Study for improvement of selective metallization on 3D printed components using LDS technology

Ricardo Freitas[1]; Luciano Rietter[1]; Clara Gonçalves[1]; Joana Silva[1]; Filipa Carneiro[1]; Cristina Furtado[2]; Sónia Gomes[3]; Rui Lobo[3]
1 PIEP - Innovation in Polymer Engineering, Portugal; 2 CENTI - Centre of Nanotechnology and Smart Materials, Portugal; 3 Doureca Produtos Plásticos, Portugal

iDOURECA

Introduction

Miniaturization of components is a strong trend and provides great contribution for overall size and weight reduction of components. Laser Direct Technology (LDS) has emerged in last decade as a promising and flexible technology to broad the application towards miniaturization. In LPKF-LDS© technology, a thermoplastic part is being produced by injection moulding based on a granule modified with an organometallic complex. After the injection process, the surface of the thermoplastic part is partially activated by laser irradiation. Finally, in an electroless bath the circuit tracks are selectively deposited on those activated areas [1]. LDS technology is commonly applied to automotive lightning [1, 2] and sensors and IoT devices [4-7]. Automotive industry has been an early adopter of this technology due to weight reduction. A broad range of materials are available, almost 130 references are approved by the LPKF for its process [8].

It must be reminded that most of these applications use injected moulded parts, as it usually provides pieces with a low surface roughness, which is recommended for a high-quality metallization as it has a great effect on the metallization processes [9]. While few commercial LDS materials are available for additive manufacturing, for general Additive Manufacturing (AM) applications, in contrast, a variety of materials can be processed: polymers, metals, ceramics and biological materials [10]. Innovations in AM allow miniaturized devices to be efficiently packaged, and with this, the promise to dramatically change various fields, including space [11]. 3D printing offers many new degrees of freedom in terms of shape [12]. This provides to the engineer/designer an extra degree of freedom in the design-to-product optimization process, as a prototype is quickly obtained and less costly, when comparing with other manufacture techniques as machining or moulding. Also, with the rapid development of the 3D printing techniques, resolutions about 20 µm or the pattern resolution could be improved to 10 µm or even higher [13]. Even a high-resolution printing will create a stair-step witch must be taken into consideration when developing the prototype, as the resulting roughness must be considered.

Seeking to evaluate the impact of surface treatments on 3D printed prototypes, this work analyzes different methods for reducing its roughness and their impact to the final metallization of components using LDS technology. Thereby, better looking prototypes can be developed with its full functionality reducing time to market development.

Methods

SAMPLES PRODUCTION:

3D geometry was developed by Computer Aided Design (CAD) in SolidWorks® (Dassault Systèmes S.A.). The material used was Polycarbonate modified for LDS technology (XANTAR PC LDS 3764, Mitsubishi Engineering Plastics). The pieces were produced by 3D printing Fused Deposition Modeling (FDM) in Roboze One +400 (Roboze SpA). The relevant processing parameters were: printing temperature 255 °C; bed temperature 110 °C; printing speed 40 mm/s; layer height 0,1 mm; retraction distance 0,8 mm; retraction speed 35 mm/s.

SAMPLES TREATMENTS:

After obtaining copies of the pieces, three different post-treatments were conducted, resulting in four cases to be evaluated: a) original pieces: obtained after the printing process; b) mechanical treatment: obtained after manual polishing of surfaces with abrasive dry wet waterproof sandpaper sheets, with assorted grit of 800 for about 10 min in each surface; c) chemical treatment: obtained after five passes on each surface with absorbent paper submerged in dichloromethane, then cured inside a fume hood at room temperature for at least 20 hours; and d) mechanical and chemical treatment: obtained after applying cases 'b' and 'c' sequentially.

LASER STRUCTURING:

Afterwards, they were structured with Nd:YAG laser with 1064 nm wavelength (LPKF Fusin3D 1100, LPKF). The relevant laser parameters used were: power: 8 W, frequency 120 kHz, velocity 2 m/s and laser beam diameter 40 µm.

