Master’s Thesis Engineering Technology

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Hierarchical texturing of injection mould materials by femtosecond laser processing

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Introduction

Nature offers many examples of functional surfaces. The Lotus leaf, for instance, is well known for its water-repellent properties due to its hierarchical surface structures (Figure 1). The surface is **superhydrophobic** (Figure 2). Ultrashort pulsed laser enables the fabrication of superhydrophobic topographies on metals, by different approaches: **direct laser writing (DLW)** and **Laser-Induced Periodic Surface Structures (LIPSS)** [2]. Applying these textures on mould materials which can significantly improve the cycle time of the injection moulding process is poorly investigated. Therefore, there is a need for a comparative study.

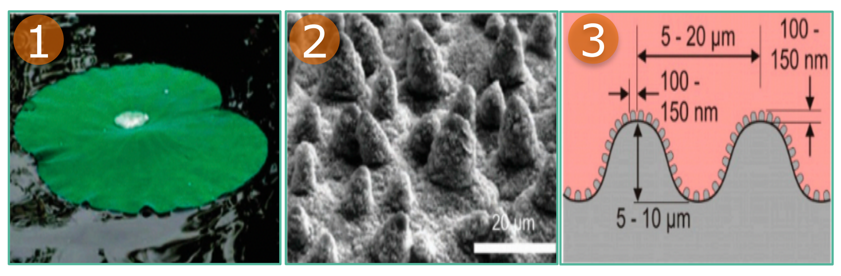

Figure 1: (1) Lotus leaf, (2) hierarchical surface topography Lotus leaf, (3) dimensions Lotus leaf [1]

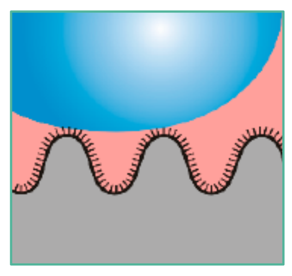

Figure 2: schematic view of water drop in Cassie-Baxter state [1]

Objectives

The main objective is to fabricate similar surface structures on **common mould materials** for injection moulding processes. A **single-step femtosecond laser process** (Figure 3) will be optimised to generate two sorts of geometries:

- Single-scale (submicron) grooves i.e. LIPSS with no ablation.
- Dual-scale topography i.e. Lotus leaf (micro pillars + submicron grooves).

Methodology

LIPSS processing was used to produce a regular 1D submicron grooves:

- **LIPSS** (lines hatched from each other): fluence 8.9-1123.2 mJ/cm² , scanning speed 100-1000 mm/s, hatch 1-10 μm.

Inspired by natural hydrophobic surfaces, a dual-scale topography was created by using two methods:

- **DLW method 1** (Figure 3): fluence 731.0 mJ/cm², scanning speed (v) 100-1500 mm/s, hatch (h) 1.5 μm, 5-35 repetitions.
- **DLW method 2** (Figure 3): fluence 8.9-1123.2 mJ/cm² , 10.10^3-3.10^6 pulses per spot (PPS).

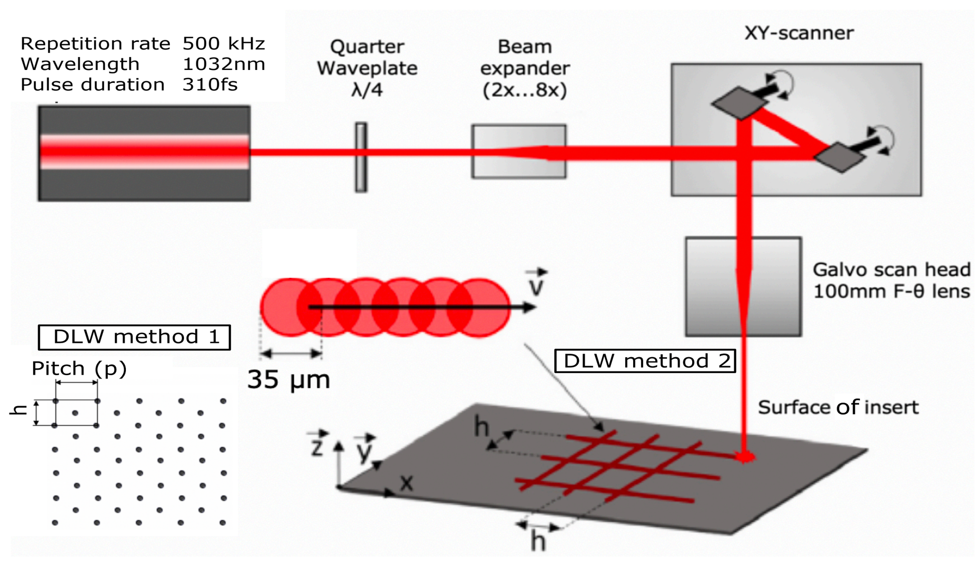

Figure 3: Setup laser process [2] and approach DLW 1 and DLW 2 method

Materials:

