Editorial

Special Issue on Surface Treatment by Laser-Assisted Techniques

Rafael Comesaña ^{1,2}

¹ Department of Materials Engineering, Applied Mechanics and Construction, University of Vigo, EEI, Lagoas-Marcosende, 36310 Vigo, Spain; racomesana@uvigo.es

² LaserON Laser Applications Research Group, University of Vigo, Industrial Technological Research Centre - MTI, Rúa Maxwel, 36310 Vigo, Spain

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1. Introduction

Laser radiation is a powerful tool for surface modification owing to its spatial and material absorbance selectivity. The non-contact and chemically clean characteristics of laser processing make this technique very attractive for surface treatment in a wide variety of scientific and engineering areas. Moreover, the advances made in laser pulse control and beam delivery, together with increasingly available and affordable laser sources, has boosted laser integration in surface modification and coating procedures at research and industry levels.

The applications of enhanced surfaces by laser-assisted treatments are very broad, and only some of them are introduced here. The fabrication of superhydrophobic, self-cleaning, and anti-icing surfaces has a potential impact in the aircraft industry by improving the structural behavior at low temperatures. Surfaces for sensing, catalytic, electronic, biomedical, as well as energy production and storage purposes are modified at nanometer level to take advantage of their high specific surface area and reactivity. In the field of the biomedical implants, the enhancement of biomedical hip joint prosthesis is addressed to improve surface fixation to host bone, avoiding the use of external acrylic cements. In the manufacturing industry, free-form surface molds can be efficiently polished by laser radiation-based systems. Lightweight hybrid structures with tailored properties can benefit from the production of metal-polymer dissimilar joints, where the structural properties are improved by the seam surface modification prior to thermal joining. Stone and mining industries require highly abrasive anti-wear components for cutting saws, which can be obtained by laser cladding of metal-diamond composites. Moreover, a stone cut surface finish can be tailored with minimal dust and no tool wear if the mechanical and flame equipment are substituted by the laser blasting technique. Finally, thermal barrier coatings for operation temperatures over 1000 °C for the aerospace, petrochemical, and energy industries can be obtained by laser cladding on metallic superalloys.

The most important laser techniques in surface engineering can be divided into the four main types of laser treatment: remelting-free techniques, remelting techniques, evaporation techniques and the special techniques for the formation of thin and hard coatings. Laser remelting-free techniques are represented, e.g., by surface annealing, tempering or preheating, surface hardening, and surface cleaning. Laser remelting techniques include surface remelting, surface alloying, and cladding. The most commonly used laser evaporation techniques are as follows: pure evaporation, detonation hardening and ablation. The technique referred as laser texturing usually involves material ablation and it can be classified as an evaporation technique, but occasionally mixed melting/vaporization are found below this term. The thin and hard coatings could be formed by the fusion alloying in the gas method, pure vapor deposition, pyrolytic, and photochemical methods as well as by chemical methods, e.g., laser-assisted chemical vapor deposition.

2. Surface Treatment by Laser-Assisted Techniques

The eleven research articles of this Special Issue “Surface Treatment by Laser-Assisted Techniques” cover laser surface modification from the nanoscale to the macroscale. Specific topics range from the production of nanoparticle-structured thin films to the deposition of mm-thick coatings, passing through the micro-texturing of metallic and ceramic surfaces. The individual work is summarised below:

The paper “Tunable Hierarchical Nanostructures on Micro-Conical Arrays of Laser Textured TC4 Substrate by Hydrothermal Treatment for Enhanced Anti-Icing Property” by Liu et al. presents the fabrication of anti-icing structured surfaces on Ti6Al4V alloy substrates [1]. Hydrothermal treatment in aqueous alkali of the microstructured laser-ablated surface led to the formation of titania (TiO₂) nanostructures. This work discusses the nanoarray growth mechanism on the micro-conical arrays and shows its superhydrophobic (approximately contact angle of 160°) and water freezing delaying properties.

