SURFACE FUNCTIONALISATION FOR INDUSTRIAL APPLICATIONS

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The possibility to modify and control surface structuring with texture dimensions down to sub-micron size has been well proven in various industrial fields. It has been shown that those structures can enhance or give new properties to materials [1, 2, 3].

However, those processes often use consumables that are toxic, difficult to handle and potentially harmful to the environment. Also, industrial deposition methods often do not enable nanoscale texture control, either changing the roughness of the surface or are too slow to be used in large scale industrial production.

To address these issues, LASEA built a dedicated laser machine that is able to texture large surfaces of parts at the nanoscale using the LIPSS (Laser Induced Periodic Surface Structures) phenomenon induced by laser-matter interaction during the laser ablation process. This work is part of the LASER4SURF European project (www.laser4surf.eu). In this article we will describe the laser workstation as well as the results obtained for applications in three different industrial sectors: medical implants, battery collectors and precision linear encoders.

Laser workstation

To generate the laser beam, a Satsuma laser source from Amplitude Systemes was used. The beam passed through an LS-Shape optical module, which adapted the beam diameter depending on the target application. The laser was directed towards the beam-shaping module, which included a DOE (Diffractive Optical Element) to modify the beam shape from Gaussian to top-hat. Finally, the laser beam entered the LS-Scan scanner-head which contained fast moving precision mirrors and a focusing lens to control the beam movements on the processed parts.

The laser workstation also included translation stages of 1.5 m which enable treatment of large surface parts. On top of the stages, there was a vacuum table system that maintained the flatness of thin samples to avoid local defocusing during the laser texturing process.

Finally, the laser workstation includes an inline monitoring system which measured LIPSS period at the end of the laser process to validate the quality of the surface texture.

Automation

To ensure that the laser workstation could be used in a production line at industrial scale, each component of the machine was tunable via control software. It is also possible to create an automated sequence of actions detailed below:

- Loading of laser and optical parameters established on the test machine.
- Use the conversion module to adapt laser parameters to the laser workstation.
- Control hardware to apply the new parameters.
- Laser processing of the part.
- Analysis of the part.

Results

For each application presented in the following subsections, the test protocol used was identical. Firstly, the test machine was used to make an exhaustive study of the different surface textures achievable on flat test samples. Then, best candidates were chosen and their performance was tested in a manner appropriate to their final application (more details are given in the following subsections for each application).

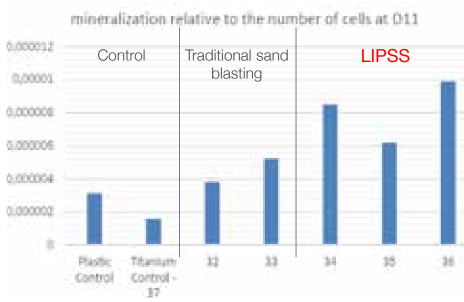

Figure 1: Quantification of mineralisation relative to the number of cells

Based on the performance results, best laser and optical parameters were established.

These parameters were adapted to the laser workstation via the parameter conversion tool to reproduce the optimal surface texture on real parts. In the frame of the LASER4SURF project, three different applications were targeted for texturing: medical implants, battery current collectors and linear encoders for motion stages.

Medical implants

In the case of medical implants, we first validated that the optimal surface texturing could be reproduced on flat test samples. This texture was applied on cervical plates (used to provide neck stability) on which different performance tests were carried out. The first one was a wear test which consists of using a tool to simulate natural friction of the implant with local tissues when implanted in the human body. Those tests showed that laser texturing achieved better performances than both non-textured parts and parts textured by sand-blasting (Figure 1).

The second test carried out consisted of developing human tissues at the surface of the sample to check adhesion and propagation. Again, laser textured parts exhibited better adhesion and propagation than non-textured parts and similar performances to parts textured by sand-blasting. However, tissue propagation direction is strongly influenced by the texture geometry, which can be precisely controlled by the laser process and opens up new opportunities to improve osseointegration of the implants [5].

Finally dental screws were also textured by laser with an LS5-3D laser machine to demonstrate the possibility to apply such textures onto parts with complex 3D geometries (Figure 2). The productivity of such a fully automated system was calculated to process more than 15,000 screws per year depending on the geometry of the parts.

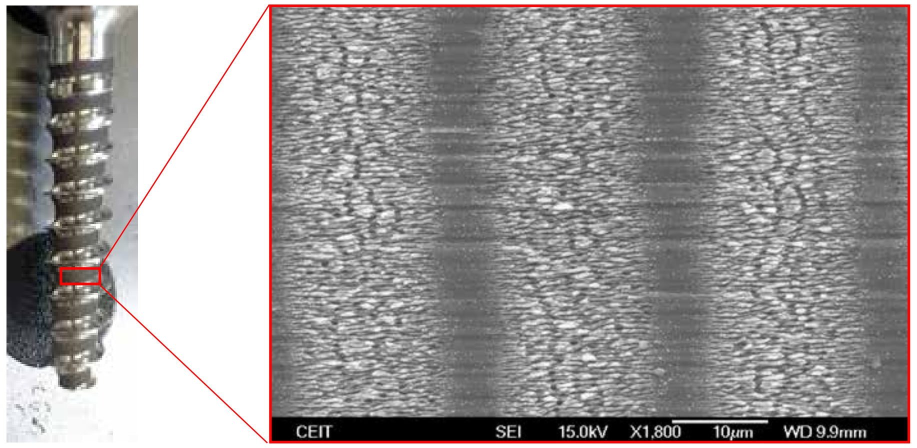

Figure 2: (a) macroscopic view of a dental screw; (b) SEM images of the LIPSS nanostructures

