Defect and Diffusion Forum
ISSN: 1662-9507, Vol. 450, pp 103-110
doi:10.4028/p-I0dGes

Submitted: 2026-01-19
Revised: 2026-03-04
Accepted: 2026-03-04
Online: 2026-04-15

Laser Surface Texturing of Cylindrical Ejector Pins for Functionalization of Injection Molding Systems: A Preliminary Study

Agata Sposato[1,a*], Maria Rosaria Saffioti[1,b], Chiara Morano[1,c], Francesco Modica[2,d], Giovanna Rotella[3,e], Irene Fassi[4,f], Vito Basile[2,g]

[1]Department of Mechanical, Energy and Management Engineering, University of Calabria, Via Ponte Pietro Bucci, Cubo 45C, 87036, Rende, CS, Italy

[2]CNR-STIIMA, Institute of Intelligent Industrial Technologies and Systems for Advanced Manufacturing, National Research Council, Via P. Lembo 38F, Bari 70124 Italy

[3]Department of Engineering, University LUM Giuseppe Degennaro, Casamassima, BA 70010, Italy

[4]CNR-STIIMA, Institute of Intelligent Industrial Technologies and Systems for Advanced Manufacturing, National Research Council, Via A. Corti 12, Milano 20133 Italy

[a*]agata.sposato@unical.it, [b]mariarosaria.saffioti@unical.it, [c]chiara.morano@unical.it,
[d]francesco.modica@stiima.cnr.it, [e]rotella@lum.it, [f]irene.fassi@stiima.cnr.it,
[g]vito.basile@stiima.cnr.it

Keywords: microinjection molding, laser surface texturing, sustainable manufacturing.

Abstract. Laser surface texturing (LST) is increasingly adopted to functionalize the surface in injection molding, enabling the control of interfacial and tribological phenomena without altering bulk material properties. While most studies have focused on mold cavities, the functionalization of ejection system components remains largely unexplored, despite its critical role in part release and process stability. This work presents a preliminary investigation of laser surface texturing for cylindrical ejector pins to promote lubricant retention at the pin–mold interface. A parametric study was first carried out on a flat to define a process window compliant with the maximum allowable groove depth constraint (20 μm). Based on this campaign, a stable ablation regime was identified and transferred to cylindrical ejector pins, where textures were fabricated along axial length. Different micro-texture geometries and spatial distributions were designed to generate controlled micro-reservoirs for lubricant retention. The textured surfaces were characterized in terms of groove depth, morphology and uniformity, confirming the feasibility of producing shallow and well-defined features within industrial constraints. The preliminary results demonstrate the technical feasibility of laser texturing on cylindrical ejector pins and its potential to modify the pin–mold interface. However, the comparative effectiveness of the different texture geometries in promoting lubricant retention will be further evaluated under extended service conditions. The study, therefore, establishes the basis for the functional optimization of textured ejection systems in injection molding applications.

Introduction

Injection molding is one of the most commonly used techniques for the production of a wide range of polymeric parts, especially those that demand high productivity, dimensional precision, and surface quality. Of the various steps in this processing technique, the critical phase is the ejection of the parts from the mold itself because of the risk of high adhesion or friction forces between the mold surfaces and the processed polymeric parts. Such forces may induce dimensional inaccuracies, deformed parts, longer processing times, and a dramatic increase in mold lifetime. As a consequence, there has been substantial interest in optimizing the functional properties of mold surfaces and ejection systems to reduce frictional and adhesive forces, as well as the wettability of the polymeric parts. This has led to the development of a range of technologies capable of modifying the textural features of polymeric parts without altering their inherent properties. Laser Surface Texturing (LST) is a modern technology that can modify the textural properties of processed parts by producing specific surface features. In the beginning, direct laser surface texturing was effectively used in the production of hydrophobic metallic surfaces. According to the research study by Gregorčič et al., laser-induced nanosecond texturing of stainless steel surfaces at high fluence can alter the material's hydrophobic properties by producing specific textural features [1]. This is just the beginning of the development of techniques capable of modifying the properties associated with the applied forces through the production of specific surface features. In addition, numerous studies have reinforced the effect of laser-induced textural properties in the production of metallic surfaces. Based on the study by Yang et al. [2], the surface texturing of 0Cr17Ni7Al stainless steel produced by laser processing was systematically investigated by correlating groove texture parameters with the resulting tribological behavior. The authors demonstrated that controlled laser-induced groove characteristics significantly influence the frictional properties of the metallic surface. This work represents a fundamental study highlighting how precise laser surface texturing can be effectively employed to tailor specific surface texture features and, consequently, the tribological performance of stainless steel.

