P18

Study on the effect of dimple formation by laser treatment on Tungsten Carbide alloys with DLC coating on friction coefficient reduction

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1. Introduction

In industrial sites, mechanical components operate in high-load and high-temperature environments, which can degrade performance due to energy loss and wear caused by friction [1]. Therefore, various coating technologies have been developed to prevent such performance degradation. Diamond-Like Carbon (DLC) coatings are drawing attention for their excellent low friction characteristics and high wear resistance. DLC coating effectively reduces wear and friction on metal surfaces, mainly when applied to metal surfaces such as tungsten, which significantly improves surface hardness and prolongs the life of coated parts [2]. However, there is a problem with DLC coating alone not effectively removing abrasion debris generated by friction conditions, which can degrade friction performance in the long run. To solve this problem, this study proposes the fusion of DLC coating and surface patterning through laser treatment. Laser treatment effectively confines debris generated during friction testing and component operation when forming dimples in a specific pattern on a surface. In addition, the Dimple can act as an oil repository when lubricating oil, allowing the lubrication function to be maintained for a long time. In this study, laser treatment was performed using Nano Pulse Laser, friction test was performed using Pin On Disk Tribometer, and results after friction test were analyzed using Confocal Microscope, Optical Microscope, AFM (Atomic Force Microscope), etc.

2. Experimental procedure

The production process of the poetry compilation used in the experiment is as follows.
A cemented carbide cut to a size of 15×15×5 mm^3 is put in ethanol and acetone, and the contaminants are removed through an ultrasonic washer for 5 minutes each. Afterward, Cr is vapor-deposited in a buffer layer with a thickness of 0.3 µm on the washed cemented carbide through a PVD sybstem. After the cemented carbide in which the buffer layer is deposited at a thickness of 1.5 µm through a (PE) CVD method, the film layer is patterned to be laser-treated using a nanosecond pulse laser so that µm-sized dimples are arranged in Hexa structure on the surface of the fabricated specimen (Fig.1). In this way, burrs are generated near the boundary of the Dimple during laser irradiation, and the reason for the burrs is as follows. When laser irradiation is applied to the surface of the test specimen in which the DLC thin film is deposited, the DLC thin film absorbs the energy of the laser, causing thermal expansion, and then the crystals are rearranged or reshaped as they shrink. If the bar is not removed, debris from the bar may occur during the friction wear test, and since the debris can damage the specimen surface and increase the friction coefficient, this study conducted a friction wear test after removing the bar. To remove the burrs, the surface of the specimen was Polished at a speed of 300 RPM using a fusion of fine-thick (diameter 1µm) raw yarn to remove the burrs (Fig.2). Afterward, the test piece was prepared to sufficiently contain oil inside the Dimple by operating the ultrasonic washer for 10 minutes while soaking the test piece with the burr removed in lubricating oil. During the frictional wear test, a 6 mm diameter STB2 ball was used to set the Wear Track radius to 6 mm with a load of 2 N, and a total of 1000 m was tested at a speed of 150 RPM, and the results were compared.

