Journal of Ceramic Processing Research. Vol. 13, Special. 2, pp. s363~s367 (2012)

JOURNAL OF
Ceramic Processing Research

Microstructure analysis of DLC thin film fabricated by filtered arc ion plating method

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DLC (diamond liked carbon) coating of the tungsten carbide (WC) alloy core surface for molding a glass aspheric lens improves the quality of glass lens and the molding core and is characterized by high hardness, high elasticity, abrasion resistance and chemical stability. In this study, the effect of DLC coating of a thin film by means of the filtered AIP (arc ion plating) technique was examined on Ra and shape of the coated surface. Roughness before and after DLC coating was measured and the result showed that the roughness was improved after coating as compared to before coating. It was observed that DLC coating of the WC alloy core surface for molding had an effect on improving the roughness and shape of the core surface. It is considered that this will have an effect on improving abrasion resistance and the service life of the core surface.

Key words: Tungsten carbide, Diamond liked carbon, Thin film, Filtered arc ion plating method.

Introduction

Expansion of the mobile market has accelerated to development of the market for an optical instruments, such as mobile device, digital camera lens, optical communication module [1]. But, it is difficult to expect highly efficient optical performance from the plastic lens or the spherical lens used in such optical instruments. Improved optical performance is achieved through production of non-spherical lens that present little error according to various aberrations generated in Lanes Assay by using glass material composed of outstanding optical characteristics [2]. Generally, non-spherical lens using glass is produced by the glass molding press, which compresses glass material in high temperature and pressure condition, and uses core to structure optical structure [3]. As the core in glass lens molding must be composed of durability of abrasion and high hardness in high pressure and high temperature, cemented carbide is generally selected for use. But, weaknesses presented by this method include the chemical changes generated in the contact part in relation to the characteristics and molding conditions of glass material as well as the decreased lifespan caused by shape abnormality reduced by high pressure and temperature [4]. To make up for such weaknesses, thin film of high quality must be fabricated in the surface of cemented carbide. So, various studies are being conducted to achieve improvement [5, 6]. As main methods used in surface improvement technologies using thin film, DLC present chemical stability, outstanding durability of abrasion and high hardness to be extensively applied in various industrial fields [7]. Especially, thin film with outstanding chemical stability, durability of abrasion and high hardness are required for the core used in lens molding to achieve improved atypia and lifespan and DLC coating is essential for this process [8]. This work deposited DLC thin film on WC used in non-spherical glass lens molding and analyzed the characteristics of thin film.

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Experimental

Composed of diamond-like properties, DLC thin film can be produced through various methods, such as ion implantation, HRPE-CVD (helical resonance plasma enhanced CVD), CVD (chemical vapor deposition), LA (laser ablation) and presents high industrial application. However, DLC thin film also displays various disadvantages, such as low adhesion with metal materials and easy oxidation in low temperatures [9]. To form high quality thin film on WC, this study used the filtered AIP method to coat DLC thin film. Filtered AIP method [10] generates carbon ion through arc discharge generated by the ignitor on the upper part of cathode, which is the location of carbon, the main component of DLC thin film. Magnetic field was used to achieve efficient transport of formed ions and arc control. The magnetic field was formed by the voltage applied in the anode coil and cathode oil located on the top and lower part of the chamber. Adjustment of movement direction of arc discharge and stable control of arc generated in cathode surface can be achieved by adjusting the applied voltage. Separate magnetic filter tube was used to transport generated plasma and eliminate macro particles commonly generated in arc source. Magnetic filter tube is composed of EM (extraction magnet) for supplying magnetic field for transporting large quantity of generated evaporation substances to substrate, BM (bending magnet) that induces charged particles to the exit, and surrounding plasma duct that blocks the exterior while maintaining vibration. Furthermore, the output of magnetic filter tube uses raster to vibrate OM (out magnet) and plasma to adjust substrate distribution and direction of particles in order to form DLC thin film of 140 nm thickness homogenized on the grinding surface of WC.

Results and discussion

Surface analysis

WC cemented carbide is generally produced by burning carbide powder of metal. Tungsten carbide (WC, FB01, Dijet Inc., Japan) was ground by diamond plate for usage. Tiny particles within 1.0 µm were observed on the surface of ground WC specimen even after grinding work. DLC thin films were performed on the ground WC specimen. SEM images of WC specimen before and after DLC thin film coating are shown in Fig. 1. The differences between two samples are clearly seen after DLC coating. The DLC thin film shows the smaller quantity of particles on the surface, compared with pre-coated grinding surface. EDS analysis was conducted to check the chemical composition of deposited DLC thin film and the results are presented in Fig. 2. DLC thin film was composed of 70.66% of C, 5.43% of Co, and 23.91% of W element. Co and W elements detected on the DLC thin film deposition was thought be originated from WC specimen.