In the context of injection molding, laser surface texturing has gained increasing attention as a means to functionalize mold cavities and inserts. A comprehensive overview of texturing technologies for plastics injection molding was provided by Masato et al., who reviewed conventional and advanced surface modification techniques, emphasizing the advantages of laser-based approaches in terms of design freedom, reproducibility, and industrial scalability [3, 4]. The review underlined how surface textures can influence polymer flow, part demolding, optical appearance, and surface functionality of molded components. Several experimental works have focused on the generation of laser-induced periodic surface structures (LIPSS) on mold steels and their replication onto polymer parts. Orazi et al. investigated the generation and characterization of LIPSS on plastic injection molds, demonstrating the feasibility of producing well-defined periodic structures and their durability under molding conditions [5]. Building on this, Piccolo et al. explored the replication of variable-pitch LIPSS onto plastic parts, showing that laser-textured molds can be used to functionalize polymer surfaces with controlled micro- and nano-scale patterns during the molding process [6]. These results were further extended by Gao et al., who analyzed the wetting characteristics of hierarchical laser-ablated textures replicated by micro injection molding, highlighting the strong link between mold texture geometry and the wettability of molded parts [7]. While most studies have focused on mold cavity surfaces, fewer works have addressed the role of surface texturing on ejection-related components. However, the ejection phase is strongly influenced by friction and adhesion mechanisms at the polymer–steel interface. Sorgato et al. demonstrated that machined cavity textures can significantly affect ejection force in micro injection molding, showing that surface topography plays a decisive role in part release behavior [8]. These findings suggest that extending surface functionalization strategies from cavities to ejection systems could offer additional benefits in terms of process stability and part quality. Recent investigations have also explored laser surface texturing in hybrid manufacturing contexts involving polymers and metals. Kim et al. studied the combined effects of laser surface texturing and injection molding parameters in direct joining between advanced high-strength steel and polyamide, confirming that laser-induced microstructures can enhance interfacial performance and mechanical interlocking [9-11]. Although focused on joining applications, this work further highlights the versatility of laser texturing in tailoring polymer–metal interactions. Within this research framework, the functionalization of cylindrical ejectors represents a relatively unexplored but highly promising direction. Unlike flat cavity surfaces, ejector pins and sleeves operate under localized contact conditions and are directly responsible for transmitting ejection forces to the molded part. The preliminary study forming the basis of the present work demonstrated the feasibility of applying controlled laser ablation to cylindrical ejectors, generating shallow vertical grooves with depths below 20 μm while preserving surface integrity. Such textures are expected to promote air evacuation, reduce real contact area, and mitigate adhesion during ejection.

The present contribution builds upon this preliminary investigation by extending the range of surface textures applied to cylindrical ejectors, exploring different geometries and spatial distributions and systematically assessing their influence on part release behavior in injection molding. By combining insights from laser surface engineering, tribology and polymer processing, this work aims to advance the understanding of how laser-textured ejector surfaces can be used as an effective tool to improve ejection performance and process robustness.