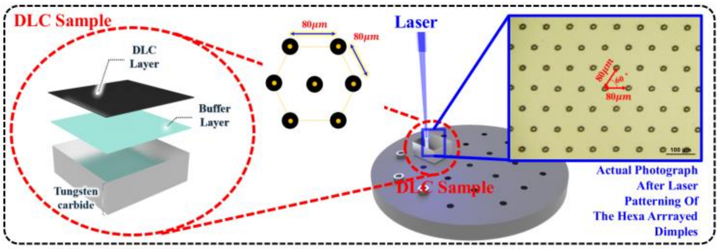

Fig. 1. Description of laser treatment process on DLC coated samples

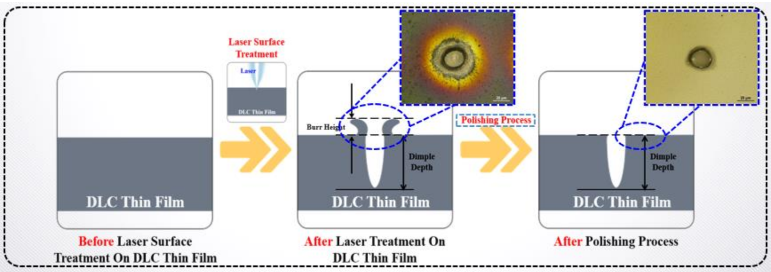

Fig. 2. Description of laser surface treatment and burr removal process

3. Results and discussion

Using Stylus, we verified that the thickness of the DLC thin film layer was 1.5 µm, and measured the adhesion strength between the buffer layer and the DLC layer and the substrate with Scratch Tester, and found that the critical load was 21.51 N. Therefore, since the ball has a diameter of 6 mm and the contact stress of the 2 N was calculated as 3.316 N when applying a load of 2 N, we verified that the risk of DLC thin film peeling is not high when performing a friction wear test with a load of 2 N. In addition, the Nano Indentation Tester confirmed that the DLC thin film has a hardness of 2672.5 HV.

The oil lubrication wear test showed that the friction coefficient was lower in the test piece, especially the narrower the spacing between the patterned dimples, the lower the friction coefficient (Fig.3). However, the narrower the distance between dimples, the larger the wear area, which is not the result of analyzing the total area of the specimen, but the result of analyzing it mainly in areas where wear is particularly high, so further analysis is needed in future.

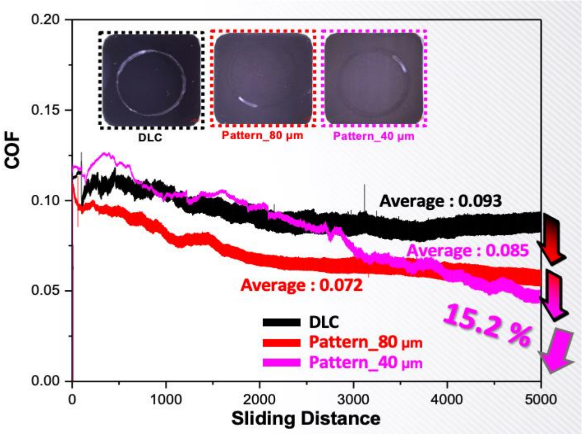

Fig. 3. Tribological result

Conclusion

The results of the dry wear and friction tests revealed a surprising outcome. While the application of a DLC coating significantly improved the tribological performance by reducing the friction coefficient, the introduction of surface patterning unexpectedly led to an increase in the friction coefficient. This counterintuitive finding challenges our conventional understanding and suggests that the patterned surface may have altered the contact mechanics in a manner that increased localized stresses or interfered with the smooth sliding of the counterface material. Despite this increase in friction, the wear analysis indicated that the patterned DLC-coated specimens exhibited the most significant reduction in wear area, which implies that patterning may still offer advantages in terms of wear resistance by distributing contact stresses more effectively.

In the oil-lubricated wear tests, a more consistent trend was observed. The patterned DLC-coated specimens consistently demonstrated a lower friction coefficient than those with only the DLC coating, with the friction coefficient further decreasing as the dimple spacing was reduced. This indicates that a denser pattern enhances the retention of lubricants within the dimples, thereby improving the lubricating effect and reducing friction. However, it was also noted that the wear area increased as the dimple spacing decreased. This increase in wear could be due to the concentration of wear in specific regions rather than a uniform distribution across the entire surface. These findings highlight the complex interplay between surface patterning, lubrication, and wear mechanisms. While patterning can enhance certain aspects of tribological performance, such as wear resistance under dry conditions and reduced friction under lubrication, it may also introduce new challenges, such as increased localized wear or altered friction characteristics. The observed increase in wear area with decreased dimple spacing under lubricated conditions underscores the need for a more comprehensive analysis of wear across the entire surface to understand the implications of surface patterning fully.

Reference

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