The paper “Characteristics of Pd and Pt Nanoparticles Produced by Nanosecond Laser Irradiations of Thin Films Deposited on Topographically-Structured Transparent Conductive Oxides” authored by Torrisi et al. shows the production of Pd and Pt nanoparticles on Fluorine-doped tin oxide (FTO) by laser-assisted dewetting of nanoscale-thick films [2]. This work explains how the substrate topography plays a role in the liquid metal film dewetting and in the associated nanoparticle characteristics, and the existence of a critical film thickness related to the change of dewetting characteristics of the film. Moreover, a surface enhancement Raman scattering effect (SERS) was observed in the Pd nanoparticle/FTO/glass samples.

The paper “Synthesis and Deposition of Ag Nanoparticles by Combining Laser Ablation and Electrophoretic Deposition Techniques” by Fernández-Arias et al. presents the production of uniform silver nanostructured thin films on silicon substrate by pulsed laser ablation in liquid (PLAL) and electrophoretic deposition (ED) techniques [3]. During the ablation process in aqueous media, the silver target constitutes the positive electrode, while the silicon substrate is the negative electrode. This work addresses the analysis of the surface topography, composition, crystallinity and optical properties of the produced thin films, and localized the surface plasmon resonance (LSPR) around 400 nm.

The paper “Laser Surface Texturing of Alumina/Zirconia Composite Ceramics for Potential Use in Hip Joint Prosthesis” authored by Baido et al. describes the texturization of bioinert composite ceramics to improve fixation to host bone of hip joint acetabular cups [4]. The incidence of the laser processing parameters in the modified surface topography is methodically analysed in this work. The surface roughness was observed to be modified between in the range of 3–30 µm, and the application to real ceramic acetabular cups with a curved profile was demonstrated to be feasible.

The paper “Influence of Aluminum Laser Ablation on Interfacial Thermal Transfer and Joint Quality of Laser Welded Aluminum–Polyamide Assemblies” by Al-sayyad et al. presents the laser ablation of aluminium alloy for aluminium-polyamide 6.6 dissimilar joining and investigates the effects of the laser irradiation on the modified surface properties [5]. Laser flash analysis (LFA) and thermal contact resistance (TCR) quantification in the obtained surfaces is performed. A strong influence of laser ablation parameters on the surface structural and morphological properties is evidenced.

The paper “Thermoelastic Response Induced by Volumetric Absorption of Uniform Laser Radiation in a Half-Space” by Tayel implements the application of the generalized theory with Dual-Phase-Lag (DPL) to the study of the thermoelastic response for pulsed laser absorption [6]. Predictions in the practical case of copper media are analysed and compared to application of Lord-Shulman (LS) and classical coupled (CTE) theories. The results give insight to the expected evolution of several important parameters in pulsed laser surface modification, for instance, temperature lag, temperature distribution, and stress distribution.

The paper “Experiment Study of Rapid Laser Polishing of Freeform Steel Surface by Dual-Beam” authored by Zhou et al. focuses on the production of steel polished surfaces by combination of a top-hat continuous wave beam and top-hat pulsed laser beam [7]. The influence of the initial surface roughness, the laser spot size, the scanned trajectory, and the waveform of the pulsed laser on the

polished surface topography is analysed. In this work, post-polished promising values down to 142 nm in average roughness were achieved, opening the door to a highly efficient final polishing step for free-form surfaces.

The paper “Laser Surface Blasting of Granite Stones Using a Laser Scanning System” by Penide et al. presents the surface texturization of granite stones by means of scanned laser irradiation in air atmosphere [8]. This work explains, through an experimental factorial design, the influence of the processing parameters on CO₂ laser roughening from as cut or polished state up to average roughness values of 20 µm. Preservation of quartz and feldspar crystallinity was observed, while annite experienced amorphization and micro-droplet formation. The authors demonstrate the induction of less mechanical stresses than in conventional bush hammering or flame blasting, therefore this technique can process lower thickness granite tiles.

The paper “Microstructures and Wear Resistance of FeCoCrNi-Mo High Entropy Alloy/Diamond Composite Coatings by High Speed Laser Cladding” by Wang et al. is devoted FeCoCrNi-Mo high entropy alloy/diamond composite coatings by laser cladding to be used as highly abrasive and wear resistance surface [9]. The authors explain the components proportion and processing parameters optimization to avoid graphitization and diamond thermal damage, and to improve bonding to the metallic matrix. In this work, the successful production of composite coatings with uniform microstructure and good wear resistance was demonstrated.

