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Friction property of Si-DLC with a local scratched damage before and after repairing deposition

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ABSTRACT – A local damage of Diamond-Like Carbon (DLC) is repaired by recoating. Conventional recoating regains through the following processes: (1) Uninstallation of the die from a processing machine, (2) Removal of all the DLC, (3) Recoating of new DLC, (4) Installation of the recoated die to a processing machine. In this work, and thus we propose a new way of repairing such a local damage of DLC without uninstallation of die. We carried out friction test of Si-DLC with a local scratched damage before and after repairing deposition by PECVD, and the repaired Si-DLC showed better friction characteristics than damaged Si-DLC.

1. INTRODUCTION

Injection mold is desired to have better releasing property, against molded plastics to DLC (Diamond-Like Carbon) coating is often considered to satisfy the demand. DLC has high hardness (over 10GPa), high wear resistance, and low frictional property. However, DLC film has poor impact resistance because of high hardness, it's easy to damage by cracking into a film and peeling from a base material.

Conventionally, a local damage by peeling and wear of Diamond-Like Carbon (DLC) on a die is repaired through the following process: (1) Uninstallation of the die from a processing machine, (2) Removal of all the DLC film coated on the die, (3) Recoating of new DLC film, (4) Installation of the recoated die to the processing machine. However, this process loses a lot of time and money, and thus we propose a new way of repairing such a local damage of DLC without uninstalling a coated die from a processing machine**.** Development of this new ray way regards at least two element technologies: (I) Cleaning process for keeping sufficient adhesive strength between pre-coated DLC and re-coated DLC, (II) micro device capable of repairing DLC on the die fixed to a processing machine. Technology (I) is regarded because re-coated new DLC partly overlaps old DLC in local repairing, where old DLC remaining is not removed before re-coating. Prior to this work, we focused on technology (I), and improved the adhesion between pre-coated Si-DLC and recoated Si-DLC [1]. In this work, we investigated the effect of re-coated Si-DLC to a local damaged part of pre-coated Si-DLC.

2. METHODOLOGY

In this work, as a local damage to be repaired, we introduced scratch scar to a pre-coated Si-DLC on a steel disk (SUJ2, JIS) by scratch tester for measuring peel-off load of hard films. The steel disk has a diameter of 22.5mm and a thickness of 4mm. Pre-coated Si-DLC has a film thickness of 2.4μm, Knoop hardness of 2350HK, was deposited onto nitrided layer of 4.3μm. In scratching, testing load from 49N to 50N was applied to the pre-coated Si-DLC at a scratch distance of 10mm. We used slit mask 0.5mm in width and length of 11.25mm in order to deposit re-coated Si-DLC within a local area including the scratch scar. For cleaning and following deposition of recoated Si-DLC, we used a plasma-enhanced chemical vapor deposition (PECVD) apparatus (Figure 1) employing Microwave sheath-Voltage combination Plasma (MVP) [2,3]. Table1 and Table 2 are respectively cleaning condition and deposition condition.

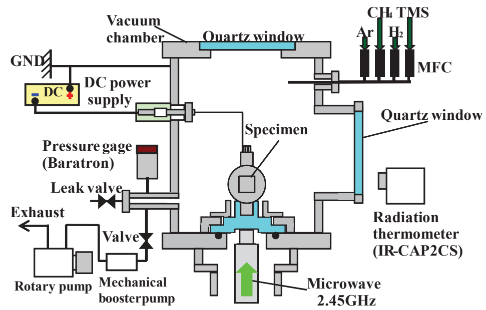


Figure 1 Schematic of vacuum chamber and peripheral equipment for deposition.

Table 1 Cleaning condition.

Cleaning time	First cleaning Bias(DC)+ Microwave(MW)	sec	300
	Second cleaning: Bias(DC)	sec	600
Microwave 2.45 GHz	Peak power	kW	1
	Pulse frequency	Hz	500
	Duty ratio	%	3
Bias (DC)	Voltage	kW	-500
	Pulse frequency	Hz	500
	Duty ratio	%	50
Pressure		Pa	50
Gas flow rate H_2 : Ar		sccm	10 : 40

Finally, in order to evaluate pre-coated, damaged, and repaired Si-DLCs from tribological view point, these Si-DLC were slid against a steel ball (SUJ2, JIS) at a normal load of 15N and a rotation speed of 10m/min (revolution number of 318rpm, revolution radius of 5mm) by a ball on disk friction tester.

Table 2 Deposition condition.

