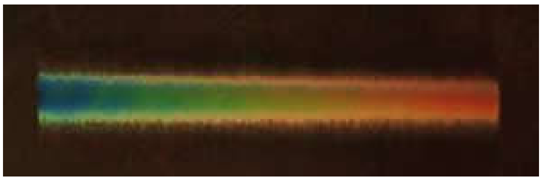
Canon Machinery Inc.

Ultrashort Pulse Laser Processing Technology
Fine Periodic Structure Texturing Using Ultrashort Pulse Laser

When a linearly polarized ultrashort pulse laser is focused and irradiated on the surface of a material, periodic structures with a pitch of the order of the laser wavelength is formed in a self-organizing manner. This fine periodic structure formulation technology is expected to lead to drastic improvements in various surface functions, including the reduction of friction loss directly linked to environmental problems, improved biocompatibility and improved hydrophilic/hydrophobic properties.



When irradiated with a linearly polarized laser having a fluence near the processing threshold, grating-like periodic structures having a periodic spacing similar to the laser wavelength are formed in a self-organized manner perpendicular to the polarization direction due to the interference of incident light and scattered waves along the surface of the substrate. The formation area of the periodic structures can be expanded widely with overlapped laser scanning. High-speed machining of up to 2 million lines per second is possible. Figure 1 shows the periodic structures with a periodic spacing of about 700 nm and a groove depth of about 200 nm formed by ultrashort pulse laser irradiation. Below we introduce functions and application of the periodic structures.

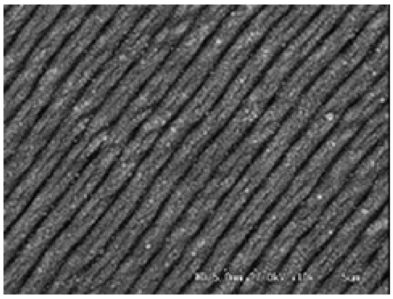


Figure 1: Periodic structures formed on SUS440C

Related papers

Hiroshi Sawada et al., Journal of the Japan Society for Precision Engineering; 69, 4 (2003) 554

Hiroshi Sawada et al., Journal of the Japan Society for Precision Engineering; 70, 1 (2004) 133

Characteristics of Periodic Structure Formation with Ultrashort Pulse Laser

1. Applicable to hard-to-process materials
2. Free texturing area
3. Direction of periodic structures controllable
4. Applicable to thin films and micro-parts
5. Applicable to curved surfaces

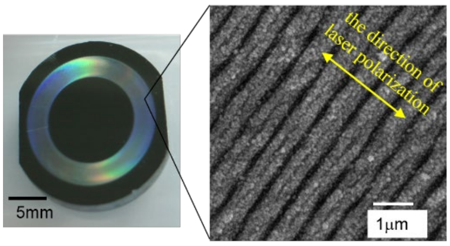


Figure 2: Periodic structures on cemented carbide (radial pattern)

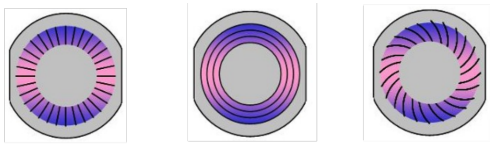


Figure 3: Various periodic structure patterns

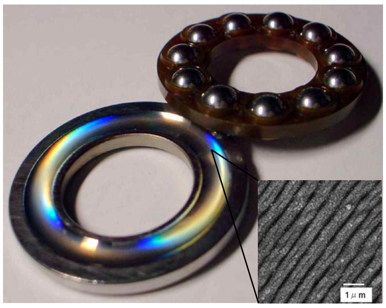


Figure 4: Periodic structures of the bearing transfer surface

The periodic structures can be textured in hard-to-process materials such as hardened steel and hard metal due to laser processing. Can also process Si, SiC, DLC, etc. Figure 2 shows the periodic structures formed in a ring-shaped region of cemented carbide. When forming periodic structures, a rainbow appears due to light diffraction. Since the direction of the periodic structure is at a right angle to the direction of laser polarization, changing the direction of polarization easily enables the formation of a pattern difficult to obtain with normal machining, as shown in Fig. 3. The ultrashort pulse laser is able to limit the heat-affected zone, it is possible to form periodic structures for micromachines and thin film coatings.