Materials and Methods

A preliminary experimental campaign was carried out on flat specimens in order to define the process window ensuring compliance with the maximum allowed groove depth. The tests were performed using an air-cooled ytterbium fiber laser system (Lasit CompactMark G8). The aim was to find the combination of laser power (P) and scanning speed (v) that is able to produce shallow and flat grooves below the 20 μm depth threshold imposed by the specification. Laser ablation tests have been carried out at varying process parameters, choosing three different scanning speeds and power levels: 1, 2, 10 mm/sec and 40, 60, 80 W, respectively. The formed grooves were evaluated using a non-contact white-light confocal profilometer (Rtec/UP-24). Among the tested conditions, the parameter combination of a scanning speed of 1 mm/s and 80 W of laser power was selected, as it provided a groove depth compliant with the imposed constraint while ensuring stable morphology.
Building on the outcomes of the preliminary phase, the following experimental campaign focused on extending the range of surface textures applied to cylindrical ejector pins (diameter 3 mm), made by nitrided steel 1.2344 (HRC 58–60), along a 15 mm axial length of the cylindrical ejector pins, according to the setup shown in Figure 1. The ejector pins used for the final application tests were surface-nitrided to increase surface hardness and wear resistance, as is typically required in industrial injection molding systems.

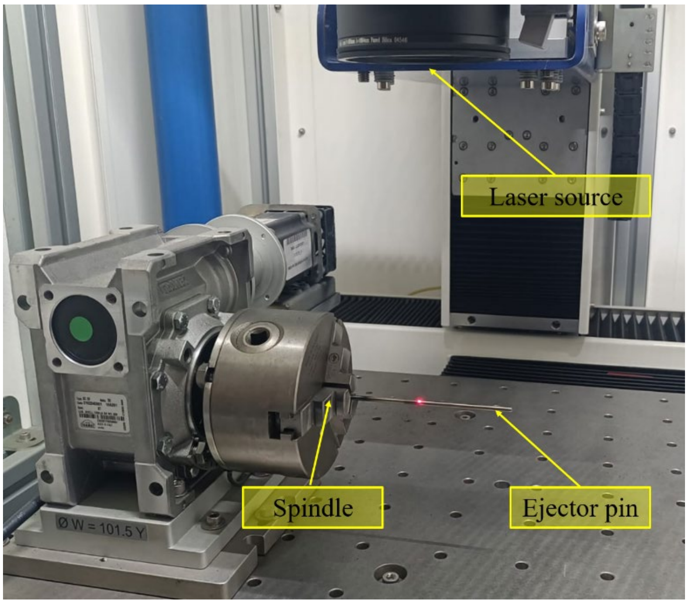

Fig. 1. Laser process experimental set up on cylindrical ejector pins.

Different texture geometries, with a spatial distribution of 250 μm, are being designed in order to investigate their influence on part release behavior as shown in Figure 2 (vertical grooves, horizontal grooves and grid pattern). The different texture geometries were designed to create distinct lubricant retention mechanisms, which will be comparatively evaluated at the application level in terms of ejection force and surface interaction. Injection molding trials are being planned and progressively implemented to evaluate the functional performance of the laser-textured ejectors. The assessment is focused on qualitative and quantitative indicators of demolding behavior, including part release stability, occurrence of surface defects, and repeatability of the ejection process. The results obtained in this phase will provide the basis for correlating surface texture characteristics with ejection performance. Overall, the activities carried out to date confirm the technical feasibility of laser surface texturing of cylindrical ejector pins and support its potential as an effective surface functionalization strategy. The ongoing developments aim to consolidate these findings and to provide design guidelines for the application of laser-textured ejectors in industrial injection molding systems.