CLEANING AND METALLIZATION:

After the structuring process, the samples were rinsed using deionized (DI) water after using an ultrasonic cleaning for 5 minutes in order to remove floating polymer dust. The samples were subsequently plated in a copper bath with two-stages. In the primary stage, the plating solution I - known as copper strike -consisted of 18 ml of Copper salts (MID Copper 100AC, Macdermid Enthone), 150 ml of Compleax agent (MID Copper 100 XB, Macdermid Enthone) and 6 ml of Formaldehyde (30-36%, PanReac AppliChem) in 1 L of DI water for 30 min. at 60 °C. Then, the samples were immersed in an aqueous plating solution II for building copper during 2 h at 60 °C. The Solution II (copper build) contains 120 mL/L of copper salts (XB; Macdermid Enthone), 15 mL/L of chelator (MID Copper 100 C, Macdermid Enthone), and 6 mL/L of formaldehyde (30-36%, PanReac AppliChem). After copper metallization, the samples were rinsed with DI water and swept by compressed air.

PROFILE AND ROUGHNESS ANALYSIS:

Profile and roughness measurements were conducted in 3D optical microscope (Alicona, InfiniteFocus SL) according to ISO 4287 and former ISO 4288. The lens used was 50x and the sampling was area about 800 x 400 µm. The integrated software allows the geometry curvature correction for an accurate roughness measurement. The mean of 1500 points (about 300 µm) was used to obtain the profile graphics. These measurements compare regions of the same the piece in a) an area without structuring, b) an area after structuring process and c) an area after the metallization process. The difference between the profile before and after the metallization is considered as the copper layer deposited. For this reason, the analysis of the profile with the mean makes sense as few points would only show an irregular profile.

Data Analysis

The topology of a 3d printed piece is close to a stair-step, which is caused by the deposition of the fused material by the printer nozzle. The objective behind the post-treatments is to reduce this effect and have a better-looking appearance and eventually improve the quality of metallization. It must be noticed that even with some treatments the stair-step appearance is just reduced, as can be seen on the chemically treated sample (figure 1). The elevated area represents the metallized track of the structured circuit. Parallel lines from AM process can be noticed.