- Aluminium-Zinc alloy (3.4365)
- (Beryllium-free) copper alloy (AMPCOLOY 940)
- Hot work tool steel (1.2343)
- Stainless tool steel (1.2083)

Characterization techniques:

- Focus-variation microscope
  - Alicona G5
- Scanning electron microscope
  - Jeol JCM-7000 Neoscope Benchtop

Results

Based on the results from **LIPSS**, more roughness is obtained for the mould materials when the effective number of pulses per line (N) increases (Figure 4).

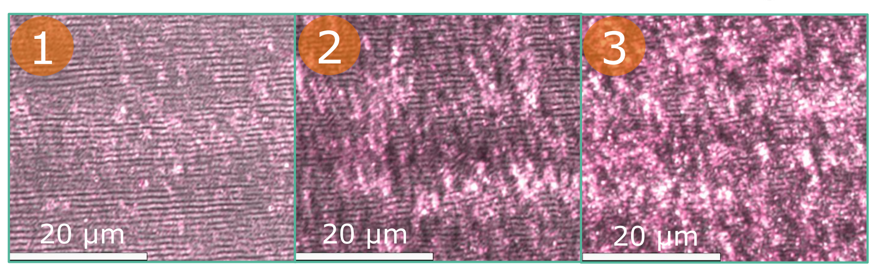

Figure 4: Alicona G5 images of (1) N = 48, (2) N =96, (3), N =192

Also, the periodicity from the **LIPSS** are in the same range for all the materials (Figure 5 and Table 1).

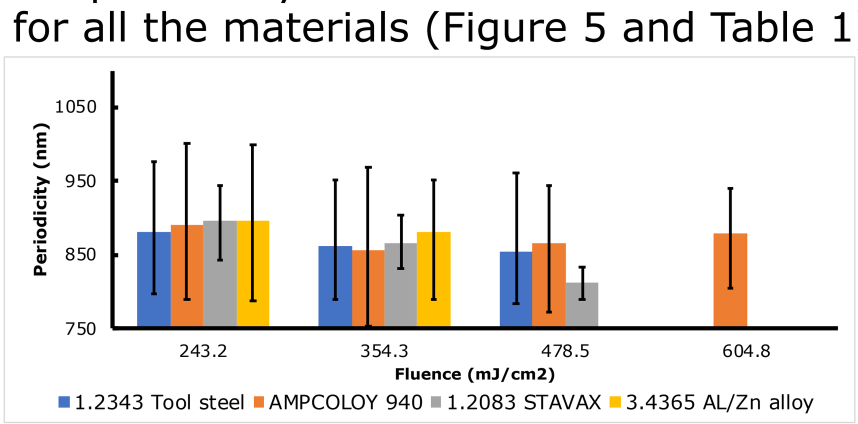

Figure 5: Evolution of periodicity with the fluence, LIPSS method

Table 1: Range of parameters to fabricate LIPSS with corresponding periodicities

Material	Al/Zn alloy	Copper alloy	Hot work tool steel	Stainless tool steel
Fluence (mJ/cm²)	80.2-150.1	150.1–730.5	80.2–354.3	80.2–354.3
Effective pulses per unit area (-)	481-192	48-962	48-96	48-96
Periodicity (nm)	**798-906**	**794-925**	**799-901**	**787-901**

Similar **LIPSS** are found at low fluences (Table 2).

Table 2: Parameters to obtain similar LIPSS with corresponding periodicities

Material	Al/Zn alloy	Copper alloy	Hot work tool steel	Stainless tool steel
Fluence (mJ/cm²)	150.1	478.5	354.3	234.2
Scanning speed (mm/s)	1000	500	1000	1000
Hatch (μm)	10	10	5	5
Periodicity (nm)	**830**	**865**	**861**	**853**

The results of **DLW method 1** show that increasing the number of pulses per line (N) leads to deeper and sharper grooves (Figure 6). Also, the pillars are getting more well-defined and **LIPSS** are appearing on the pillars.

