Development of DLC Coating on Camshaft and Rocker Arm

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ABSTRACT

Among the Formula One engine valve train parts, the camshaft and rocker arm are subject to severe sliding conditions and constant demands for higher rotating speeds, so it was necessary to increase endurance reliability. Therefore, diamond-like carbon (DLC) coating films that strengthen the surface were developed, the film compositions and hardness balance were optimized, and the coating films were applied. As a result, friction was reduced by a total of approximately 5 kW, and endurance reliability was achieved that enables continuous camshaft use in 4-Race events.

1. Introduction

The camshaft and rocker arm are Formula One engine valve train parts that are subject to severe sliding conditions. The sliding conditions in the boundary lubrication area reach a contact pressure of 1 GPa or more, and a PV (contact pressure x sliding velocity) value of 20000 MPa m/s or more. Figure 1 shows the position of the sliding conditions on a Stribeck curve.

To secure sufficient endurance reliability under these conditions, it was necessary to cover the parts with a tough coating film that does not experience scuffing, even when the oil film breaks, and does not wear under high speed and high contact pressure sliding conditions. For this reason, DLC coatings have been used since 2002.

Engines are becoming increasingly high power and high speed, a pneumatic valve return system (J-VLV mechanism) using an orifice has been applied, and Formula One regulations also prescribe the continuous use of a single engine in 2-Race events, so further increases in durability were required. This increased the need to develop a DLC coating for the camshaft and rocker arm.

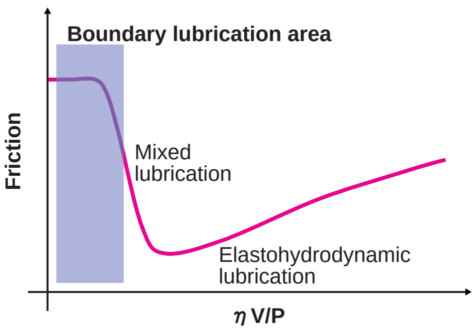

Fig. 1 Stribeck curve

2. DLC Specifications

2.1. Approach towards DLC Layer Configuration

The sliding surfaces of both the cam robe and the rocker arm slipper were treated with DLC, and this was confirmed to increase wear toughness and reduce friction for both parts. Figure 2 shows the film configuration concept. To realize uniform contact, the top layer forms a low-hardness running-in layer. In addition, the DLC layer that serves as the main sliding layer achieves a balance between hardness and toughness, and the

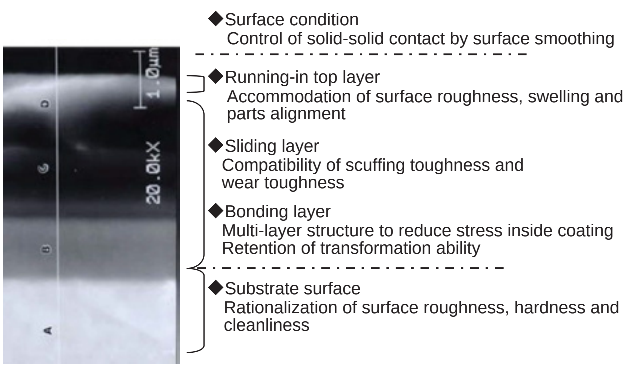

Fig. 2 Concept of DLC and bonding layer

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bonding layer, which has a hardness gradient, is formed by the spattering method to increase the scuffing toughness and adhesion strength of the DLC film.

2.2. DLC Treatment of Parts

For DLC to slide well against each other, the film hardness balance between them must be optimized. For example, DLC with the same hardness or that have topcoats that are too hard will attack each other, which is not desirable.

The combination of DLC specifications was evaluated and confirmed by basic sliding tests performed under high contact pressure conditions that simulated the actual sliding conditions. The results showed that a hardness balance of approximately 1.3 times in terms of the main sliding layer hardness reduced friction and provided high seizing durability. Figure 3 shows the hardness profiles of IDV38S, made by ICS Corporation, and DF1, made by Kobe Steel, Ltd., which were selected as the combination of DLC specifications.

The DLC treatment for each part was as follows. The camshaft was treated with the high hardness IDV38S, and the rocker arm slipper surface was treated with DF1, which has a lower hardness than IDV38S. This was done so based on the rule of thumb that when these parts slide, the camshaft experiences greater damage. Figure 4 shows the parts appearance after DLC treatment and an image of sliding. Figure 5 shows the DLC film configurations.