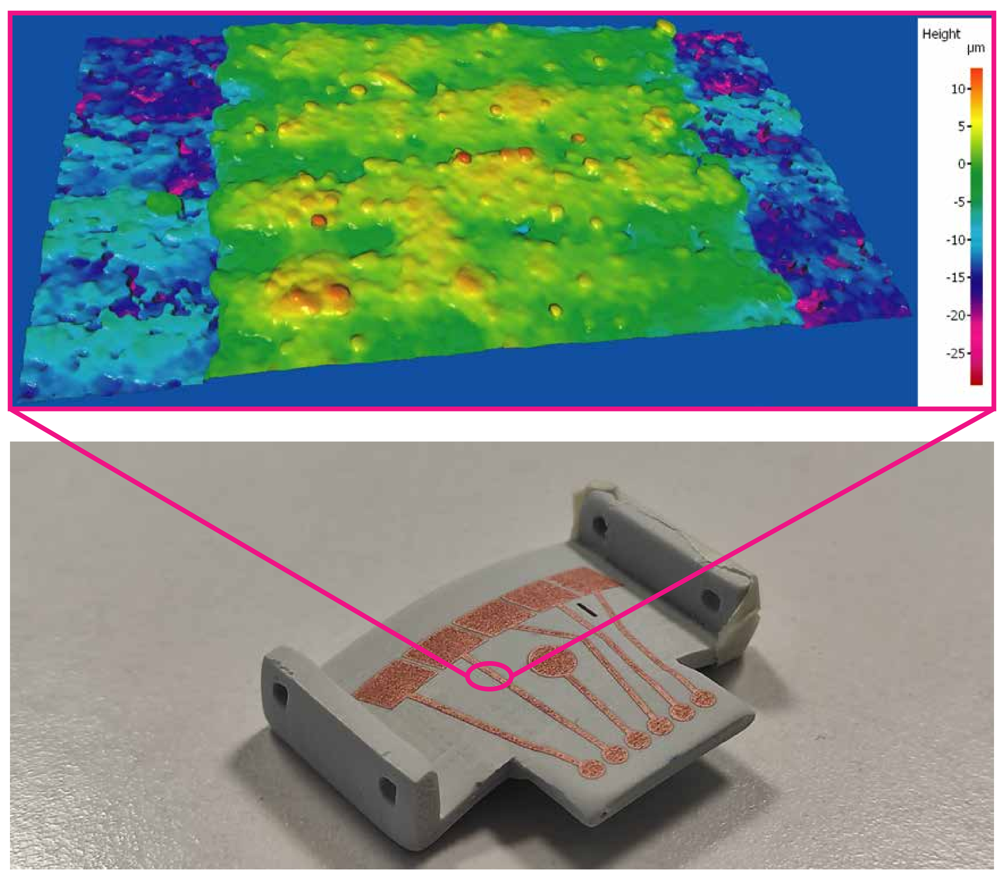

Figure 1 - Topographic detail obtained by the optical microscope, after the metallization, on the sample with the chemical treatment.

The profile's measurements were conducted by analyzing the profile of the 400 µm thick trace through the measured area. The graphics below show these profiles (figures 2 - 5). The difference between the orange and the blue lines is expected to be the amount of copper deposited. As the exact place of measurement required a high precision on the positioning of the sample, the mean of 1500 points were taken into consideration.

