Development of DLC for Transmission Gears

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ABSTRACT

A diamond-like carbon (DLC) coating has been developed for the transmission gears to increase their transmission efficiency. Using the carbon sputter method increased topcoat hardness and suppressed the formation of interfaces within the coating film, which enhanced durability under high surface pressures. This DLC was applied to the shift gear, final gear and bevel gear, and contributed to reducing friction. In addition, it secured the reliability needed to enable continuous use in the 4-Race events that Formula One regulations prescribe.

1. Introduction

Transmission loss is mainly due to losses from the bearing and gear, and gear sliding loss accounts for a large percentage of this. Therefore, DLC coatings that have good friction characteristics are thought to effectively increase transmission efficiency. However, the transmission gears (hereafter, “gears”) have a high surface pressure load, so the DLC used by engine valve train parts lacked sufficient durability and could not be applied.

Therefore, to increase transmission efficiency by utilizing the DLC’s good friction characteristics, the following targets were newly set, and a DLC coating for gears was developed.

(1) A coating film composition that can withstand surface pressure loads up to a maximum 2.2 GPa, enabling continuous use in the 4-Race events that Formula One regulations have prescribed since 2008

(2) Establishment of a coating method that forms a uniform film over the complex gear tooth shape

2. Development Concept

Engine valve trains that use a DLC coating perform reciprocal motion, so there is an oil film break point with a sliding speed of 0 m/s. This means that a hard bonding layer is required below the coating film to enhance scuff resistance.

On the other hand, the gear sliding environment has a high maximum surface pressure of 2.2 GPa, but the sliding speed does not go to 0 m/s, and there is no oil film break such as in a valve train. For this reason it was thought that a bonding layer is not required for the gear DLC, so efforts focused on developing a topcoat and coating film composition with an emphasis on wear resistance.

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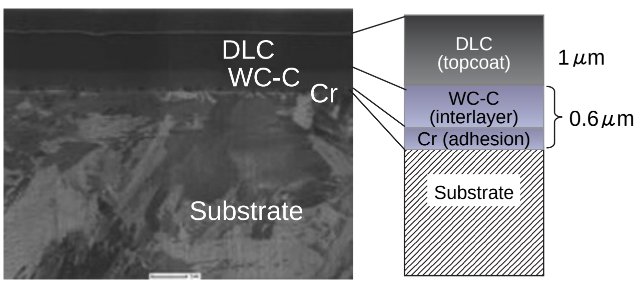
3. Developed Technology

To increase adhesive strength between the coating film and the substrate, which is an issue under high surface pressures, the substrate surface roughness was finished to approximately 0.1 Ra, and surface contamination (oil components and minute corrosion) was eliminated by enhanced cleaning. As a result, this has resolved issues rooted in the substrate surface condition.

The nano-indenter hardness of the topcoat was increased to 60 GPa to enhance the wear resistance. From there down to the substrate, the coating film consists of an interlayer metal-carbon coating film (hereafter “WC-C”) with a hardness that changes gradually until the interlayer joins with the chrome (Cr) adhesion layer. Figure 1 shows the DLC coating film composition.

The carbon sputter method was used continuously from the DLC topcoat to the WC-C. Hydrocarbon gas is generally used in many cases, but continuous sputter enabled the formation of interfaces to be suppressed, which prevented interlayer peeling under high surface pressures.



(a) FIB-SIM image　(b) Schematic diagram

Fig. 1　DLC cross section

In addition, gears have an uneven shape (especially the bevel gear), so uniformity of the coating thickness between the tooth tip and the tooth root is an issue. However, efforts were made to secure a uniform coating thickness by adjusting the bias voltage and work placement inside the DLC chamber. Figure 2 shows the coating thickness reduction ratio in the direction towards the tooth root, using the coating thickness at the tip of the bevel gear tooth as the reference. This shows that the developed DLC has a more uniform coating thickness compared to the conventional DLC.

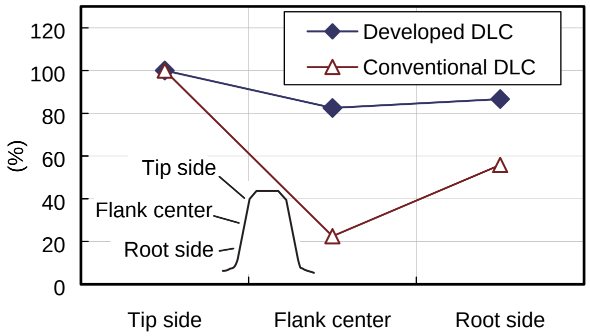


Fig. 2 Coating thickness distribution at tooth flank

4. Confirmation of Effects

Pin on disk seizing limit tests and actual transmission tests were performed. In the pin on disk seizing limit tests, oil was applied, wiped off, and then the load at which the friction coefficient rose due to seizing measured. As shown in Fig. 3, the seizing load increased by 40%. This is thought to be due to an increase in the

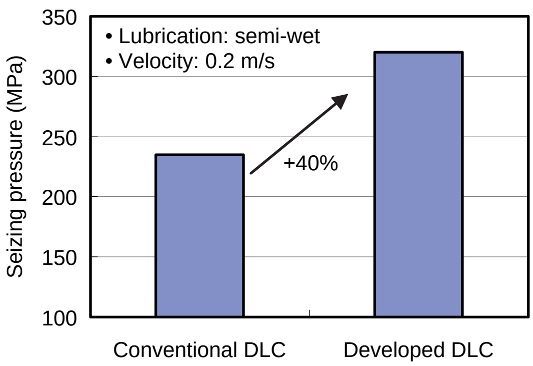
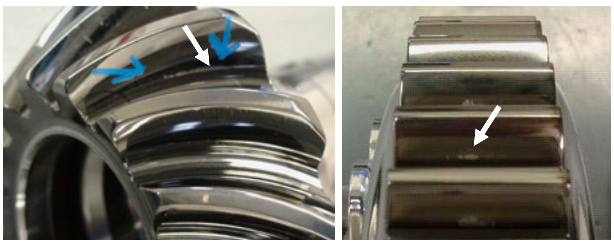


Fig. 3 Result of pin on disk test (DLC disk-DLC pin)



(a) Bevel gear (b) Final gear

Fig. 4 DLC after 4-race event

Table 1 Friction reduction of each DLC gear in actual gear box

	Shift gear	Bevel gear	Final gear
Friction	–0.8 kW	–1.3 kW	–1.2 kW

adhesiveness between layers. In addition, engine tests using an actual transmission verified an increase in both performance and durability. Friction was reduced by a total of 3.3 kW as shown in Table 1, and a transmission efficiency of 97.0% was achieved.

Figure 4 shows the condition of the bevel gear and the final gear after running in a 4-Race event. The figure indicates that the damage at the tooth roots is miniscule (indicated by the arrows in the figure), and that there is no issue with durability.

5. Conclusion

A DLC coating for transmission gears has been developed that has good durability under high surface pressures. This DLC was applied to the shift gear and the final gear from 2007, and to the bevel gear from 2008. Friction was reduced by a total of 3.3 kW, and a transmission efficiency of 97.0% was achieved. In addition, the developed DLC was confirmed to have sufficient durability for use in 4-Race events.

Acknowledgements

The authors wish to express their deep thanks to ICS Corporation for their cooperation with the hard DLC condition settings and gear coating production process.

Reference

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