Roughness and PV (peak-to-valley error) were analyzed to observe changes in shape abnormality caused by thin film coating. Fig. 3(a) and (b) presents the comparison of roughness before and after DLC coating. The average roughness was presented as 8.807 nm before coating but was verified to be reduced to 5.148 nm after DLC coating. This signifies that DLC thin film triggered

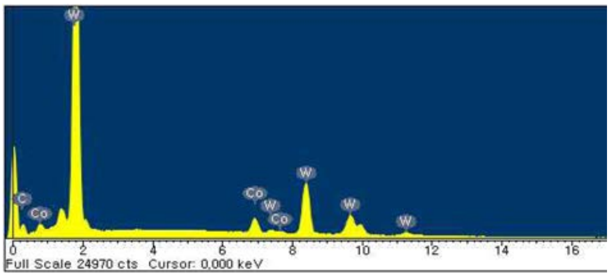


Fig. 2. EDS analysis conducted on DLC thin film.

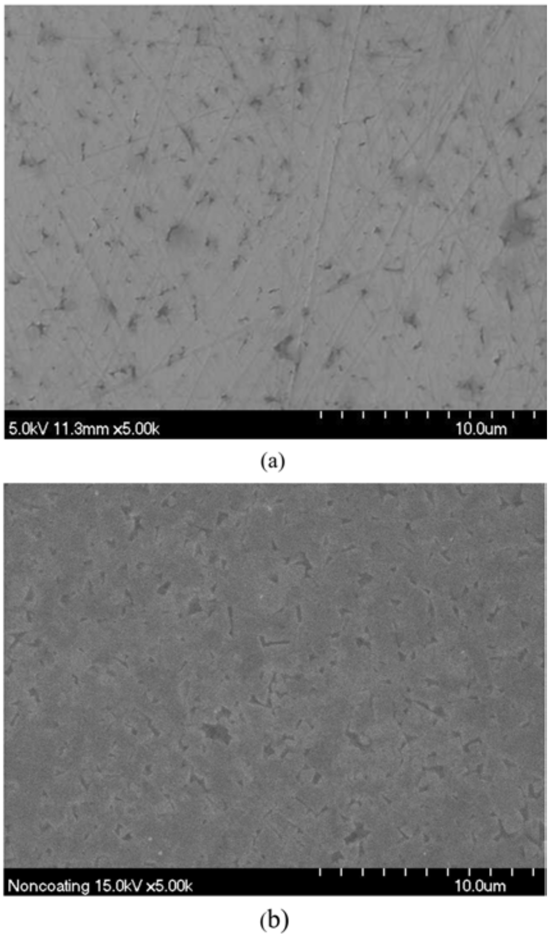


Fig. 1. SEM images of (a) DLC thin film and (b) Tungsten carbide.

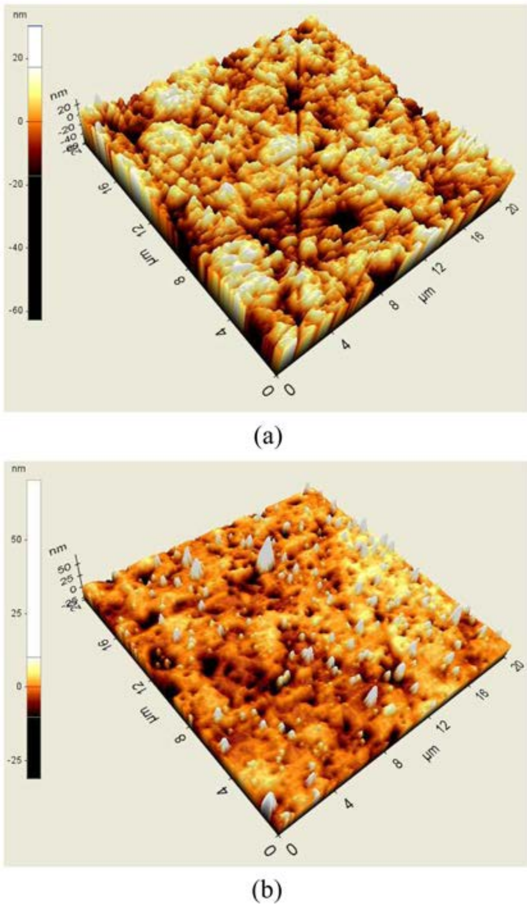
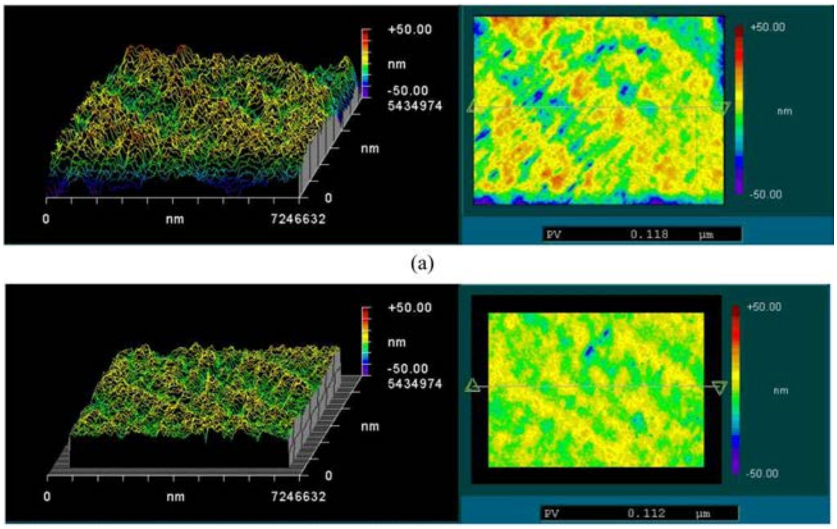