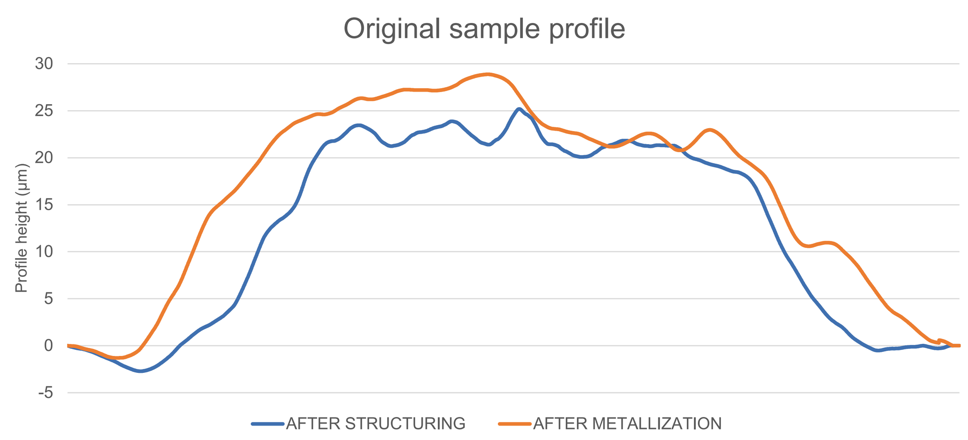

Figure 2 - Original sample profile

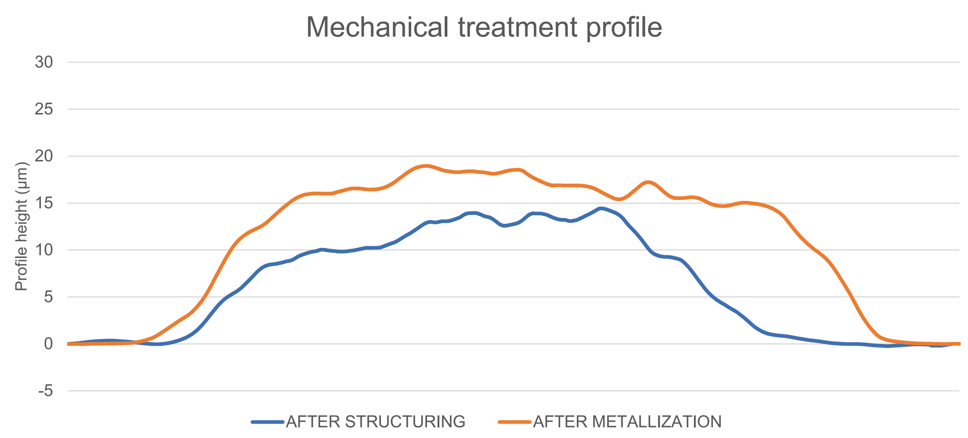

Figure 3 - Mechanical sample profile

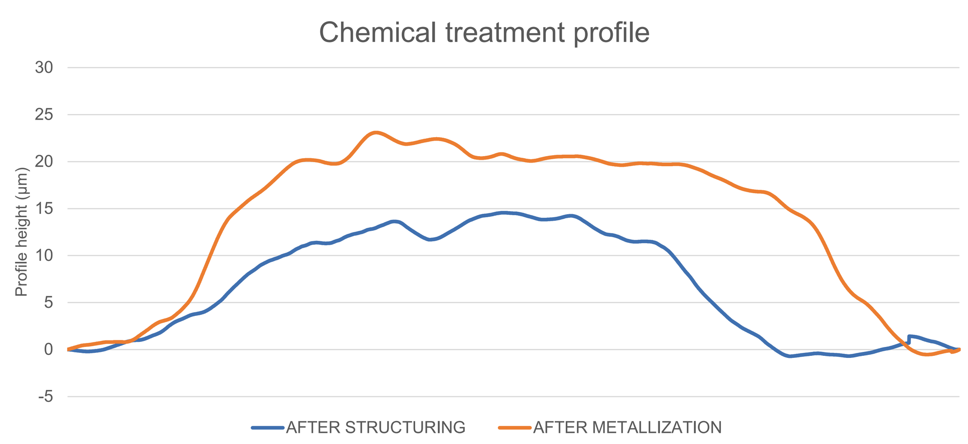

Figure 4 - Chemical sample profile

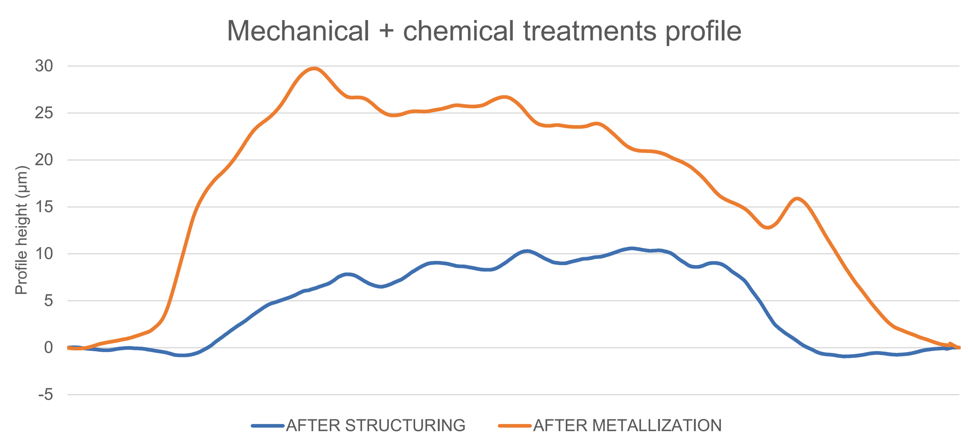

Figure 5 - Mechanical + chemical sample profile

The average roughness (Ra) and the mean peak to valley height (Rz) were used to compare the samples. The structuring process with the laser consist on the ablation of the material to expose the metallic additives present on the polymer matrix of the material. For this reason, an increase on the roughness is expected after the structuring process. However, during the metallization phase, the copper particles are deposited mainly on the cavities so after the metallization a reduction on the roughness occurs. This effect can be noticed on figures 2 and 3.

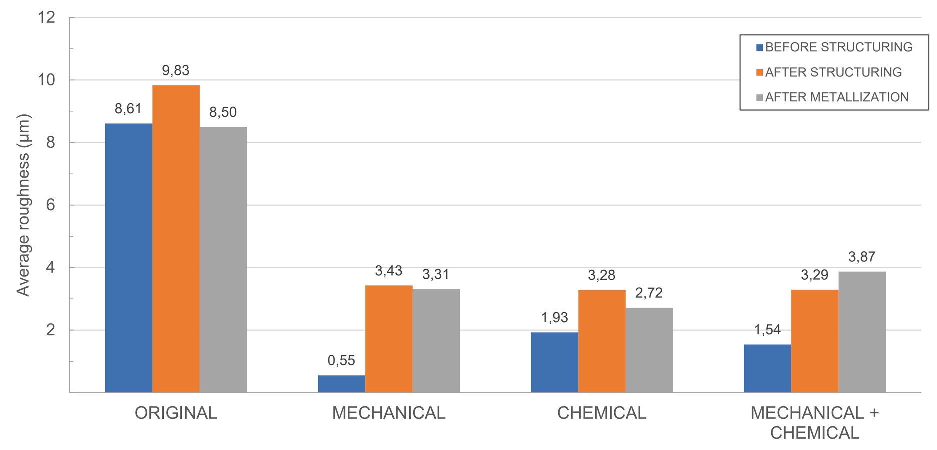

Figure 6 - Average roughness of profile (Ra) for all samples (in µm).