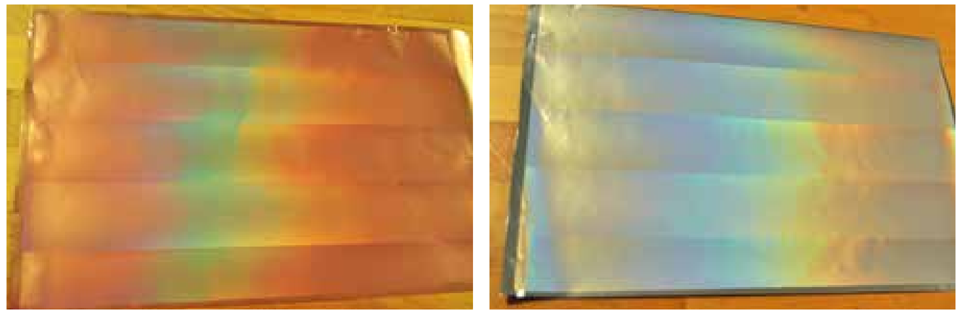

Figure 3: (a) A4 format texturing of Cu foil; (b) A4 format texturing of Al foil

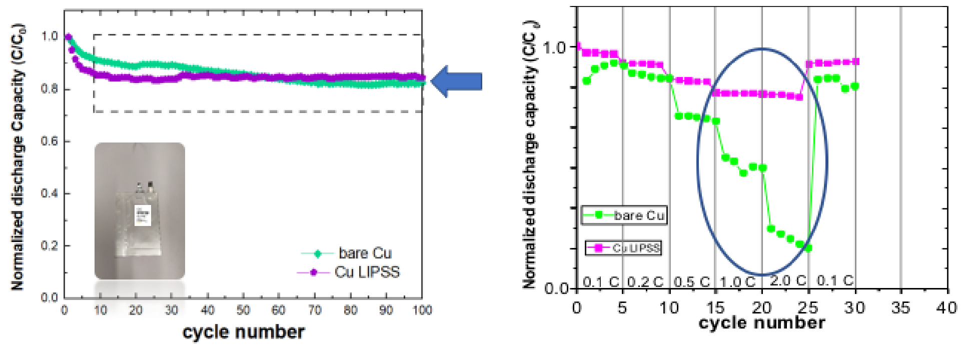

Figure 4: (a) Normalised discharge capacity at 1C; (b) Normalised discharge capacity at different C-rates

Current collectors for batteries

After validating texture reproducibility on test samples, large surface current collectors (A4 format) were textured both on Cu and Al foils, then treated by adding an $Li_4Ti_5O_{12}$ (LTO) slurry to fabricate the anode and cathode (Figure 3).

The adhesion of the LTO slurry on the structured samples was proven to be better on textured surfaces using peeling tests. Indeed, these tests showed that less material was removed on laser textured samples as well as requiring a higher strength to remove the material.

After the assembly of pouch cells with the textured current collectors, electrochemical tests were performed demonstrating that lifetime of the pouch cells could be increased by 10% as well as having a higher charge and discharge rates at higher current densities (Figure 4).

Linear encoders

We validated that we could reproduce the optimal texture on test samples, then real encoders were textured by laser over an area of 10 x 150 mm. The signal/noise ratio of the encoder was then qualified through optical tests which validated the precision and quality of the laser texturing (Figure 5).

Conclusion

We demonstrated the feasibility of building a fully automated laser workstation capable of nanoscale texturing of LIPSS structures on industrial parts in the medical, battery and linear encoders industries.

After various performance tests were carried out for each application, it could be proven that laser textured parts showed better results than untextured parts or parts with more conventional treatment, enabling a reduction in the overall manufacturing process by removing several steps, so supporting greener manufacturing.

Acknowledgements

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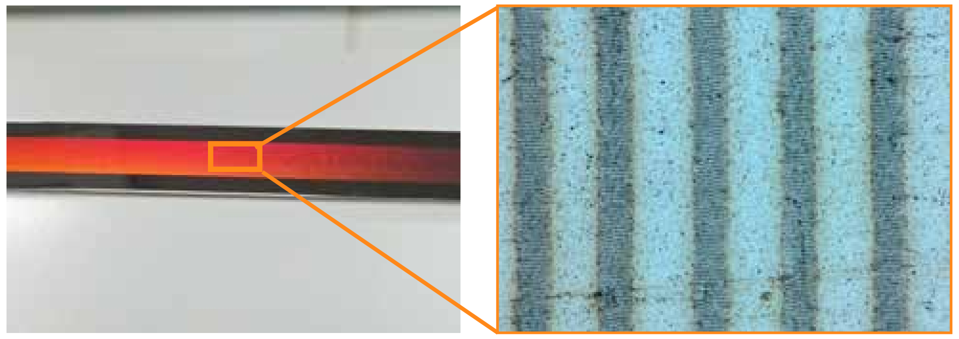

Figure 5: Encoder scale using LIPSS to obtain finer features and improve performance

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