Research on the mass production process of 30GPa high-hardness carbon coating on piston rings of automotive power transmission components

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1. Introduction

Diamond-like carbon (DLC) is an excellent coating material for a variety of applications such as automobiles, mechanical machinery and optical lenses. In many applications, the main role of DLC is to enhance mechanical durability [1–2]. For automobile applications, coated films must have high thermal stability to prevent film delamination during actual operating conditions. However, many types of hard coatings (a-C, a-C:H) have been shown to be very unstable under high temperatures. During operation, coated surfaces experience high mechanical, thermal, and chemical stresses. Therefore, the surface quality degrades very quickly to an unacceptable level. Tetrahedral amorphous carbon (ta-C) is a well- known hydrogen-free carbon coating with 70–80% of sp3 phase, which results in both a smooth surface and good thermal and wear resistance. Moreover, ta-C coating can be synthesized using a relatively convenient method, and the resulting surface is much smoother. Thus, the tribological performance of ta-C coating is superior to that of DLC. To achieve the mass production efficiency of hard coating, the thickness uniformityof a large area and a high deposition rate are critical. For these reasons, modern coating systems have been developed to achieve high-quality coating films. In this study, a Multi type of filtered cathode vacuum arc (FVCA) system is introduced for application to automobile accessories.
Although thick coating of ta-C film is an essential requirement for industrial applications, there have been clear limitations in film properties and coating systems. Despite superior properties of ta-C film including hardness, thermal stability, and wear resistance, ta-C films deposited by a vacuum arc method was hard to be thickened due to their high internal stress. Furthermore, it is hard to proceed the coating process for a long time because of the instability of carbon cathode. Our research group tried to improve the stability of the carbon cathode for the long-time coating by controlling electric and magnetic fields around the deposition path. The processing parameters were optimized for the discharge stability, so that the carbon arc target could be used stably over 24 hours at a discharge current of 160 A. For 5 μm coating of ta-C, the total 20-hours coating was performed including etching, deposition of interlayer, and ta-C coating. In addition, the further application of proposed system, the demonstration was successfully performed through the ta-C coating on non-ferrous cutting tools (0.3 ~ 2 μm in thickness) and piston rings (5 ~ 7 μm in thickness).

2. 500 mm Class of FCVA Hybrid Coating System

Fig. 1 Schematic drawing of the FCVA for ta-C coating system. The hybrid coating system was proposed, and it is consisted of anode layer ion source (LIS) for the etching process, unbalanced magnetron sputter (UBM) for the deposition of interlayer, and filtered cathodic vacuum arc (FCVA) for the deposition of ta-C film. The maximum working area of the proposed system is 900 mm in diameter and 500 mm in height.

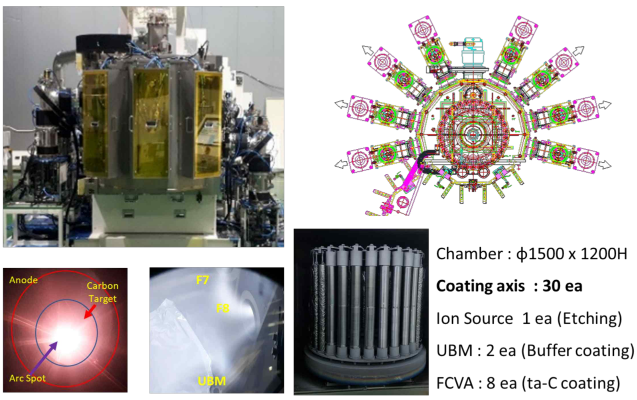

Fig. 1 Schematic drawing of the FCVA for ta-C coating system

Fig. 2 ta-C coated on piston rings.

3. Thick film coating process on piston rings

To coat 5um of ta-C on the piston, etching and buffer processes are performed to maintain adhesion, and then ta-C is coated using FCVA. However, when coating is performed at room temperature, the minimum hardness of the coated ta-C is 45 GPa or more, so in order to lower it to 25 GPa, the overall hardness can be lowered by adjusting the process temperature among the coating variables. In addition, during single layer coating, the stress of the coating film is high, resulting in strong brittleness of the coating film, resulting in breakage of the film. To solve this problem, the stress of the coating film is controlled by depositing high-hardness ta-C and low-hardness ta-C in layers by adjusting the bias voltage applied to the substrate during coating. The coating results for this are shown in the SEM photo in Figure 2. Despite the high hardness of the ta-C coating film deposited on the piston ring, no delamination of the coating film occurred.

4. Tribological applications

ta-C coatings exhibit high hardness, ultrahigh load bearing and low frictional properties. These superior properties protect the coating surface, which can be applicable not only for the automobile industry but also for the other industrial fields. Multi cathode approach has strong merit with freedom from size of coating chamber for mass production. Figure 3 shows the ta-C coating surface on the various industrial products using FCVA. The thickness can be effectively controlled to meet the suitable purpose and application, and the surfaces are uniform, smooth, good functionality and colors.

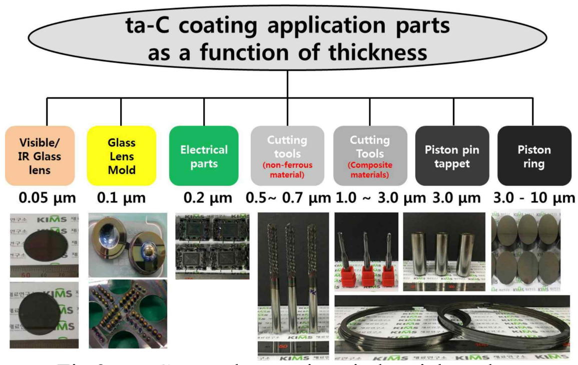

Fig.3 ta-C coated on various industrial products

5. Conclusion

In this study, ta-C thick film coating was performed on the piston ring using the FCVA hybrid coating system for mass production. The summary that can be drawn from this study is as follows.

1) A coating system is equipped with an anode layer ion source for etching of the base material, a UBM source deposited with Ti metal to ensure adhesion between the base material and the ta-C coating film, and FCVA to form a low-friction, high-hardness film. , it was possible to operate it stably for a long time.

2) In order to control the physical properties of the ta-C coating film, the internal stress was reduced by laminating a ta-C film with low hardness characteristics and a ta-C coating film with high hardness characteristics, and the final thickness was 5 - 7 um and hardness was 30 GPa. The ta-C film could be deposited stably.

Acknowledgement

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