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Editorial

Tribology and Surface Engineering

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Abstract: The Special Issue on Tribology and Surface Engineering includes nine research articles and one review article. It concerns a very important problem of resistance to wear and shaping the properties of the surface layers of different materials by different methods and technologies. The topics of the presented research articles include reactive direct current magnetron sputtering of silicon nitrides on implants, laser surface modification of aeroengine turbine blades, laser micro-texturing of titanium alloy to increase the tribological characteristics, electroplating of Cu–Sn composite coatings incorporated with Polytetrafluoroethylene (PTFE) and TiO_2 particles, arc spraying of self-lubricous coatings, high velocity oxygen fuel (HVOF) spraying and gas nitriding of stainless steel coatings, HVOF spraying composite WC-Co coatings, testing of coatings deposited by physical vapour deposition (PVD), and also analysis of material removal and surface creation in wood sanding. The special issue provides valuable knowledge based on theoretical and empirical study in the field of coating technologies, as well as characterization of coatings, and wear phenomena.

Keywords: surface engineering; coatings; tribology; wear resistance; properties of surface layers

1. Introduction

The progressive wear of moving parts and components of machines or tools under operating conditions is a natural phenomenon, leading to a gradual decrease in performance, efficiency and work parameters of a given element. The used machine parts or tools need to be replaced with new ones, which is usually associated with the need to temporarily shut down the machine or the entire technological process.

Meanwhile, global industry constantly strives to increase the efficiency and effectiveness of technological processes, as well as machines and vehicles. This makes the working conditions of tools and machine parts increasingly difficult. Therefore, the industry is constantly searching for new and advanced structural and tool materials, as well as methods of their production, which in specific operating conditions will ensure maximum durability, at an acceptable level of unit costs.

One of the most significant and interesting achievements in materials engineering and manufacturing processes is the development and introduction of composite materials to the industry. Research and development on production methods of metal matrix composites (MMC) are carried out in many research centers around the world [1–9]. These types of composite materials combine the advantages of the metal matrix characterized by high ductility with the reinforcing material. Therefore, such composite materials have excellent fatigue strength, high ultimate strength, and simultaneously low specific weight. In the case of composite coatings, usually dispersion particles or phases with high hardness provide increased wear resistance.

Another significant achievement in materials engineering and manufacturing processes in recent years is the introduction and now widespread use of nanomaterials, as well as amorphous materials [10–16]. However, intensive research is still ongoing, and the attention of researchers from around the world is focused on manufacturing processes and the application of nanomaterials due to the high potential of this group of materials, characterized by grain size on a nanometric scale, most often in the range below 100 nm. Nanostructured materials—both metallic, and composite—have functional properties (e.g., mechanical strength) often many times higher than conventional materials. Even by grain refinement and creating a nanostructure in the case of already known and conventional engineering materials, it is possible to significantly improve physical, chemical, and mechanical properties—such as e.g., increase in hardness and strength—increase in wear resistance of contact surfaces, increase in ductility of fragile materials, etc. For example, the tensile strength of copper with grains of the order of 50 microns does not exceed 500 MPa, while after grains refinement to dimensions of the order of 8 nm, the strength increases up to five times to 2500 MPa.

The manufacturing of coatings of modern composite and metallic materials in micro or nanometric scale, as well as the manufacturing of surface layers with special properties is possible only by applying the most advanced technologies of coatings and surface engineering.

Currently, the most commonly-used technologies of coatings in industry are as follows:

- Arc and plasma cladding technologies ensuring high melting efficiency of the additive material (consumable). However, the disadvantage is the relatively huge amounts of heat introduced into the substrate material make it difficult to obtain fine-grained structures. For this reason, these technologies are used usually for cladding of relatively large and massive components.
- Laser beam and electron beam cladding, providing very low heat input, low dilution, and narrow heat affected zone.
- Thermal spraying technologies including flame, arc, and plasma spraying, high velocity oxygen fuel spraying (HVOF), and cold spraying (CS) at supersonic gas jet velocities, that allow the production of coatings with a structure and chemical composition unattainable by the cladding technologies. The disadvantage is that the coatings are characterized by discontinuity and often considerable porosity, which reduces their utility values and limits the scope of practical application.
- PVD and chemical vapor deposition (CVD) coating technologies that allow the creation of metallic and composite nanostructured coatings. However, in this case the thickness of the coatings is small and the manufacturing process is time consuming, and also extremely expensive.