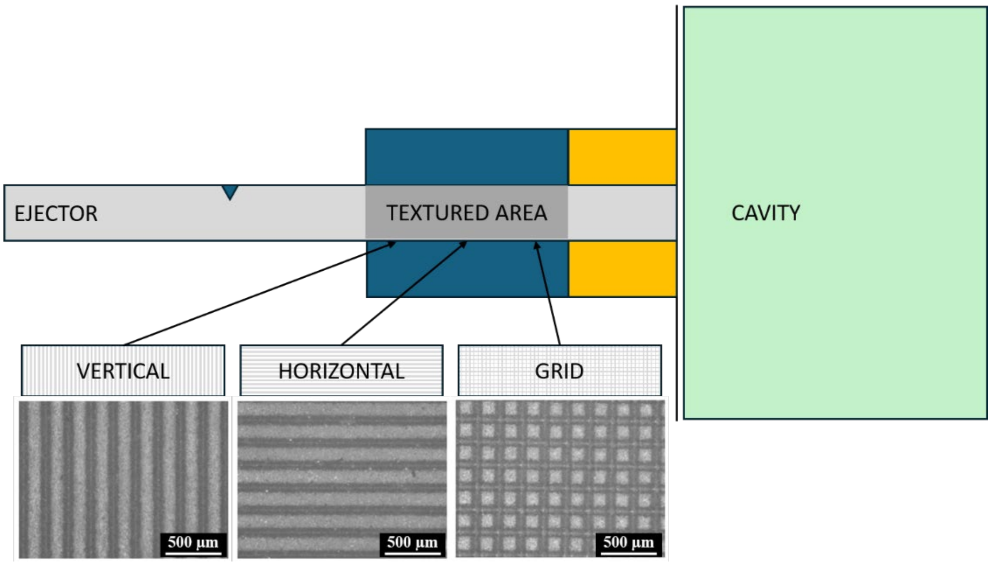

Fig. 2. Different surface textures applied to cylindrical ejector pins.

Results

Figure 3 shows representative grooves obtained during the preliminary campaign on flat samples. The highlighted configuration corresponds to the selected set of parameters (1 mm/sec, 80 W), which ensured the constraint on the maximum allowed depth (20 µm). When the power levels are low with a high scanning speed, the ablation depth is negligible (only a few microns), which confirms that there is a lack of energy input. By increasing the levels of power while reducing the scanning speed, deeper and more defined grooves have been obtained. However, even with the hardest conditions, the depth did not exceed 20 µm. This range is considered optimal with regard to the constraint, as it is effective in surface modifications with a significant safety margin below the maximum allowable threshold. The selected parameter combination, therefore, ensured a controlled and stable ablation regime, suitable for subsequent transfer to the cylindrical ejector pins.

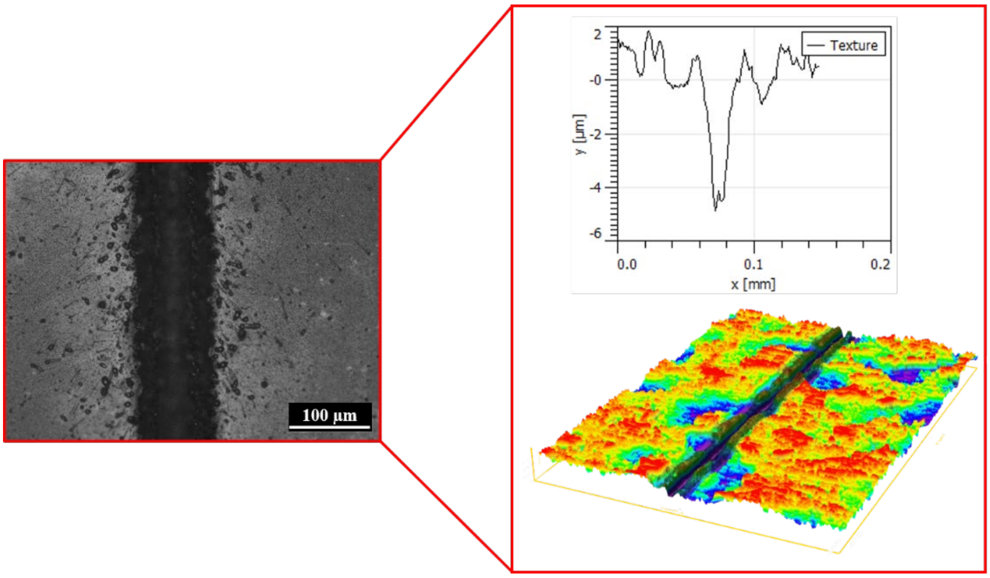

Fig. 3. Groove generated on flat steel.