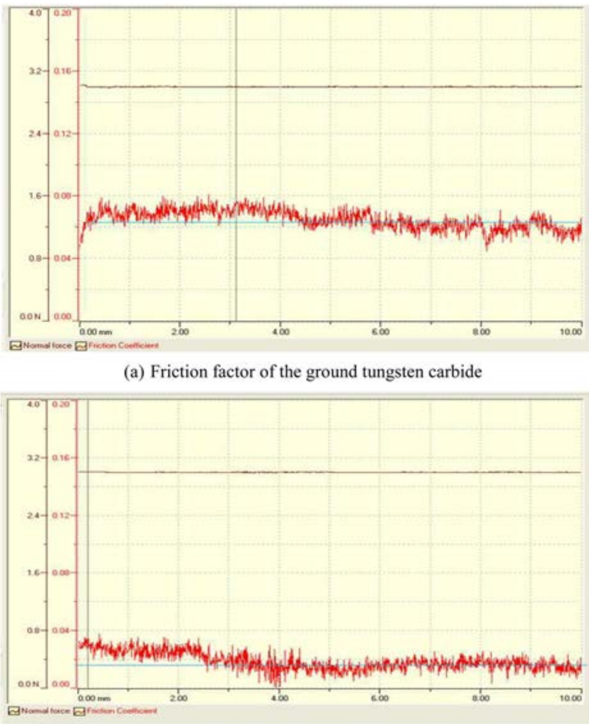
Fig. 3. Comparison of AFM images (a) before and (b) after DLC coating.



(a)

(b)

Fig. 4. Comparison of PV (a) before and (b) after DLC coating.


(a) Friction factor of the ground tungsten carbide

(b) Friction factor according to DLC coating

Fig. 5. Friction factor according to DLC coating

structural changes in the WC surface to reduce roughness and form smoother surface.

3D surface measuring instrument was used to analyze PV before and after film coating. Principle of optical coherence was used for fine surface form measured by the 3D surface measuring instrument (NewView 5000, Zygo Inc., USA) to measure partial form without contact. X axis 7.25 mm, Y axis 5.43 mm were measured in equivalent conditions by using 2.5 diameters. Fig. 4 presents the comparison between PV before and after DLC coating. In case of DLC thin film, form accuracy was increased from 0.118 µm to 0.112 µm after DLC coating.

Hardness analysis

High temperature and large pressure above the yield point of glass material are required in initial pressurization point to increase transcription estimation of lens during lens molding. Glass material can be welded between the molding surface that contacts the glass in high temperature· high pressure conditions to deform molding lens or damage surface. To prevent such damages, it is favorable to establish low friction factor of contact surface between glass material and core used in molding. Fig. 5 presents friction factors according to WC specimen and DLC thin film. Scratch tester (Revetest, CSM instrument, Swiss) was used for measurement and diamond tip of 200 µm diameter was used as the indicator. X axis presents the scan length while the Y axis presents the friction factor value and the strength exerted on the tip during measurement. Applied load used in the measurement of friction factor was selected as 3N to be performed in identical conditions. The friction factor before WC coating was approximately 0.062 but reduced to 0.018 after DLC coating. Thus, it is judged that friction factor would be reduced to improve surface damage phenomenon during DLC coating when compared with the ground WC material. Enhanced shape abnormality and core lifespan are expected through molding of lens after coating DLC thin film in WC material.