Another issue is the shaping properties of surface layers to improve the tribological characteristic and wear resistance by various surface engineering methods including heat treatment and thermochemical treatment.

Various methods of surface heat treatment to improve the tribological properties of metals and alloys were investigated and are widely described in the literature [17–21]. The most interesting and most advanced are laser and plasma surface treatment, and ion implantation. The basic principle of the surface heat treatment methods is to change the microstructure in the surface layer, without changing the chemical composition, by extremely high heating and cooling rates. Depending on the processing parameters and conditions the mentioned above methods can be also used for thermochemical treatment. Thanks to the thermochemical surface treatment coupled with enrichment of the surface layer by different elements, the corrosion resistance and wear resistance can be improved, as well as the friction coefficient can be significantly lowered. Oxidation, carburizing, and nitriding are the most popular and widely used methods of thermochemical surface treatment of metals and alloys, in particular in the case of titanium and titanium alloys.

Summarizing, the intensity and the type of wear are dependent on the type and intensity of the load, and also on the environmental factors such as corrosive liquid or gaseous agents, temperature, etc. Therefore, in order to provide the durability and reliability of components of machines or tools an individual approach to each of the working surfaces is required, choosing the proper material, design its microstructure, and application the optimal method of manufacturing or processing.

2. This Special Issue

This special issue, entitled "Tribology and Surface Engineering", is a complementary and valuable resource of knowledge in the field of phenomena and mechanisms of surface wear, and methods of enhancing tribological properties of working surfaces.

Liu et al. [22] provide comprehensive review of the analytical and empirical studies on micro pitting phenomena in the case of steel gears used in wind turbines, helicopters, or ships. They identified and pointed several relevant factors influencing the micro pitting behaviors, e.g., gear materials, surface topographies, lubrication properties, working conditions. They also described mechanisms of wear, and indicated the way to improve the micro pitting resistance of the gears. The information presented in the review can be very helpful and useful for designers of modern heavy-load, high-speed mechanisms.

In turn, a very similar problem related to gear wear was investigated and described by Michalczewski et al. [23]. They pointed out that the type of the oil used for the transmission can have a significant impact on its durability and reliability. Therefore, they investigated the influence of three commercially available industrial gear oils on test samples with a new type of W-DLC/CrN coating. One mineral oil, and two synthetic oils with polyalphaolefin (PAO) and polyalkylene glycol (PAG) bases, respectively, were applied in the study. Based on the abrasion, scuffing, and pitting tests, they showed that synthetic polyalphaolefin (PAO) type oil provides the most favorable working conditions and the highest durability.

The microstructure and tribological properties of metallic coatings produced by high velocity oxygen fuel spraying (HVOF) were investigated by Lindner et al. [24], while the composite WC-Co type coatings produced by HVOF spraying were investigated by Ding et al. [25]. Lindner et al. applied additional thermochemical treatment of the HVOF-sprayed AISI 316L coatings to improve the wear resistance. The gas nitriding process was conducted at different temperatures. They successfully enriched the coatings in as-sprayed conditions by the nitrogen, and showed significant increase in wear resistance. In turn, Ding et al. produced composite conventional, multimodal, and nanostructured WC-12Co coatings with different WC sizes and distributions were prepared by HVOF spraying. The microstructure, phase composition, hardness, porosity, and cavitation erosion were investigated. The results revealed that the despite serious decarburization of nanostructured WC-Co coatings resulting in formation of W_2C and W phases, the nanostructured WC-Co coatings have the densest microstructure with lowest porosity, the highest fracture toughness, and also they exhibit the highest resistance to cavitation erosion wear.