Figure 4 shows the groove morphology obtained on the cylindrical ejector pin using the selected laser parameters. Compared to flat samples, the surface response is influenced by both the hardened nitrided layer and the cylindrical geometry, resulting in slight variations in melt dynamics and groove edge definition. Under these conditions, a slightly greater groove depth was observed with respect to the flat specimens. However, the measured depth remains within the predefined allowed range and therefore complies with the functional constraint imposed for the application. The 3D reconstruction and the profile confirm that process stability was preserved during the transfer from planar to cylindrical geometry, maintaining a controlled ablation regime and a consistent groove morphology.

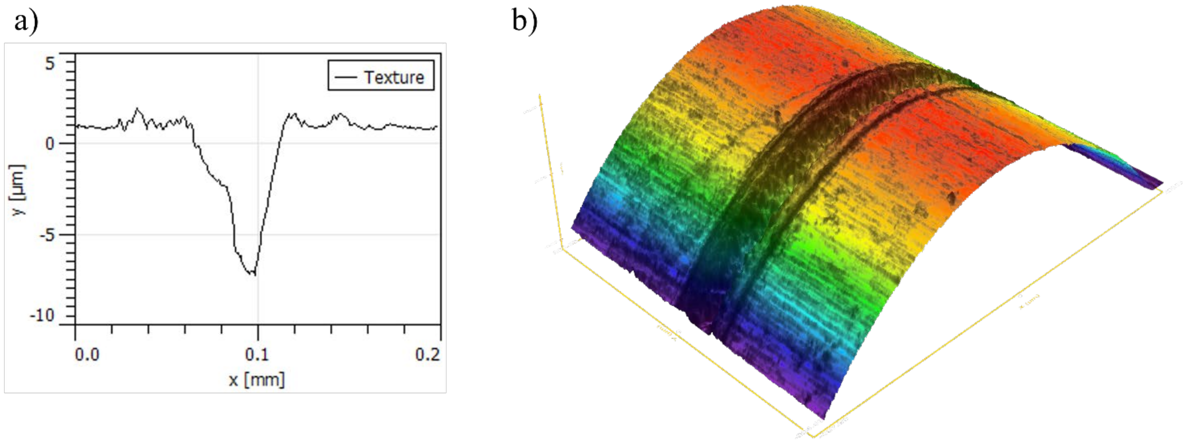

Fig. 4. Groove generated on cylindrical ejector surface (a) profile, (b) 3D view.

As can be seen from Figure 5, the 3D morphological comparison of the considered texture configurations has a more consistent look for the vertical grooves, where the sidewalls are also smoother, compared to the horizontal textures, where the valleys are deeper and the edges are more defined, and the grid texture, where the directionality of the textures creates a more complex surface, enhancing the depth in the intersection of the grooves.

These morphological differences are expected to influence lubricant retention mechanisms and interfacial behaviour during demolding, aspects that will be addressed in subsequent functional testing.