Raman spectroscopy

Raman spectroscopy is very efficient analysis method to analyze the structure of amorphous substance. In this study, it was used to examine the joint distribution of DLC thin film. Although graphite and diamond with carbon as their main substance is in crystalline state with complete sp^2 and sp^3 bonding respectively, the property of carbon film in amorphous state differs according to sp^3/sp^2 fraction of carbon atom that exists inside. DLC thin film which has intermediate character between

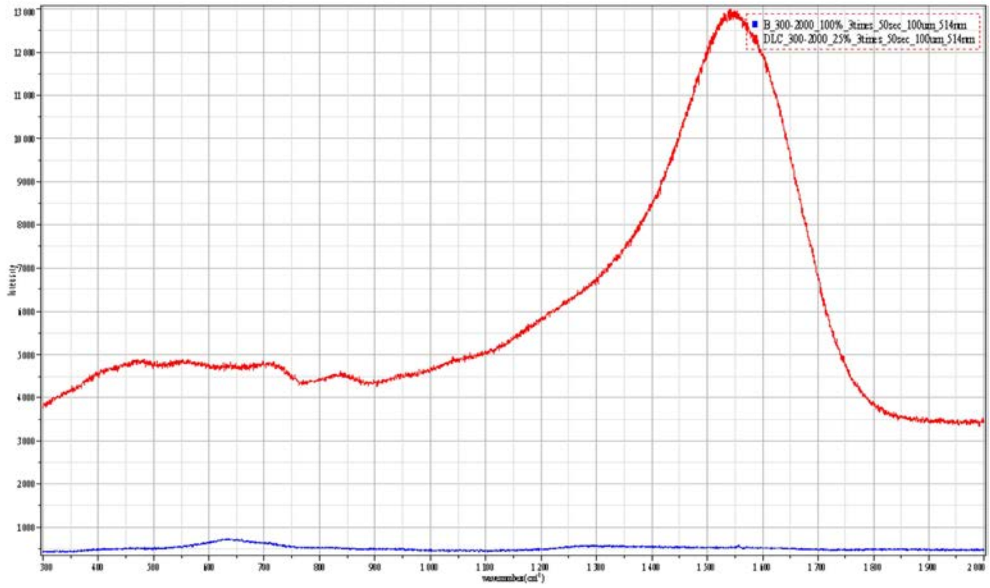


Fig. 6. Raman spectrum of DLC thin film.

diamond and graphite is a type of carbon film in amorphous state and its property changes according to sp^2 and sp^3 fraction. Especially, DLC thin film is classified into non-hydrogenated amorphous carbon (a-C) and hydrogenated amorphous carbon (a-C:H) based on the hydrogen content within the film and the hardness decreases with the increase in hydrogen content[11]. Therefore, in order to produce DCL thin film with superior mechanical property, more attention is paid to a-C film that does not contain hydrogen [12, 13]. Amorphous film with sp^3 fraction of over 80% among a-C film is referred to as ta-C. The range of 300 ~ 2,000 cm^{-1} was measured using Raman spectroscopy (Spex Inc., laser Raman and photoluminescence spectrometer). Fig. 6 shows Raman spectra of the coated DLC thin film. In some studies, produced DLC thin film was examined in connection with G position and sp^2 joint distribution and it is proposed as ta-C without sp^2 content when the location of G peak is 1560 ~ 70 cm^{-1}[14]. In this study, the production of a-C film without hydrogen content was available since carbon ion could directly be used as coating source by applying the filtered AIP method for DCL coating. As for DLC thin film coated in this study, ta-C film with G peak of about 1,560 cm^{-1} could be produced as a result of producing film by using carbon ion without hydrogen content through the filtered AIP method that does not use hydrogen.

Conclusions

This work presented the characteristics and mechanical properties of DLC coating surface by coating DLC thin film to enhance durability of abrasion after grinding Tungsten carbide used in molding of glass lens based on glass molding press. DLC thin film was coated on grinded WC. The experimental results shows that the noticeable decrease in particles was observed in ground WC specimen and main component C was extracted in 70.66% of DLC thin film. Although the average roughness of surface before DLC coating was measured as 8.807 nm, and PV was measured as 0.118 μm, the average roughness was improved to 5.148 nm and PV was elevated to 0.112 μm after coating. It is stipulated that high-quality lens can be gained during lens molding through DLC coating. The friction factor of Tungsten carbide that only performed grinding before coating was measured as 0.062. Friction factor decreased to approximately 0.018 after DLC coating. Raman spectroscopy analysis revealed that superior ta-C film with sp^3 fraction of over 80% was produced by coating the film with the filtered AIP.

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