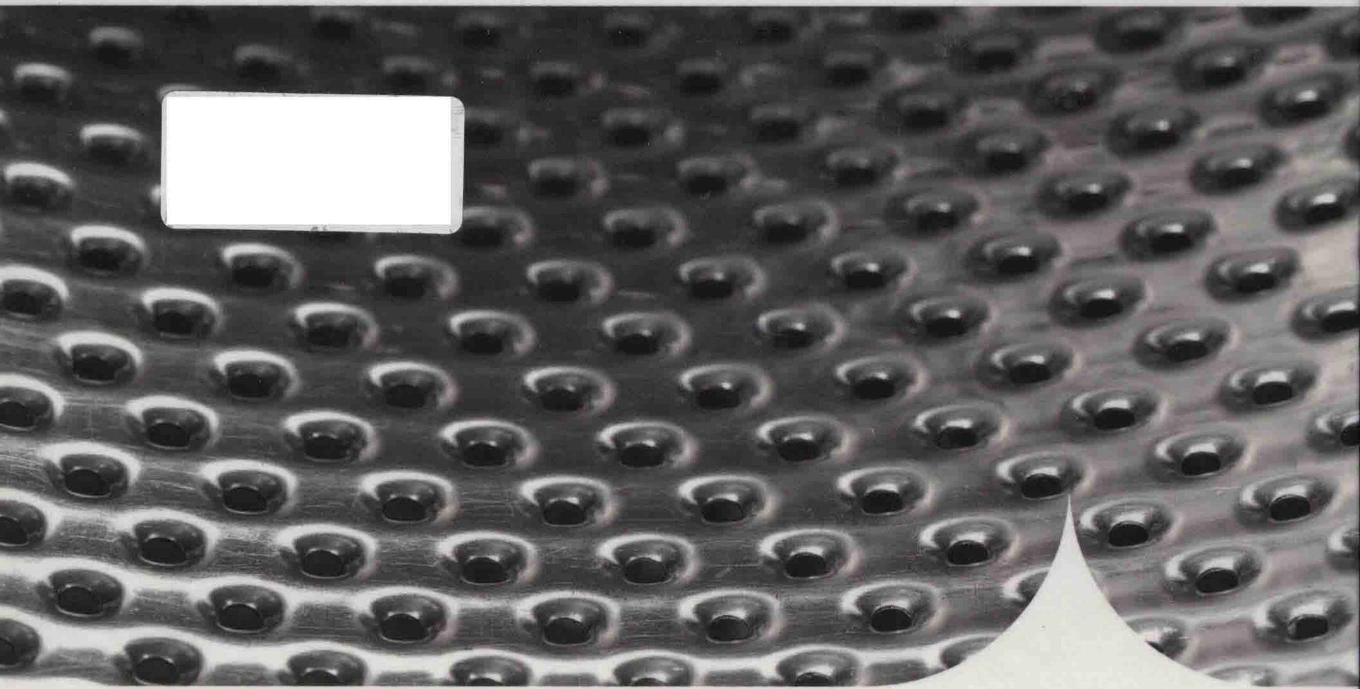
Research Essentials



Surface Engineering Techniques and Applications

Research Advancements

Loredana Santo and J. Paulo Davim

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Surface Engineering Techniques and Applications:

Research Advancements

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Preface

In recent years, great attention has been focused on surface engineering that deals with methods for achieving the desired surface requirements for engineering components. Surface engineering incorporates, consequently, all the techniques by which a surface modification can be accomplished, including both coating and modification of the surface by different processes.

The surface of any components may be selected on the basis of texture and color, but in the case of engineering components it generally needs other functions because it often works under various conditions and also in aggressive environments. The engineering environments can be generally complex, often combining loading with chemical and physical degradation to the surface of the components. Therefore, aesthetics and functionality are both required for engineering applications and today the goal is to achieve more function at a time, defining the multi-functionality of the surfaces. Mechanical, optical, electrical, photoelectric, magnetic, and tribological properties are modified particularly in the area of thin films, adding some functionality to the surface. In this context, the interfaces can have a great importance.

For all these purposes, the surface engineering includes many facets of material science that help regulate the function, quality, and also safety of products such as automotive, aerospace, biomedical, textile, and electronic materials. Friction, wear, erosion, corrosion, adhesion, surface tension, interface science, surface finishing are just some aspects of interests, commonly investigated. New technologies and methods of characterization are developing to help enhance the surface performance.