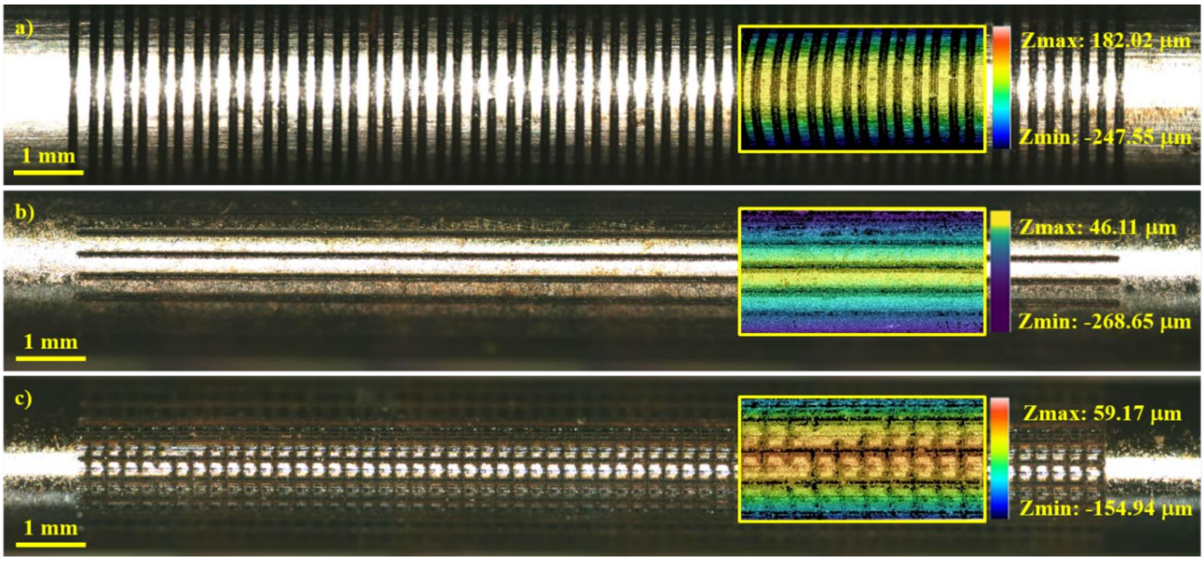

Fig. 5. 3D surface topography of laser-textured cylindrical ejector pins: (a) vertical grooves, (b) horizontal grooves, (c) grid configuration. Measurements performed by optical profilometry; color scale represents height variation in µm.

Table 1 summarizes the quantitative depth measurements of the different textured configurations obtained on cylindrical ejector pins. The vertical groove configuration had the lowest mean depth of 7.63 µm and the smallest standard deviation of 1.68 µm, indicating a highly stable ablation process. For horizontally oriented grooves, a higher mean depth of 13.74 µm was observed, indicating greater interaction between the laser energy and the cylindrical surface when the scanning direction is perpendicular to the pin axis. The grid configuration showed intermediate depth values (10.44 µm), with higher dispersion particularly in the horizontal component. This behaviour can be attributed to pulse overlap and local thermal accumulation effects occurring at groove intersections. Overall, all textures remained within the predefined functional depth range, confirming the feasibility of controlled surface functionalization on cylindrical geometries.

Table 1. Quantitative depth characterization of laser-textured ejector pins (optical profilometry measurements).

Texture	Mean depth [μm]	Max depth [μm]	Std. Dev.
Vertical	7.63	13.90	1.68
Horizontal	13.74	17.22	3.05
Grid vertical	10.34	15.31	2.54
Grid horizontal	10.63	16.97	4.12
Grid mean	10.44	16.97	3.07

Figure 6 presents the integration of the quantitative and morphological analysis of the investigated textures. In the bar chart, the depth trends, as previously reported in Table 1, are confirmed, showing that the grooves of the horizontal configuration are significantly deeper compared to the vertical configuration, while the grid texture has intermediate values. Error bars indicate the standard deviation, confirming good repeatability of the laser process, particularly for the vertical orientation. The 3D topography maps of the horizontal and grid textures further illustrate the morphological differences induced by the scanning strategy. The horizontal configuration generates deeper, more pronounced valleys, whereas the grid pattern produces localized depth amplification at groove intersections due to pulse-overlap effects. The longitudinal surface profile measured on the vertically textured sample shows a regular and periodic groove distribution, with limited depth fluctuation, supporting the stability of the selected laser parameters on cylindrical geometries. These morphological characteristics are expected to influence lubricant retention mechanisms and contact behaviour during ejection, which will be systematically investigated in future functional tests.