In addition, coating film quality is important for camshaft and rocker arm sliding, as DLC peeling trouble occurs for films with quality issues. Therefore, quality assurance methods were established for film uniformity, adhesion strength, wear toughness and other items; quality check samples were created that determine the allowable number, size and location of pinholes; and the quality was controlled.

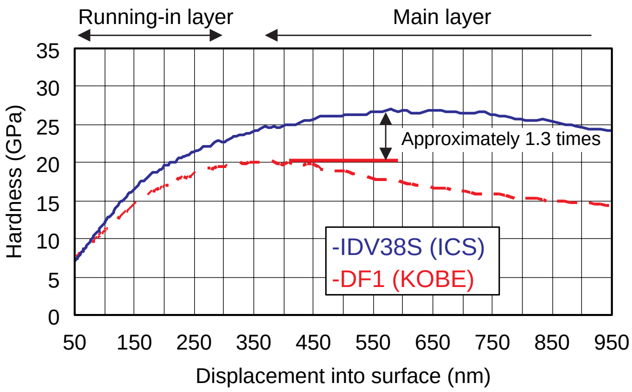

Fig. 3 Coating hardness of IDV38S and DF1

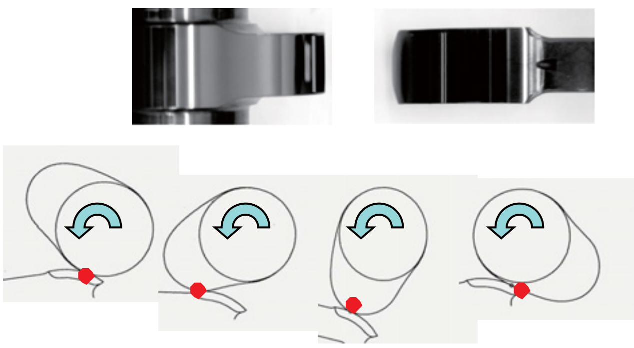

Fig. 4 Parts after DLC coating

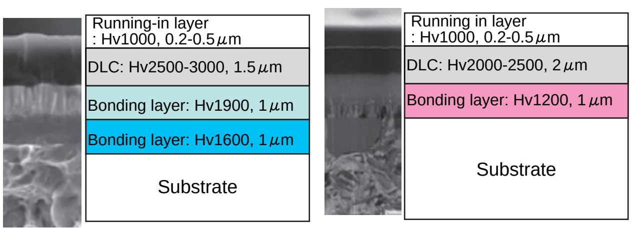

Fig. 5 IDV38S and DF1 layer configuration

3. Confirmation of Effects

An IDV38S-treated camshaft and DF1-treated rocker arm were introduced in the second half of 2006, and sliding reliability was assured under conditions of a contact pressure of 1.37 GPa and a PV value of 22 000 MPa m/s. Constant development led to yearly increases in the limit contact pressure, enabling high load and high speed operation at a contact pressure 17% higher and a PV value 32% higher than that of the combination of DLC specifications for 2004 (Fig. 6).

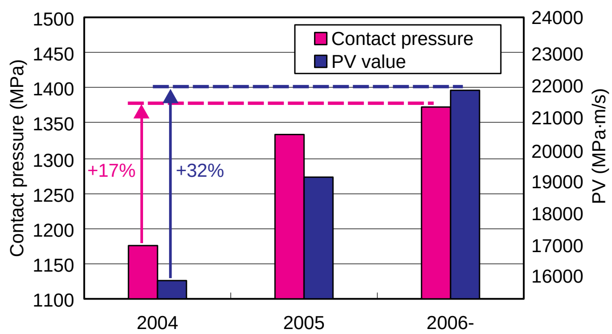

Fig. 6 Change in contact pressure and PV value

4. Conclusion

As Formula One engines evolve to higher output and higher speeds, steady progress was promoted to develop camshaft and rocker arm DLC that can withstand operation under harsh sliding conditions. As a result, performance was enhanced by a total of approximately 5 kW. In addition, these cam parts have been used in 4-Race events since 2007 with the aim of reducing costs, and the DLC coatings were able to assure sufficient endurance reliability.

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