This method of forming the periodic structures uses only one optical path, so the optical system is very simple. Moreover, unlike 2 optical path interference processing, it is possible to process irregular surfaces as well as flat surfaces.

In figure 4, periodic structures are formed on a bearing transfer surface. They are formed on a curved transfer surface with a single laser scan.

Periodic Structure Functions

Offers a variety of surface functions for periodic structures created by ultrashort pulse laser.

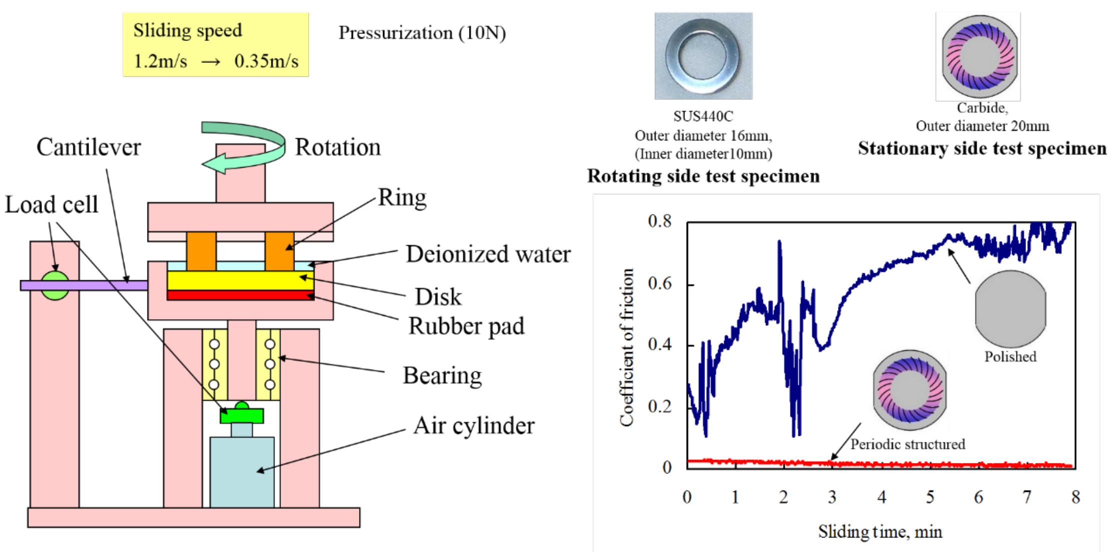
Friction/wear reduction	→	Automobile parts, bearings
Wettability, cell control	→	Dispensing nozzles, medical equipment
Adhesion control	→	Cutting tools, molds
Improved adhesion of thin film	→	Pretreatment for coating, highly durable monolayer

Applied Research

We are researching surface function improvements. Below we introduce four research themes: (1) Tribology (friction, wear reduction), (2) Wettability control, (3) Improved adhesion of thin film and (4) Cellular control

1. Friction, wear reduction

In recent years, environmental destruction on a global scale, including global warming, has become a major problem. To prevent global warming and conserve the rich global environment, it is essential to reduce CO_2 emissions, which are the main cause of global warming. In particular, reducing the friction loss of sliding parts on automobiles and industrial equipment is an important issue. Therefore, studies are underway to improve the holding function of lubricants and the load capacity of fluid lubrication films via the formation of a periodic structure on the surface of sliding parts to reduce frictional force and seizure resistance.



Hiroshi Sawada: Journal of the Japan Society for Precision Engineering; 72, 8 (2006) 951.

Figure 5: Ring-on-disk test

Figure 5 shows the ring-on-disk test apparatus used in the experiment and the experimental results. Tempered material SUS440C is used for the rotating test specimen and the cemented carbide is used for the stationary test specimen. The test specimen is immersed in pure water and the load is applied from the rotating shaft side. The sliding dynamic torque is detected by the load cell via the cantilever. A spiral periodic structure is formed on the disk test specimen. For comparison, experiments were also conducted between specular test specimens.

By forming a spiral periodic structure, we can see that large dynamic pressure is generated and the friction coefficient is drastically reduced.

A periodic structure with a submicron groove depth produces a thinner and more rigid oil film than spiral groove bearings with a typical micron size groove depth. Figure 6 shows the result of calculating the relative load capacity when the groove depth of the spiral pattern is 200 nm and 6 μm. As the oil film becomes thinner, it can be seen that the groove depth of 200 nm has an overwhelmingly higher load capacity and rigidity.