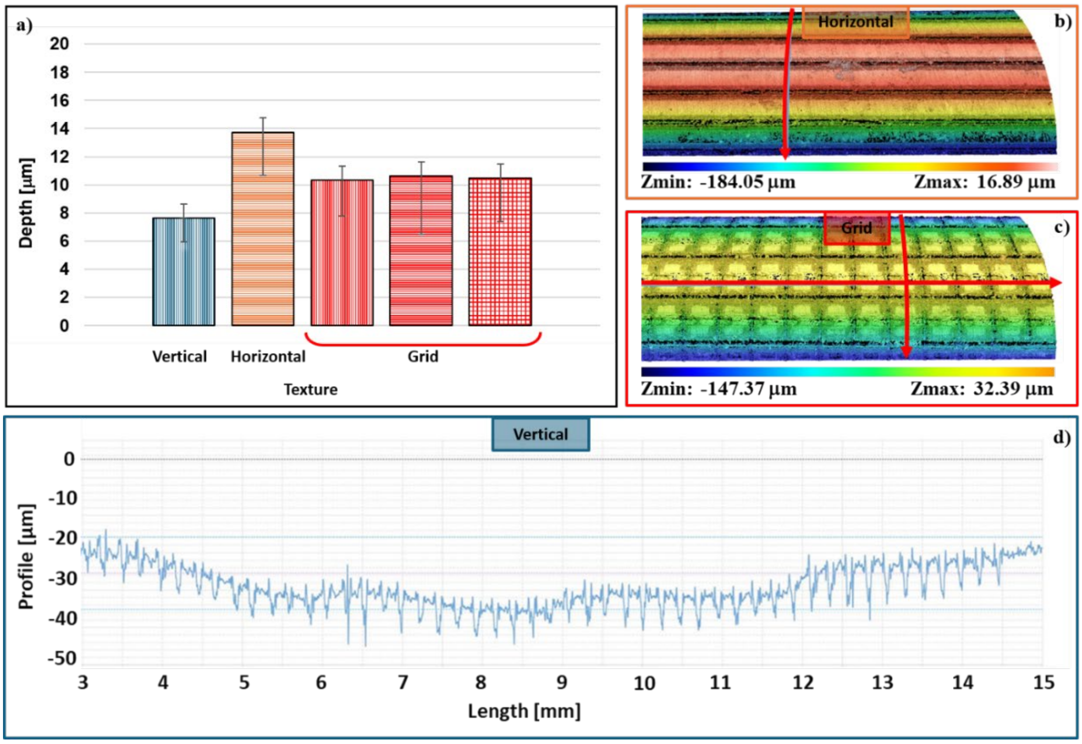

Fig. 6. Integrated quantitative and morphological characterization of the textured ejector pins. (a) Average groove depth for vertical, horizontal and grid configurations, (b) and (c) 3D optical profilometry of horizontal and grid textures and the red arrows represents the measurement direction, (d) longitudinal surface profile of the vertical texture.

Conclusion

This preliminary study demonstrated the feasibility of applying controlled laser surface texturing on cylindrical ejector pins for injection molding applications. The experimental results confirmed that the selected laser parameters enable stable and repeatable micro-scale groove generation on cylindrical surfaces while maintaining the depth within the predefined functional range.

Quantitative measurements highlighted a clear influence of scanning orientation on groove morphology. Vertical textures exhibited the highest process stability and lowest depth variability, whereas horizontal grooves produced significantly deeper valleys, likely due to the interaction between scanning direction and cylindrical geometry. The grid configuration resulted in intermediate average depths but showed localized amplification effects at groove intersections, attributable to pulse overlap and thermal accumulation phenomena.