Techniques for coating and surface modification strictly depend on the substrate material. In the case of traditional materials, surface engineering techniques include, for example, nitriding, boriding, and carburizing, while the newer ones can be ion implantation, laser beam melting, and coating of different materials mainly by chemical and vapour deposition.

Recently, the growing use of light alloys (aluminium, magnesium, and titanium alloy) in industry, such as aerospace, sport equipment, and biomedical devices, is driving research into surface engineering technologies to improve the corrosion, wear, and tribological properties of these materials. Surface engineering technologies, such as anodising, thermal spraying, physical vapour deposition, plasma-assisted surface treatment, and laser surface modification, are the most relevant for the applications.

New classes of materials, such as superlattices, nanotubes, nanocomposites, smart materials, molecularly doped polymers, and structured materials, can expand and increase the functionality of thin films and coatings used in different applications. New advanced deposition processes and hybrid processes are being used and developed to deposit advanced thin films and structures, obtaining performance not possible in the past.

In this context, the book provides recent developments in surface engineering techniques and applications, addressing mainly mechanisms of microstructure formation, properties, and characterization of surface layers. A wide range of applications is discussed. Greater emphasis is given to unconventional processes that today play a very central role in the manufacturing of many parts with high performance. Laser-additive manufacturing is an example of emerging technology, very useful to obtain very complex parts and surfaces by using different materials.

The book details scientific and technological results of different surface engineering techniques applied to different fields so that academics, practitioners, and professionals in these fields, as well as students studying these areas, can deepen their understanding of new surface processes. The audience can be therefore broad and multidisciplinary.

The book is organized into nine chapters. A short summary about the contents of the chapters is as follows.

Chapter one, written by A. Godi et al. from Denmark, deals with the functional surfaces in mechanical systems. A classification is proposed taking into account how the texture is designed. An overview of the fabrication methods and some practical examples are discussed. Finally, the surface metrology is proposed. This topic becomes fundamental in the design and generation of surfaces for functional purposes.

Chapter two, written by P. Sahoo et al. from India and Portugal, deals with design and selection of chemically deposited nickel coatings for optimum tribological behaviour. Different experimental tests are carried out to evaluate the performance of the coatings. Taguchi-based grey relational analysis is used for the optimization of the multiple response problem.

Chapter three, written by D. Persuad from USA, deals with surface treatment advancements and corrosion control techniques for degradable magnesium alloys. This chapter provides a detailed explanation of the most successful mechanisms used to control the corrosion of magnesium and its alloy and highlights the benefits and challenges for using them.

Chapter four, written by K. Surekha et al. from South Africa, is focused on the recent advances in the solid-state surfaces engineering techniques, including Friction Stir Processing (FSP) and Friction Surfacing (FS). The effectiveness of such techniques in improving the surface properties is discussed.

Chapter five, written by R. M. Mahamood et al. from South Africa, Nigeria, and India, deals with laser metal deposition used for improving the surface integrity of components. The chapter shows the capabilities of this process in production, repair, and improvement of surface properties.

Chapter six, written by M. Totleng et al. from South Africa and India, deals with Laser-Assisted Cold Spraying process (LACS). In the chapter, coatings of composite powders made of titanium and hydroxyapatite deposited on Ti-6Al-4V substrate by LACS technology are discussed.

Chapter seven, written by R. M. Mahamood et al. from South Africa, Nigeria, and India, deals with Laser-Additive Manufacturing (LAM) in surface modification of metals. Some of the LAM techniques are highlighted in this chapter, and a specific example is discussed for the surface modification of titanium alloy.

Chapter eight, written by Boschetto et al. from Italy, deals with surface characterization in fused deposition modelling. In this chapter, prediction models are presented and a new characterization approach is detailed.

Chapter nine, written by H. Kamiya from Japan, deals with surface modification and structure control for nano-and fine-particle aggregation and adhesion behaviour control in liquid phase. Two kinds of approaches for preparing surface-modified nanoparticles are discussed: post-synthesis surface modification and in situ surface modification. That ends the summary of the chapters.

The treated topics are across several fields of study and show different targets. This highlights the complexity of organizing a book on this matter.