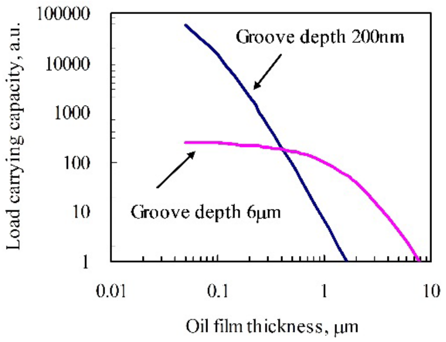


Figure 6: Comparison of load capacity in different groove depths

Related papers

Hiroshi Sawada, Journal of the Japan Society for Precision Engineering; 48, 2 (2013) 65.

2. Wettability Control

Wettability is known to be strongly affected by surface energy. Hydrophilicity and hydrophobicity can be accentuated through the introduction of surface roughness. Thus, research is underway to create super-water-repellent surfaces by applying designed surface roughness using an ultrashort pulse laser.

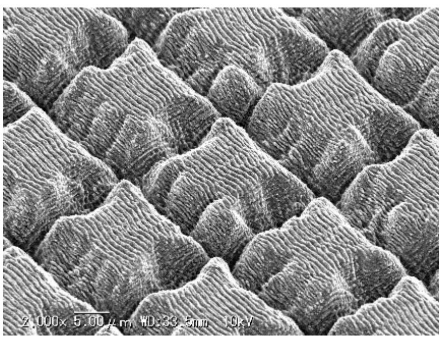


Figure 7: Two-dimensional lattice groove composite surface and periodic structure

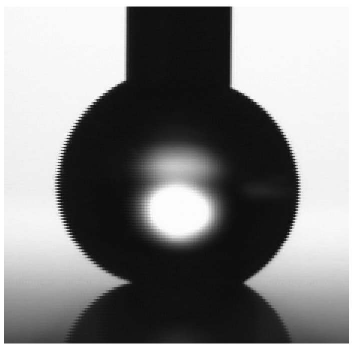


Figure 8: Droplet in contact angle measurement

Periodic structures with submicron periodic spacings formed by an ultrashort pulse laser can contain even finer roughness of less than several tens of nanometers. In addition, the periodic structures can be superscripted on the surface of a high-strength material with the roughness on the order of μm, and different orders of roughness can be easily compounded, making it a useful surface treatment technology for high-durable ultra water-repellent surface structures. Figure 7 shows the composit surface with two-dimensional lattice grooves and periodic structures. This composite surface has a surface area of 2.67 times that of a smooth surface. When a fluorine-based monolayer is formed on this complex surface, the calculated contact angle is 157 degrees. When the actual contact angle is measured it is 155 degrees, achieving a super-water-repellent surface nearly as designed. Figure 8 shows droplet in contact angle measurement.

Figure 9: Droplet bounce

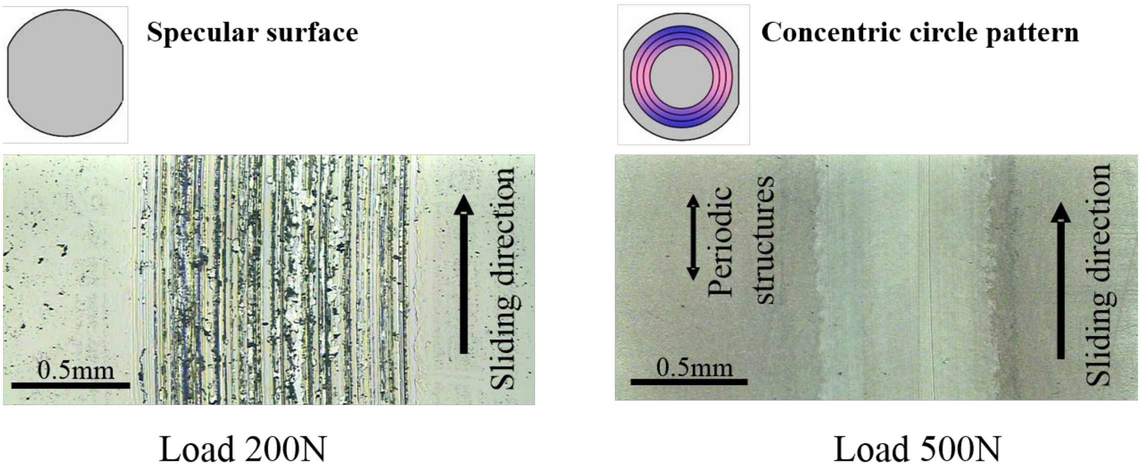
As shown in Figure 9, this superhydrophobic surface can vigorously repel water droplets.