Deposition time		sec	30
Microwave (2.45 GHz)	Peak power	kW	1
	Pulse frequency	Hz	500
	Duty ratio	%	50
Bias (DC)	Voltage	V	-500
	Pulse frequency	Hz	500
	Duty ratio	%	50
Pressure		Pa	75
Gas flow rate CH_4 : Ar : TMS		sccm	200 : 40 : 20

3. RESULTS AND DISCUSSION

Table 3 shows microscope photo and cross-sectional shape of damaged and repaired Si-DLC. You can identify the depth of scratch scar on the damaged Si-DLC as about 7μm, while that on the repaired Si-DLC as about 6μm. These results clearly indicate that re-coated Si-DLC about 1μm in thickness was deposited onto the damaged Si-DLC. We tried to recoat film thickness of over 1μm, however recoated Si-DLC film thickness of over 1μm was peeled.

Table 3 Result of before and after part of deposition on scratch scar.

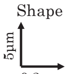
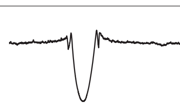
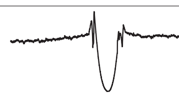
	Damaged Si-DLC	Repaired Si-DLC
Scope photo		
Shape 		

Figure 2 shows relationship between friction coefficient and sliding distance by using ball on disk friction tester. In sliding against a steel ball, friction coefficient typically increases at the beginning because of initial oxide layer on the steel ball, subsequently, friction coefficient turns to decrease due to the formation of the transfer film of low shear strength onto the surface of the steel ball. This behaviour is ascribed to the initial oxide layer mentioned above. In typical Si-DLCs, Friction coefficient of about 0.05-0.1 is achieved after running-in process when it is slide against a steel ball under dry sliding condition [2]. In other word, we can say running-in process is finished, when friction coefficient is kept less than 0.05-0.1 in a sliding distance which is longer than the initial sliding distance where friction coefficient is higher than.

In Figure 2, in pre-coated Si-DLC, friction coefficient increased from the start to the sliding distance of 50m, subsequently it turned to decrease. Pre-coated Si-DLC was not finished running-in process even at the sliding distance of 300m, friction coefficient has kept decreasing. Damaged Si-DLC showed a similar tendency, however frequent fluctuation of friction coefficient has kept appearing from sliding distance of about 60m to that of 300m. On the contrary, repaired Si-DLC finished running-in process at a sliding distance of about 100m, when friction coefficient was almost constant at 0.06.

The period of the fluctuation of friction coefficient in damaged Si-DLC did not synchronize to the rotation period; in addition, the fluctuation of friction coefficient did not appear from the start of the test to a sliding distance of about 60m. Because the exposed steel around the scratch scar in the damaged Si-DLC can strongly adhere with transfer film, we consider the fluctuation of friction coefficient in damaged Si-DLC is caused by adhesion and detachment of transfer film between ball and disk.

In the repaired Si-DLC, running-in process was finished at a sliding distance of about 100m. Furthermore, in repaired Si-DLC, fluctuation of friction coefficient as seen in damaged Si-DLC was not observed. This should be because the exposed steel around the scratch scar is successfully covered by recoated Si-DLC in the repaired Si-DLC.

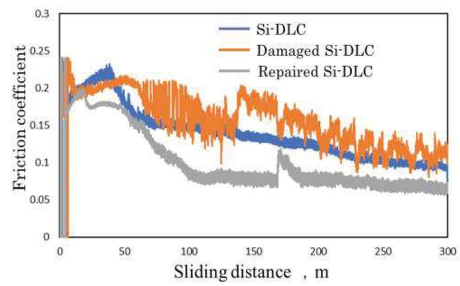


Figure 2 Relationship between damaged Si-DLC and repaired Si-DLC by using friction test. (revolution:318rpm; radius:5mm; load:15N)

4. CONCLUSION

We evaluated the friction property of pre-coated, damaged and repaired Si-DLCs. In damaged Si-DLC with scratch scar, fluctuation of friction coefficient appeared and average friction coefficient ignoring the fluctuation was slightly larger than that of pre-coated Si-DLC. In repaired Si-DLC, fluctuation of friction coefficient was not observed, it showed better friction characteristics than damaged Si-DLC.

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REFERENCES

[1] Takamatsu H. (2018). Development of redeposition technology and assessment of restoration effect. *63*(1), 22-27. (in Japan).

[2] Kousaka, H., Umehara, N., Ono, K., & Xu, J. (2005). Microwave-excited high-density plasma column sustained along metal rod at negative voltage. *Japanese Journal of Applied Physics*, *44*(8L), L1154.

[3] Tanaka, I., Nakano, T., Kousaka, H., & Hashitomi, H. (2017). Tribological behavior of unlubricated sliding between a steel ball and Si-DLC deposited by ultra-high-speed coating employing an MVP method. *Surface and Coatings Technology*, *332*, 128-134.

[4] Mori, H., Takahashi, N., Kazuyuki, N., Tachikawa, H., & Ohmori, T. (2007). Low friction property and its mechanism of DLC-Si films under dry sliding conditions. *SAE Technical Paper.*