The next articles concern the impact of reducing the coefficient of friction between contact surfaces on wear phenomena. Tillmann et al. [26] proposed a method for creating self-lubricous coatings based on arc spraying of vanadium containing iron-based deposit. The wear characteristic was investigated under dry sliding experiments, while the worn surfaces were examined by means of electron microscopy and energy dispersive X-ray (EDX) spectroscopy. They found that the vanadium-containing coatings exhibited a distinctly reduction of the coefficient of friction above 450 °C temperature, due to prevalence of specific vanadium oxides which promote a self-lubricating ability of the coating. Silicon nitride (SiN_x) coatings are considered as bearing surfaces for joint implants, due to their low wear rate and the good biocompatibility. Therefore, reactive direct current magnetron sputtering was applied by Filho et al. [27] to coat the CoCrMo disc samples with a CrN interlayer, followed by a SiN_x top layer, which was deposited by reactive high-power impulse magnetron sputtering. The phase composition, surface roughness, hardness distribution, and wear rate of the test coatings were investigated. They found that the bias voltages have a significant influence on the performance of SiN_x coatings, characterized by low wear rates. The promising results of study, conducted by Filho et al., support further development of silicon nitride-based coatings towards clinical application. In turn, Ying et al. [28] investigated the effect of TiO_2 particles and PTFE emulsion on properties of Cu–Sn composite coatings. Cu–Sn, Cu–Sn–TiO_2, Cu–Sn–PTFE, and Cu–Sn–PTFE–TiO_2 coatings type were electroplated with a pulsed power supply. The microstructure, phase composition, microhardness, corrosion resistance, and tribological properties were investigated. They described the influence of PTFE and TiO_2 on the microstructure, corrosion resistance, hardness, and tribological properties of the test coatings. They proved that presence of both PTFE and TiO_2 in the deposited coating leads to a lower friction coefficient of 0.1 and higher wear and corrosion resistance. Vazquez Martinez et al. [29] applied laser micro-texturing of the Ti6Al4V alloy surface to improve the friction, wear, and wettability behavior under sliding conditions. They investigated the influence of processing parameters such scanning speed of the laser beam, and the energy density of pulse on the tribological characteristic of the titanium alloy, including measurements of the contact angle using water as a contact fluid. The wear mechanisms were also studied and determined by means of microscopic observations. They found a strong dependence between the wear behavior and the laser patterning parameters. The micro-texturing of the surface caused reduction in wear up to a 70%, compared to untreated surfaces of Ti6Al4V alloy.

Another example of laser beam application in surface engineering for repair cladding and shaping properties of surface layers was demonstrated by Liu et al. [30]. Authors investigated the laser cladding of K417G Ni-based superalloy by analyzing the possibility of built-up cladding of worn turbine blades. Additionally, the laser surface remelting was applied for controlling the cracking sensitivity. Microstructure, hardness, and tribological properties of the base metal, coating after cladding, and after additional remelting were determined and described in details. Authors showed that, despite high tendency to cracking of the investigated Ni-based superalloy, the additional laser remelting process is advantageous, because it results in decreasing the size of cracks of the multilayer laser clads.

The last research article described here concerns investigations on sanding process of medium-density fiberboard (MDF) and Korean Pine. Zhang et al. [31] determined the mechanisms of material removal and the influence of processing parameters on the surface quality of the investigated materials. Authors declare that the finding and used approaches could provide insights to investigate other wood species or wood composites to improve the efficiency of sanding and simultaneously the surface quality.

3. Concluding Remarks

The special issue was very successful due to valuable articles submitted, a wide range of research problems undertaken, as well as in-depth analysis of the state of the art. The Special Issue consists of 10 papers; however, the total number of manuscripts submitted to the Special Issue was almost twice that. Unfortunately, some of the manuscripts have not gone through a very rigorous review process. Such a large interest and a large number of articles show the importance of the issue and themes.

It should be noted that in the field of materials engineering and surface engineering, each original scientific and research article is the culmination of hard research work and long-term study, usually a team of scientists. In turn, the results of such research have practical significance and contribute to the development of civilization.

Thanks to the MDPI Publisher and the reputable Open Access Journal "Coatings", interesting and innovative achievements of interdisciplinary teams of scientists from different countries can be presented to a wide range of readers around the world.

That is why I strongly encourage readers to thoroughly read all articles, and also I encourage the scientists to continue their research work and publish interesting results.

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