Related papers

Hiroshi Sawada et al., Japan Society of Tribologists Premilinary Draft Collection Spring 2016, D30.

3. Improved Thin Film Adhesion

Although highly functional thin films such as diamond-like carbon (DLC), which exhibits excellent tribological properties, and hydroxyapatite, which greatly improves biocompatibility, are attracting attention, they are not considered sufficient for substrate adhesion. Since Film delamination becomes a problem under high surface pressure, adhesion improvement is an important issue. Thus, research is being conducted to improve thin film adhesion by forming periodic structures as a foundational treatment on the substrate.



Hiroshi Sawada et al., Tribologist, 51, 2 (2006) 180

Figure 10: DLC adhesion evaluation

Figure 10 shows the results of evaluating DLC film adhesion using a pin-on-disk test device, formed on the SUS304 substrate. The DLC film formed on the specular substrate exhibits severe delamination with a vertical load of 200 N. However, there is no noticeable damage with a vertical load of 500 N on the periodic structure substrate.

Related papers

Hiroshi Sawada, Tribologist; 51, 2 (2006) 180.

4. Cell Control

Since bone exhibits high mechanical function due to its orientation, the importance of bone orientation is indicated in bone regeneration as bone mineral density recovers. On the titanium plate forming the periodic structures, as shown in Figure 11, osteoblasts start to progress along the periodic structures one hour after culture and the orientation rate improves over time. Recent studies have revealed that not only osteoblasts, but also bone matrix (collagen fibers/apatite crystals) produced by osteoblasts are oriented by perodic structures. Bone matrix was thought to be oriented parallel to the direction of development of osteoblasts, but the bone matrix is formed in a direction perpendicular to the periodic structures. By forming periodic structures on the surface of an artificial joint, etc., new bone tissue around the artificial joint can develop into sound bone (oriented bone) at an early stage, which is expected to shorten the time required for treatment.

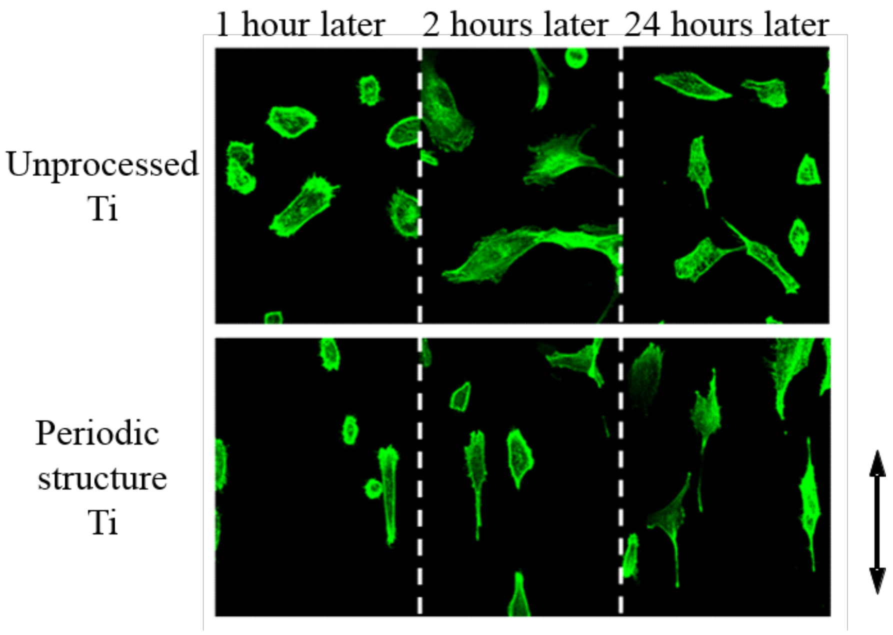


Figure 11: Osteoblast orientation

Related papers

Aira Matsugaki et al., Biomaterials 37 (2015), pp. 134.

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