Laserpolishing of hard materials

Conference Paper · June 2004

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Laser polishing of hard materials
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Abstract
Laser polishing of hard materials creates the possibility to obtain smooth hard surfaces. An important application of polished hard surfaces is to be found in friction reduction. Experiments were performed to polish hard surfaces with a copper vapor laser (Oxford Laser LM100). Sample materials have been used that have been polished before deposition of a surface layer: metal with Ni(P) surface, TiN and Diamond-like Carbon. Ra values were measured of 2.7 nm, 2.7 nm and 2.4 nm respectively with a spread of 1.5 nm. The laser polishing experiments were set up using Design of Experiments with the aim to remove peaks from the surface. Laser polished samples were measured using a Mitutoyo type SVC-624-3D surface measuring instrument and a Nomarski interference-microscope. The laser polished samples did not show the removal of peaks.

Introduction
Surface qualities in the order of a few nanometre Ra value can be obtained with mechanical surface treatment. With laser polishing the same order of surface quality can be attained, also extreme hard surfaces can be polished.

With mechanical polishing roughness values [1] are reported of: Si3N4, (Ra 8 - 12 nm), WC (Ra 2 - 3 nm), ZrO2 (Ra 1 - 2 nm), Si (Ra 6 - 8 nm), Stainless steel (Ra 5 - 8 nm), Zerodur (Ra 7 - 8 nm)
Advantages of laser polishing are (a) the option to polish hard materials like Diamond and Diamond like Carbon (DLC) coatings and (b) to polish complex shaped surfaces. With laser polishing, the following surface roughness figures are reported [2, 3, 4]: DLC Ra start 140 nm, Ra after laser polishing 54 nm, DLC Ra start 20 - 50 nm, Ra after laser polishing 3 - 6 nm DLC Ra start 450 nm, Ra after laser polishing 123 nm. Aim of our experiments was to investigate the possibility to create a smooth surface (e.g. low Ra value, low Rz value) and determine the friction properties of a smooth, polished surface.

Shift of the Stribeck curve
TNO has developed a laser machining strategy to perform surface modifications to manipulate the tribological behaviour of a surface. This can be demonstrated in the position of the Stribeck curve. An unfortunate side effect is softening of the metal surfaces. Use of protective coatings of hard materials would be very beneficial.

Figure 1: Modified surface

In Figure 1 a laser modified surface is shown. This modified surface results in a change in friction behaviour [3]. Friction behaviour can be classified based on the nature of mechanical contact: unprotected mechanical contact, partial mechanical contact and full boundary lubrication. A boundary layer is formed from lubricant molecules, interacting with the surface. At very low velocities there is not any hydrodynamic pressure build-up generated and unprotected mechanical contact can occur. At lower pressures hydrodynamic lubrication can be maintained easier with the modified surface, thus leading to a shift in the Stribeck curve.

Laser structuring of a metal surface leads to softening of the metal surface, the so-called heat affected zone. This softening reduces the useful life of the modified surface. Softening of the modified metal surface can be addressed by (a) using very short laser pulses or (b) applying coatings of hard materials. The experiments that have been performed by TNO with femto second lasers to modify a metal surface in order to improve tribological behaviour have not been satisfactory. The main reasons for this unsatisfactory behaviour are the low repetition rates of the femto second lasers used and the obtained quality of the modified surface.

Application of a hard coating can protect the modified metal surface, peaks in the surface can lead to undesired mechanical contact.

For polished, very smooth surfaces, it is expected that the coefficient of friction will increase dramatically, because a normal three point contact will change into a surface contact, leading to the stiction effect, which occurs in micro systems. It is therefore important to study the behaviour of surfaces coated with hard materials with a very low roughness.
Experimental

Sample materials
Sample materials have been used that have been polished before deposition of a surface layer. Metal with Ni(P) surface, TiN and Diamond-like Carbon. Ra values were measured of 2.7 nm, 2.7 nm and 2.4 nm respectively with a spread of 1.5 nm.

Laser polishing experiments
All experiments at TNO Industrial Technology were done with a pulsed (20 ns, 10 kHz) Copper Vapour Laser system (Oxford Laser LM100 wavelength 510.6 nm /578.2 nm). Laser parameter settings were studied using Design of Experiments (DoE). Some experiments on DLC material were conducted with an Excimer laser with a wavelength of 192 nm.

Parameters studied were processing speed (8.3, 17.7, 25 mm/s), beam energy (0.7, 2.8, 6.3, 11.2 W) and line distances (10, 25 micron). The processing angle was at a constant value of 84 degrees. In order to reduce the number of experiments, a setup following a Taguchi experimental design approach [5] was used.

Table 1: Taguchi L4 Experimental setup

<table>
<thead>
<tr>
<th>Exp #</th>
<th>V [mm/s]</th>
<th>Energy [W]</th>
<th>Line distances [micron]</th>
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<td>8.3</td>
<td>2.8</td>
<td>10</td>
</tr>
<tr>
<td>2</td>
<td>8.3</td>
<td>11.2</td>
<td>25</td>
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<tr>
<td>3</td>
<td>25</td>
<td>2.8</td>
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</tr>
<tr>
<td>4</td>
<td>25</td>
<td>11.2</td>
<td>10</td>
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</tbody>
</table>

Sample Measurements
The roughness of each of the treated surfaces was measured with a Mitutoyo type SVC-624-3D surface measuring instrument. Of each of the treated surfaces, a 1.25 mm trace was measured with a cut-off length of 0.25 mm. Each measurement was repeated 6 times for the same trace, and averaged according to a special method which removes noise influences [6]. The influence of the reference guidance at the same trace has been determined by measuring randomly selected traces on a very flat surface. The reference guidance profile was calculated according to the method described in [6] and subtracted from the measurements.

Results: the laser-treated areas all had an Ra value of 2.0 ± 1.0 nm; different traces within those areas differ less than 0.2 nm. The non-treated areas have a Ra value of 1.4 ± 1.0 nm. The Rz value is 12.0 ± 1.0 nm for both the treated and non-treated surfaces. Visually in a Nomarski interference-microscope it is observed that the treated parts are a bit 'rougher', i.e. it looks like small cracks are present in the treated parts.

Figure 2 Surface roughness measurement of Modified surface

Results
It has been proven difficult to polish surfaces below 2 nm roughness with the lasers used. We have not been able to prove our assumption that friction behaviour can be altered by removing peaks from the surface.

References