

Special Issue: “Micro/Nano Manufacturing Processes: Theories and Optimization Techniques”

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Manufacturing at the micro/nano scale creates many opportunities to fabricate micro- and nanostructures or to manufacture high-precision components, which has attracted considerable attention in fields such as optics [1], electronics [2], precision instruments [3], the semiconductor industry [4], biomedical engineering [5], etc. Over the years, much effort has been devoted to investigating the micro/nano manufacturing processes, but there are still some challenges to fully understanding them since the deformation mechanism of materials at the micro/nano scales is quite different from the well-known deformation mechanisms at the macro scale [6,7]. This Special Issue is dedicated to the special theories and some optimization techniques of the micro/nano manufacturing processes. The Special Issue is available online at: https://www.mdpi.com/journal/processes/special_issues/LN028R4O8S.

Fabrication of micro/nano-structured surfaces

Material surfaces with micro-structured patterns have attracted much attention in communication, medical, and military fields due to their superior properties, such as light trapping, antibacterial, and self-cleaning [8]. Generally, the micro-structured functional surfaces could be achieved by methods of ultraprecision machining, photolithography, etching, ion beam machining, microforming, micromolding, etc. [9,10].

The paper by Ma et al. [11] gives a state-of-the-art in fabrication methods and assisted technologies for micro-structured surfaces. The primary methods include lithography technology, high-energy beam direct writing technology, special energy field machining technology, molding technology, LIGA (a combination of lithographie, galvanoformung, and abformung) technology, and ultra-precision machining technology. In particular, the authors compared the advantages and disadvantages of different ultra-precision machining technologies such as fast/slow tool servo machining, ultra-precision diamond scratching, ultra-precision fly cutting, and raster milling. They also give some perspectives about the future trend in fabricating micro-structured functional surfaces and suppose that a combination of different methods is of great significance for the fabrication of multi-layer and multi-scale micro-structures.

The paper by Wu et al. [12] proposed an efficient method to fabricate the mold cavity structure for a helical cylindrical pinion based on a plastic torsion-forming concept. A new method termed low-speed wire electrical discharge machining (LS-WEDM) was used to fabricate the spur gear cavity. In comparison to the multi-stage helical gear core electrode and the complex spiral EDM process, the proposed method provides an efficient and simple way to generate the structure of the helical gear cavity by twisting the spur gear cavity plastically around the central axis. Some theoretical models were also proposed to evaluate the precision of the helical gear geometry. Based on this theoretical model and experimental results, the proposed LS-WEDM method could precisely control the shape accuracy of a helical cylindrical structure by adjusting the machine torsion angle.



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The paper by Du's team [13] successfully fabricates the micro/nanoscale hierarchical micropillar arrays on the thermoplastic polymer surface by an ultrasonic plasticizing and pressing (UPP) method. A high aspect ratio of up to 24.1 was achieved by the UPP methods since they could make full use of the ultrasonic vibration and avoid the violent friction between the raw material and template. In comparison to other template methods, the UPP has advantages in superior forming capability, a simple process, a short production cycle, and high cost-effectiveness. The authors also measured the wettability of the surface with micro/nanoscale hierarchical micropillar arrays and found that the micro-structured surface shows superhydrophobic and superoleophilic properties, which provide potential uses in both research and applications.

Simulation and experimental investigation of laser manufacturing

Laser manufacturing has been widely used in industry applications such as cutting, drilling, welding, scribing, and additive manufacturing due to its high precision, high speed, and versatility. The paper by Xu et al. [14] studied the femtosecond laser ablation of $\text{Cu}_{50}\text{Zr}_{50}$ metallic glass by molecular dynamics simulation based on a two-temperature model. They found that the maximum electron temperature at the same position on the target surface decreased as the pulse duration increased, but there was no significant change in the electron–lattice temperature coupling time. They also investigate the effect of absorbed fluence on the maximum electron temperature at the same position on the target surface and the electron–lattice temperature coupling time. Melting, spallation, and phase explosion caused by femtosecond laser irradiation give rise to the surface ablation of the target material.

The paper by Zhao et al. [15] investigated the high-speed laser-induced thermal crack propagation (LITP) dicing of a glass–silicon double-layer wafer. Both numerical simulations using the ABAQUS and experiments were conducted in this study. Their results indicate that the region near the upper surface of the glass layer cracked asynchronously with the silicon layer during the stable extension, and the crack propagation in the glass layer material is not synchronized with that in the silicon. In addition, a good surface roughness of 19 nm and 9 nm was achieved in the silicon and glass layers, respectively. In order to address the problem of trajectory deviation that usually occurs in actual glass cutting operations by the LITP, Zhao et al. [16] further proposed a low-temperature gas cooling trajectory deviation correction technique, which optimizes the temperature and stress distribution by spraying low-temperature gas onto the processing surface and maintaining a relative position with the laser. The proposed trajectory deviation correction benefits the application of LITP technology in practical glass cutting.

Optimization techniques in the microscale machining

The paper by Zhou et al. [17] presents a scheduling optimization approach for the micro-hole drilling production line of printed circuit boards (PCBs). A complex event model considered an emergency insertion event, a production line equipment operation event, and a tool failure event was proposed. A catastrophe genetic algorithm was also used to solve the initial scheduling scheme of the micro-hole drilling production line. Compared to the traditional genetic algorithm, the proposed catastrophic genetic algorithm is more accurate and effective in solving various production line scheduling problems. In addition, a dynamic scheduling of the production line was realized by considering complex events and scheduling optimization, which contributed to an improvement in the scheduling optimization rate to 25.1%. The paper by Liu et al. [18] proposed an improved prediction model to predict the remaining useful life (RUL) of the drill bit in micro-drilling of the packaging substrate. The experimental results indicate that the modified model, taking into account the degradation rate and offset coefficient, could provide more accurate and stable results in comparison to traditional models, which are supposedly a reliable theoretical foundation for the health state monitoring of drill bits in the micro-drilling of packaging substrates.

In their paper, Zhao et al. [19] propose a novel approach for the topology optimization of compliant mechanisms to solve design challenges including static strength, fatigue

failure, and manufacturability. An improved solid isotropic material with penalization (SIMP) interpolation method is also used to derive the shape sensitivity of the optimization problem. The results indicate that the von Mises stresses in the force inverter and compliant gripper were below the materials strength limit of 275 MPa, and the fatigue-constrained topology optimization could reduce stress concentration. In order to meet the manufacturing process requirement, a three-field density projection approach was used to control the minimum size in the layout optimization. In addition, two numerical examples of an inverter and a gripper are given to illustrate the effectiveness of the proposed method.

The paper by Louis et al. [20] studied the performance improvement of milling tools by the chemical vapor deposition coating in the milling of zirconia ceramics (ZrO_2). Different diamond films with various diamond grain sizes, and film thicknesses were coated on the tungsten carbide milling tools by hot filament chemical vapor deposition (HFCVD). As the distances between substrate and filament decrease, the grain size and coating thickness of the diamond film on milling tools tend to decrease. In addition, the coating film with smaller grain sizes and thinner thicknesses could contribute to higher machining quality in terms of surface topology, surface roughness, and tool failure. Their findings provide useful instructions for parameter optimization in the production of coated tools by the HFCVD.

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