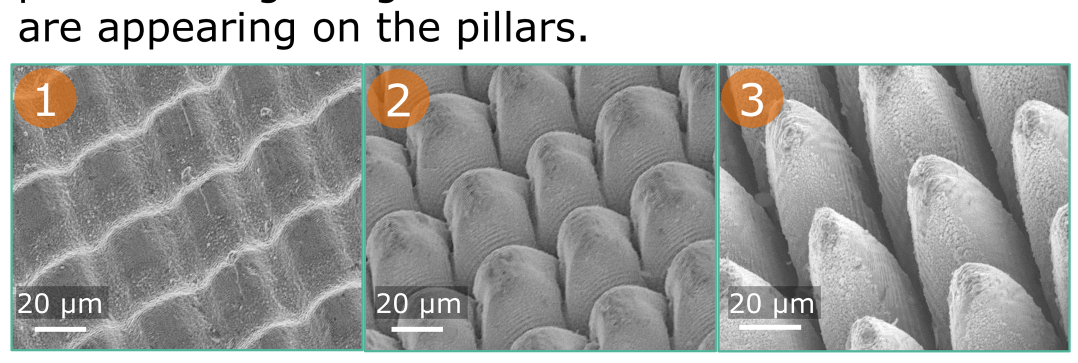

Figure 6: DLW method 1, SEM images of (1) N = 4000, (2) N = 28000, (3) N =210000

In term of ablation, both steels observe a same behaviour. Aluminium has highest removal rate, this leads to the lowest number of pulses per line for a specific depth (Figure 7 and Table 3).

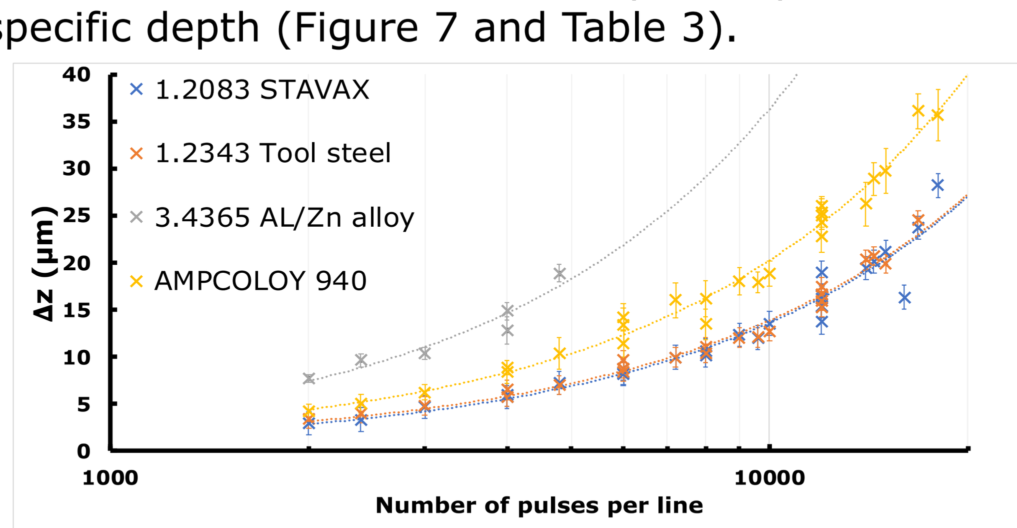

Figure 7: Evolution of depth of the grooves with the number of pulses per line, in DLW 1 method

Table 3: Parameters for similar dual scale topography with DLW method 1

Material	Al/Zn alloy	Copper alloy	Hot work tool steel	Stainless tool steel
Number of pulses per line	5342	7348	10839	11060

DLW method 2 shows that a rise in pulses per spot (PPS) leads to deeper hole and larger diameters. Also, **LIPSS** were found in all of the holes (Figure 8).

