Laser Surface Texturing
Laser Surface Texturing

- Laser surface texturing has emerged as a viable means of enhancing tribological performance and biomedical applications in recent years.
- The laser is extremely fast, clean to the environment and provides excellent control on shape and size of microstructures.
- Several applications will be shown to benefit from LST which are dynamic sealing, magnetic recording, internal combustion engines and biocompatible surfaces.
Biomedical Applications for Laser Texturing

- Wettability for better interaction with biological liquids
- Rougher Ti surfaces provide increased osseointegration
- Laser textured surfaces promote better contact guidance (cell alignment) as compared to sand blasted surfaces
Experimental Setup

100 W Yb-doped Fiber Laser
SPI Laser SP-100C-0020
Wavelength: 1064 nm
Frequency: CW - 100 kHz
Positioning stages: MikroTools
Resolution/Accuracy : 0.1 µm and ± 1 mm

Indian Patent Application No 442/MUM/2011 Filed on 17 February 2011

Method and device for generating laser beam of variable intensity distribution and variable spot size
Creation of Textured Surfaces

- Parametric studies for simple channels
- Optimal parameters used for creation of textures
  (scan velocity 700 mm/min, Laser power 70 W, Frequency 5 KHz, pulse width 0.1 ms, single pass)
Wettability Characterization

- Wettability tests could capture the functional response of the surface
- Wettability tests with different fluids:
  - Water
  - Ethylene Glycol (EG)
  - Polyethylene Glycol (PEG)
- Three different surfaces:
  - Baseline untreated
  - Sand blasted
  - Laser textured

Contact angle on laser treated surface
Contact Angles obtained in Textured Surfaces

![Bar chart showing contact angles for different media and textures.]

- Water: 7% improvement
- Ethylene Glycol (EG): 14% improvement
- Polyethylene Glycol (PEG): 7% improvement

Legend:
1. Simple Channels
2. Coarse Ridges
3. Fine Ridges
Comparative wettability test (Water)

- Reference Surface
- Sand Blasted Surface
- Laser Textured Surface

Contact angle (degree)

Serial number

62%

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Comparative wettability test (ethylene glycol)

Contact angle (degree)

Serial number

Reference Surface
Sand Blasted Surface
Laser Textured Surface

56%
Comparative wettability test

Contact angle (degree)

- Reference Surface
- Sand Blasted Surface
- Laser Textured Surface

Serial number

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Physical explanation

(a) Wenzel Model; (b) and (c) Cassie-Baxter Model

• Laser textures are not close to Wenzel’s model and hence are not hydrophilic

• The air pockets trapped in the textures or the micro-scale roughness amplitudes prevent the drop from spreading over the rough surface

• A wetting condition closer to Cassie Baxter state of wetting is obtained
Contact angle

\[
\cos \theta = \frac{\gamma_{SV} - \gamma_{SL}}{\gamma}
\]

\[
\gamma^{SV} = \gamma^{sl} + \gamma^{lv} \cos \theta
\]

Where, \( \gamma_{SV} \), \( \gamma_{SL} \) and \( \gamma \) are the surface tension of solid-vapour, solid-liquid and liquid-vapour interfaces respectively.
$0^\circ < \theta < 90^\circ$ : Solid is wet by the liquid and the surface is termed as hydrophilic.

$90^\circ < \theta < 180^\circ$ : Solid is not wet by liquid and surface is termed as hydrophobic
Advancing and Receding Contact angle
Lotus leaf effect

Self cleaning property as CA =160
Wenzel and Cassie Model:

When drop is put on the textured surface then there are two possibilities in which drop interact with the pattern on the surface.
Wenzel Equation:

\[ \cos \theta^* = r \cos \theta \]

\[ r = \frac{\text{Total surface area}}{\text{Total projected surface area}} = \frac{\text{Actual surface area}}{\text{Apparent surface area}} \]

\[ r = \frac{4dh + (d + w)^2}{(d + w)^2} \]

\[ \theta^* \] = Apparent Contact angle of a drop on the rough surface

\[ r \] = roughness factor

Surface texture parameters to quantify roughness of surface
Cassie-Baxter Equation

\[ \cos \theta^* = -1 + \phi (\cos \theta + 1) \] ...........(1)

Where \( \phi \) is the fraction of solid contacting the liquid

\[ \phi = \frac{\text{Total pillar top surface area}}{\text{Total projected surface area}} \]

\[ \phi = \frac{d^2}{(d + w)^2} \]

Equation (1) can also be written as:

\[ \cos \theta^* = (1 - \phi) \cos 180^\circ + \phi \cos \theta \]

\[ \cos \theta^* = (\text{Fraction of liquid vapour interface})^* (\text{contact angle of liquid vapour interface}) + (\text{fraction of liquid solid interface})^* (\text{contact angle of liquid solid interface}) \]
Force required to move the drop

Force per unit length of perimeter when drop is just about to move is

\[ F = \gamma (\cos \theta_r - \cos \theta_a) \]
Tribological Applications-Regular Micro-structured surface in the form of dimples
Direct Processing
Indirect Processing
Laser ablated pores in SS
Indirect Laser Surface Texturing on 52100 Steel
Frictional Response
Hydrodynamic Pressure distribution over a single Protrusion
Why dimple?

- complicated etching technology
- high wear
- high leakage (seals)

- simple & cheap laser technology
- lower wear
- low leakage/spacing
Film Thickness and Geometry of micro-dimples

dimensionless minimum clearance: \( \delta = \frac{h_0}{2r_p} \)
dimensionless local film thickness: \( H = \frac{h}{h_0} = H(\varepsilon, \delta) \)
micro-dimple aspect ratio: \( \varepsilon = \frac{h_p}{2r_p} \)
Mechanical Face Seal
Ring on Ring scheme

Friction Torque vs Face loading
For textured and non-textured Seals
laser surface texturing of Mechanical Seal

Full and Partial LST on Seal

Schematic of Partial LST on Seal

Friction Torque vs Sealed Pressure

Untextured

Textured
Field Test with water Pump

- Carbon Ring - Standard Seal After 400 Hours
- WC Ring - Standard Seal After 400 Hours
- Carbon Ring - LST Seal After 550 Hours
- WC Ring - LST Seal After 550 Hours
Laser Textured Piston Ring

Piston

Textured Piston Ring

Cylinder Liner

Textured Friction Surface

Full Textured Piston Ring Segment

Partially Textured Piston Ring Segment
Tape moving on LST Guide