The combined statistical and topographical analyses confirm that laser texturing can be effectively tailored to modulate surface morphology without compromising geometric integrity. Although the present work focused on morphological and metrological characterization, the observed differences in groove depth and spatial distribution are expected to influence lubricant retention and interfacial behavior during part ejection. Future work will therefore involve functional testing under real injection molding conditions to assess the impact of each texture configuration on lubricant stability, adhesion reduction, ejection force reduction and repeatability.

Acknowledgment

The authors sincerely thank @STAR and MaTeRiA laboratories, funded by “Progetto STAR 2 PIR01-0000800”, for providing the equipment employed for experimental analysis. This research was supported by the European Union under the Italian National Recovery and Resilience Plan (NRRP) of NextGenerationEU, partnership on “Next generation of sustainable and highly efficient molding processes” Italian Projects of Significant National Interest (PRIN) PNRR 2022 grant n. P2022ZE23N.

References

[1] P. Gregorčič, B. Šetina-Batič, M. Hočevar, Controlling the stainless steel surface wettability by nanosecond direct laser texturing at high fluences, Applied Physics A, 2017. https://doi.org/10.1007/s00339-017-1392-5.

[2] L. Yang, W. Ma, F. Gao, S. Xi, Effect of Different Laser Groove Texture Collation Frequency on Tribological Properties of 0Cr17Ni7Al Stainless Steel, Materials, 15(13), 4419, 2022. https://doi.org/10.3390/ma15134419.

[3] E. R. Moldovan et al., Morphological Analysis of Laser Surface Texturing Effect on AISI 430 Stainless Steel, Materials, 15(13), 4580, 2022. https://doi.org/10.3390/ma15134580.

[4] D. Masato, L. Piccolo, G. Lucchetta, M. Sorgato, Texturing Technologies for Plastics Injection Molding: A Review, Micromachines, 13(8), 1211, 2022. https://doi.org/10.3390/mi13081211.

[5] L. Orazi, M. Sorgato, L. Piccolo, D. Masato, G. Lucchetta, Generation and Characterization of Laser Induced Periodic Surface Structures on Plastic Injection Molds, International Journal of Advanced Manufacturing Technology, 2020. https://doi.org/10.1007/s40516-020-00115-1.

[6] L. Piccolo, M. Sorgato, A. Batal, S. Dimov, G. Lucchetta, D. Masato, Functionalization of Plastic Parts by Replication of Variable Pitch Laser-Induced Periodic Surface Structures, Micromachines, 11(4), 429, 2020. https://doi.org/10.3390/mi11040429.

[7] P. Gao et al., Wetting Characteristics of Laser-Ablated Hierarchical Textures Replicated by Micro Injection Molding, Micromachines, 14(4), 863, 2023. https://doi.org/10.3390/mi14040863.

[8] M. Sorgato, D. Masato, G. Lucchetta, Effects of machined cavity texture on ejection force in micro injection molding, Precision Engineering, 2017. https://doi.org/10.1016/j.precisioneng.2017.06.019.

[9] Y. Kim et al., Investigation of Laser Surface Texturing and Injection Molding Parameters in Advanced High-Strength Steel–Polyamide Direct Joining, Steel Research International, 2024. https://doi.org/10.1002/srin.202400686.

[10] Caruso, S., Umbrello, D. “Numerical and experimental validation of gas metal arc welding on AISI 441 ferritic stainless steel through mechanical and microstructural analysis”. International Journal of Advanced Manufacturing Technology, 120, 7433-7444, (2022). https://doi.org/10.1007/s00170-022-09208-x.

[11] Nie, G., Zhang, K., Outeiro, J., Caruso, S., Umbrello, D., Ding, H., Zhang, X., “Plastic strain threshold determination for white layer formation in hard turning of AISI 52100 steel using micro-grid technique and finite element simulations”. Journal of Manufacturing Science and Engineering, Transaction of the ASME, 142(3), 034501 (2019). https://doi.org/10.1115/1.4045798.