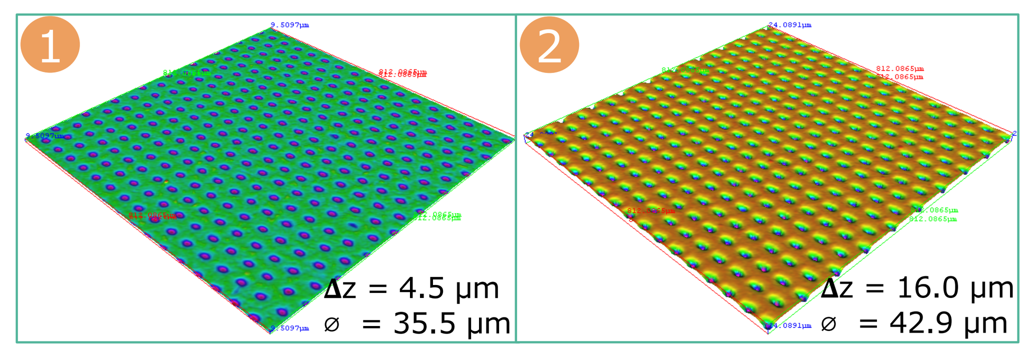

Figure 8: DLW 2 method, (1) Fluence = 478.5 mJ/cm², PPS = 100.10^3; (2) Fluence = 478.5 mJ/cm², PPS = 750.10^3

The results from the **DLW method 2** show that **similar holes** with the same depth are **obtainable** (Figure 9). Also, the lowest amount of energy can be achieved for Al/Zn alloy in order to get a similar depth (Table 4).

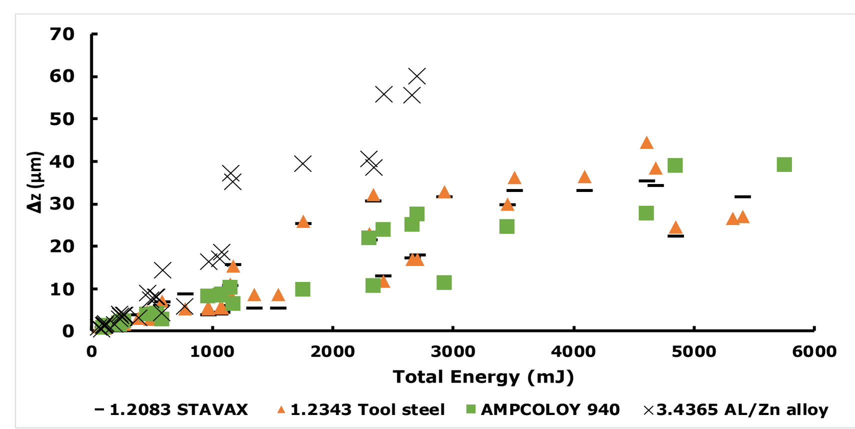

Figure 9: Depths in function of total energy (PPS x Pulse Energy), in DLW 2 method

Table 4: Parameters for obtaining diameter 41 μm of and depth of 32 μm

Material	Al/Zn alloy	Copper alloy	Hot work tool steel	Stainless tool steel
Fluence (mJ/cm²)	478.5	478.5	1123.2	1123.2
PPS (10^3)	221	1092	610	500
Diameter (μm)	**37.30**	**41.19**	**44.30**	**45.14**
Depth (μm)	**32.00**	**32.00**	**31.57**	**31.57**

Conclusion

Mimicking the Lotus leaf with the DLW 1 and DLW 2 method has been achieved on the mould materials with a small deviation. Also, producing 1D submicron grooves (LIPSS) are achieved with same roughness and a small deviation on the periodicity.

LIPSS:

- The similar LIPSS have a periodicity 852±23 nm.

DLW 1 method:

- A depth is fixed at 15 μm which leads to different number of pulses for each mould material (5342 – 10839).

DLW 2 method:

- Similar holes were found with a diameter of 41±4 μm and depth of 32±0.5 μm.

Future research

- Replication efficiency via injection moulding will be analysed to investigate the influences of different thermal conductivities of the mould materials.
- Tool wear of the mould inserts will be investigated for a certain number of injection cycles.

References

[1] F. A. Müller, C. Kunz, and S. Gräf, “Bio-Inspired Functional Surfaces Based on Laser-Induced Periodic Surface Structures,” Materials, vol. 9, no. 6, Jun. 2016.

[2] J.-M. Romano, M. Gulcur, A. Garcia-Giron, E. Martinez-Solanas, B. R. Whiteside, and S. S. Dimov, “Mechanical durability of hydrophobic surfaces fabricated by injection moulding of laser-induced textures,” *Appl. Surf. Sci.*, vol. 476, pp. 850–860, May 2019.

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