The paper “Statistical/Numerical Model of the Powder-Gas Jet for Extreme High-Speed Laser Material Deposition” authored by Schopphoven et al. describes the gas-powder stream modellization with practical application in laser cladding, and in additive manufacturing based on laser cladding (laser material deposition, LMD) [10]. This mathematical and experimental work considers coaxial powder delivery and spherical precursor material, and provides useful information for the prediction of precursor particle trajectories and particle-radiation interactions in the jet and laser beam intersection volume.

The paper “High Temperature Oxidation and Thermal Shock Properties of La₂Zr₂O₇ Thermal Barrier Coatings Deposited on Nickel-Based Superalloy by Laser-Cladding” by Huang et al. presents the production of thermal barrier coatings on a superalloy substrate and its characterization after isothermal oxidation and thermal cycling up to 1100 °C [11]. Preservation of the La₂Zr₂O₇ coating composition after processing was observed, and moderated improvements in the thermal shock lifetime and oxidation weight gain in comparison to the superalloy substrate were demonstrated.

3. Perspectives

In the laser-assisted techniques, the wavelength, pulse length, pulse energy, and associated surface irradiation density play a principal role to delimit the surface modification capabilities for a specific material. No single laser source is able to provide the optimal optical radiation for a specific surface treatment. Thus, having a clear overview of the laser beam capabilities is important for a correct research design. The applied laser treatment and optical radiation for each material surface in the scientific works collected by this special issue are recapitulated in the following paragraphs.

Laser texturing of titanium alloy is performed by means of a Nd:YAG pulsed laser with a wavelength of 1064 nm, 100 ns pulse width, and 0.1 mm spot size [1]. Laser ablation of Pd and Pt is achieved via nanosecond pulsed Nd:YAG laser working at 532 nm, 12 ns pulse length, and fluence of 0.50 J/cm² [2]. Laser ablation of Ag nanoparticles in liquid media is done by the use of of nanosecond pulsed Nd:YVO₄ laser source operating at 532 nm, 14 ns pulse length, and average optical power of 6 W [3]. Laser texturing of ceramic composites is made by means of Q-switched Nd:YVO₄ laser source operating at 1064 nm, 10 ns pulse length, and pulse energies in the range 240–800 µJ [4]. Laser ablation of aluminium alloy as pre-processing for laser assisted metal-polymer joining is accomplished by using a Nd:YVO₄ laser source operating at 1064 nm, and fluence values in the range 8.7–28.6 J/cm², and subsequent laser joining by a fiber laser operating at 1070 nm, and 35 µs pulse length [5].

Laser polishing of steel is implemented via combination of two top-hat laser beams, a continuous wave fibre laser delivering 600 W at 1080 nm and 0.47 mm spot size, and a pulsed Q-switched fibre laser delivering 80 W at 1064 nm, pulse length 1.3 μ s and 0.32 mm spot size [7]. Laser surface blasting of granite stone is performed by means 1 kW of CO₂ laser radiation operating at 10600 nm, a 710 mm focal length, a polygonal scanner, and 0.56 mm spot size [8].

Metal-diamond composite coatings are produced by laser cladding by the use of continuous wave diode laser irradiation with optical power in the range 3.0–5.5 kW, robot scanning speed between 30 and 60 mm/s, 4.6 mm spot size, and coaxial powder delivery [9]. Thermal barrier ceramic coatings on a high temperature nickel super alloy are deposited by laser cladding by means of continuous wave diode laser irradiation with optical power in the range 3.5 kW, 10 mm/s scanning speed, 5 mm $\times$ 5 mm spot size, and preplaced powder [11].

It can be outlined the use of the nanosecond pulsed laser radiation in the visible and near-infrared ranges of the spectra for micro- and nano-texturing of a wide range of materials, while the semiconductor diode laser radiation in the near-infrared range is employed for laser cladding. Moreover, the combination of the laser radiation and other non-optical processes, or the implementation of dual laser radiation systems, is a current requirement to improve both scientific reach and the quality of technical results. The prospective research in surface treatment by laser-assisted techniques appears to be directed towards short and ultra-short laser pulse texturing and the exploration of new laser wavelengths around the near-infrared and mid-infrared frontier.

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