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We would like to express our heartfelt thanks to all of those who have taken the opportunity to work on this book. Thanks to all the authors for their effort in preparing the texts. Thanks to our assistant development editor, Austin M. DeMarco, for his faith in the project from the outset. Thanks also to Dr. Donatella Gagliardi for her precious support in the final stages of the book. And a special note of thanks to our families whose constant support keeps us going.

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Chapter 1
Functional Surfaces in Mechanical Systems:
Classification, Fabrication, and Characterisation

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ABSTRACT

This chapter deals with functional surfaces in mechanical systems. These surfaces are named in a multitude of ways; therefore, a classification is provided based on how the texture is designed. For a better clarification, a number of practical examples for each category are given. An overview of fabrication methods employed to produce such surfaces is presented. The numerous fabrication methods are classified based on the mechanism they employ for providing a texture. Three main categories (removing, moving, and adding material techniques) are identified, and for each of them, a number of processes are described with examples of the textures they can create. The last section of the chapter deals with surface metrology, a topic of central importance in the design and generation of surfaces for functional purposes. The process of surface characterisation is outlined, reviewing measuring instruments, classical and advanced filtering procedures, quantification methods, and eventually, providing traceability considerations.

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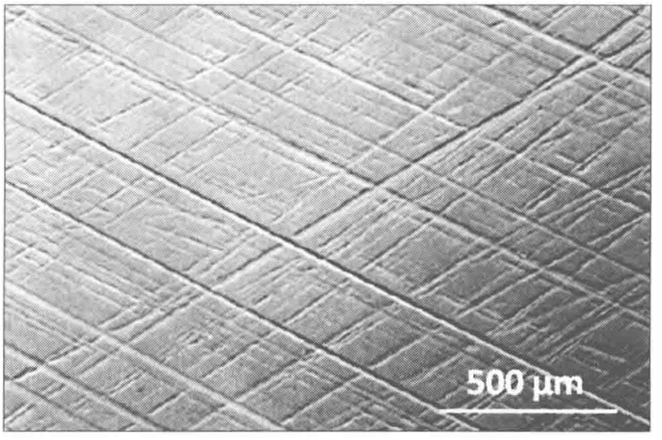
INTRODUCTION

Surfaces are defined as the outer boundaries of an object, separating it from the surrounding medium (Lonardo et al., 2002; ISO 25178-2, 2012). The most important physical phenomena involving exchange of energy take place on them, so it is not surprising that they play a decisive role in governing the functionality of a product (Bruzzone et al., 2008; De Chiffre et al., 2003). This is particularly true for mechanical systems in manufacturing processes and machine components, in which surfaces of different parts are in relative contact and movement. Those are called tribo-systems, from the word "Tribology," the science studying contacting surfaces in relative motion and covering disciplines as friction, lubrication and wear (Gohar & Rahnejat, 2008). The control of these three parameters gains high economical relevance if considered that around 30% of the world energy consumption is used to overcome friction (Williams, 1994); and the costs associated with wear is in the order of percentage units (as high as 5%) of the Gross Domestic Product of developed countries (Jost, 1966; Jost, 1990; Hutchings, 1990). Over the last few decades, the worldwide expansion of micro/nano manufacturing technologies has given origin to a "rush towards miniaturization," which contributed in a decisive manner among other things at the progress of the research about surfaces (Bruzzone et al., 2008). The manufacture and control of singular features on a surface was made possible, allowing the creation of dedicated surfaces able to provide one or more functional properties. Plateau-honed surfaces represent one of the first and maybe the most classical example of a surface presenting a texture purposely aimed to improve the tribological properties of the part featuring it. These surfaces have been widely utilized in the automotive industry since the 70s, applied particularly in cylinder liners of internal combustion engines. Plateau-honing is a double-step process: a coarse honing operation is initially performed providing a rough texture, followed by a much finer one truncating the original texture (Santochi & Vignale, 1982; Malburg & Raja, 1993). The resulting outmost texture will then be nominally flat, without main outwards peaks, but crossed by deep scratches (Figure 1). Creating a flat area gives good bearing properties to the surface and reduces drastically the so-called run-in period, in which the peaks of the surface are eliminated by attrition produced by the reciprocating action of the piston (Whitehouse, 1983). Moreover, the scratches, residuals of the coarse honing process, provide the surface with good lubricant retention properties and offer a location for debris storage. The employment of plateau-honed surfaces offers the great advantages of reducing wear phenomena and oil consumption; the process was therefore taken up with enthusiasm by car manufacturers already in the early years after its introduction (Whitehouse, 1983).