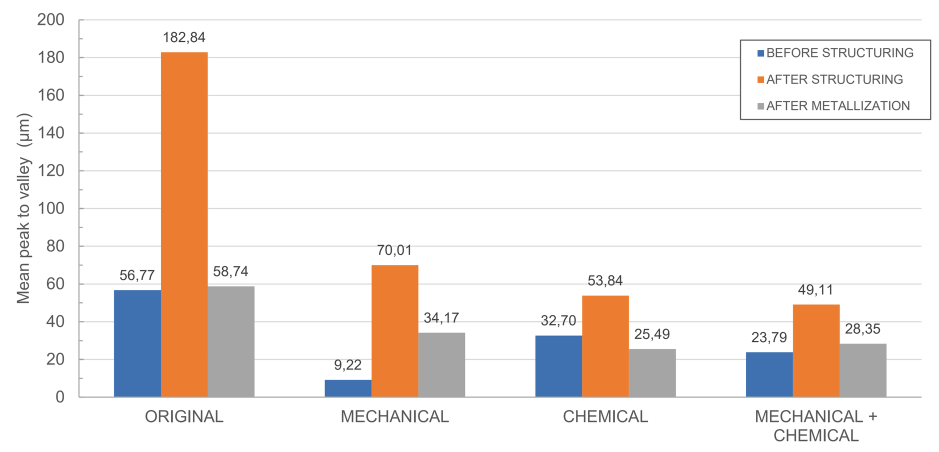

Figure 7 - Mean peak to valley height of roughness profile (Rz) for all samples (in µm).

Results

The original sample, obtained after the FDM process, presents a high roughness and a stair-step appearance, which is undesirable for some applications. The profile analysis (figure 2) show a thin layer of copper. In addition, the electrical continuity may be affected when the copper doesn't deposit due to the high difference on the surface, i.e. the existence of high peaks and valleys as obtained by the measurements (figure 7).

Even adding an additional step to the process – meaning cost, time and complexity –, post-processing methods can be used to reduce the stair-step aspect. Depending on the treatment used, after their implementation, the samples may acquire matte (cases 'a' and 'b') or shiny aspects (cases 'c' and 'd'), caused by the use or not of the chemical product, which must be taken into consideration. All the treatments conducted are manually handled. For this reason, they are highly susceptible to variations from piece to piece, as they depend on the ability of the operator. Some of them take a long time to be performed, so they become undesirable for industry. However, for proof-of-concepts or few prototypes using the LDS technology, as for iDoureca project, they become an interesting alternative. The reduction on the roughness of treated samples is evident so they have proofed to be effective, as can be observed on figures 6 and 7.

The mechanically treated sample is the one who presents lowest average roughness before the structuring process and by its profile after the metallization (figure 3) shows a reasonable copper layer. The same occurs to the chemically treated sample, as the lower average roughness after the metallization process indicates that this is the most homogeneous post-treatment from those explored. The profile obtained (figure 4) shows a good copper layer, indicating that even without the best surface appearance, the metallization quality can be optimized. The case where the two post-treatments were conducted sequentially have the cons of adding both time and uncertainness regarding the reproducibility. However, the amount of copper deposited is the best obtained (figure 5) for this research and the roughness levels are very close to the other two treatments (figures 6 and 7).

Conclusions

FDM printed parts presents a high roughness, a direct result from the processing parameters used. This roughness reduces the amount of copper deposited within the LPKF-LDS© process. Even adding time to the overall process, post-treatments have proofed to be effective by reducing the roughness of surface and improving the quantity of copper deposited over structured areas through LDS technology. For proof-of-concepts or few prototypes this factor is neglectable but not for industry. However, for an industrial large-scale production the chemical treatment can be implemented by a serial method, in which the components are subjected to an automated process as evaporation rather than manually application of the chemical. Also, the curing time and amount of chemical must be further studied to be optimized, as well alternative methods.

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