Figure 1. Plateau-honed surface (Malburg, ©2002 Digital Metrology Solutions, Inc. Used with permission)

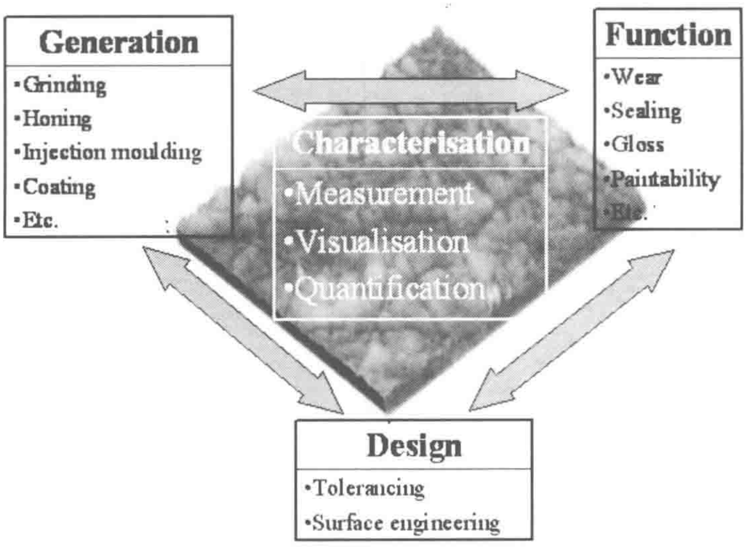


Plateau-honing is just one in the multitude of texturing techniques that have been developed, and nowadays a broad range of functional surfaces typologies is available. Limited to the field of tribology, textures with the most various designs (grooves, dimples, herringbone patterns, etc.) have been experimented and have shown promising results in terms of reduction of the friction coefficient both in machine element and metal forming applications. These surfaces are named in different ways by the different authors and that can cause confusions and misunderstandings. A univocal classification of functional surfaces eliminating all ambiguities is therefore provided. Afterwards an overview of the manufacturing methods mostly utilized to realize those surfaces is presented, classifying them also by the main characteristic of the process. The most appropriate manufacturing method must be selected in relation to the design to be achieved and, especially, to the function to be pursued. Surface characterisation is the tool acknowledged connecting these three aspects as it can be seen from Figure 2. Surface characterisation is therefore a topic of central importance in the realisation of functional surfaces and to it the third section of this chapter is dedicated.

CLASSIFICATION

Surfaces able to achieve certain functions exist both in the natural and in the artificial, industrial world. The range of applications explored is extremely broad spanning from optics to machining, from self-cleaning to biomedicine. The nomenclature used to identify those surfaces is various and terms as "textured," "structured,"

Figure 2. Surface characterisation links design, generation and function (De Chiffre, 2011b)



"functional" and "engineered" are easily found in literature. Sometimes, in industry, the term "engineered surfaces" refers to surfaces which have undergone some sort of superficial treatment such as CVD or PVD coating, but with no reference to functionality. The confusion can be high, so at the end of the 90s Evans and Bryan (1999) wrote a well-known CIRP keynote paper providing definitions of these terms as well as numerous examples of applications. According to them an engineered surface is "a surface where the manufacturing process is optimized to generate variation in geometry and/or near surface material properties to give a specific function;" whereas a structured surface is "a surface with a deterministic pattern of usually high aspect ratio geometric features designed to give a specific function." Moreover, they also recommend not using the word "textured" for not generating confusion with the term surface texture. Few years later Stout and Blunt (2001) take up the discussion providing a comprehensive surface classification valid for all kinds of surfaces, including 'classical', non-engineered surfaces, direct consequence of the manufacturing process where the main objective of their creation is to provide the final geometry to the workpiece. In Figure 3 is shown a surface classification deliberately inspired to theirs but limited to the engineered surfaces part. Instead of using the term "engineered," the term "functional" is preferred. In this text they are treated as synonyms, since the only difference is where the focus lies when reading the definition. The term "engineered" sets focus on the first part of the definition, the way by which the surfaces are produced; "functional" sets focus on the second