Effect of Mo-N-Cu doping on the mechanical and tribological properties of thick tetrahedral amorphous carbon (ta-C) coatings

Young-Jun Jang, Jae-Il Kim, Ji Woong Jang, and Jongkuk Kim

Korea Institute of Materials Science, (KIMS), Korea

1. Introduction

Protective coatings have been used to improve the performance and extend the life of mechanical components used at extreme conditions such as very high or cryogenic temperatures under LN_2, hydrogen, and ammonia liquids and gases environments. When tetrahedral amorphous carbon (ta-C) coatings exhibit a low friction coefficient, but their use in cryogenic environments is limited because of their low fracture resistance. Normally, the ta-C coating has a relatively high hardness and can be used to enhance the wear resistance. However, the high hardness of ta-C can accelerate the wear of counterparts. This wear imbalance between the coating and its counterpart can cause mechanical vibrations. This issue can be resolved by improving the wear of the counterpart. Therefore, one of the representative's solutions are transition metals (such as Mo and Cu) and N are doped into ta-C coatings containing nanocomposite carbides or nitrides such as Mo-C, Cu-C, and Mo-N. These effects can reduce wear of the disk and the mating material by increasing the toughness of the coating and increasing adhesion strength by releasing internal stress. In other words, to reduce the hardness and improve the fracture toughness of ta-C coatings by nanocomposite toughening and crack bridging by the ductile phase. Therefore, this research aims to the effects of Mo and Cu doping on the structure, mechanical properties, residual stress, and tribological properties of ta-C coating was analyzed to provides insights into improving the mechanical and tribological properties.

2. Experimental details

A 1-μm-thick Mo-N-Cu-DLC multilayered nanocomposite coating was prepared by filtered cathodic vacuum arc and unbalanced magnetron sputtering techniques (Fig. 1(a)). Nitrogen (5 sccm) and argon (28 sccm) gases were introduced into the chamber using mass-flow controllers. The Mo and Cu ratio was controlled by changing the direct current sputtering powers. The coating structure was analyzed using field-emission transmission electron microscopy (FE-TEM; JEOL JEM-ARM200F, USA). The cross-sectional scanning transmission electron microscopy (STEM) and energy-dispersive X-ray spectroscopy (EDS) images of the Mo-N-Cu-DLC coating are shown in Fig. 1(b). Mechanical analysis and ball-on-disk tribo-tests were performed to the fracture resistance, and tribological characteristics of all coatings. An SUS316L ball (diameter = 6 mm) was positioned against a disk eccentrically located 3 mm from the center of the coated disk during tribo-tests. A normal load of 15 N was applied to push the ball down while the disk was rotated at 200 rpm for 24,000 cycles.

3. Results and discussion

Figure 2(a) shows the hardness (H) and elastic modulus (E) the ta-C coating and ta-C coatings doped with Mo, Mo-Cu, and Mo-N-Cu. The hardness and elastic modulus of the ta-C coating were measured to be 33±2 and 282±7 GPa, respectively. However, as the transition materials (Mo and Cu) and N were doped ta-C coating, the hardness (33 to 12 GPa) and elastic modulus (282 to 150 GPa) decreased

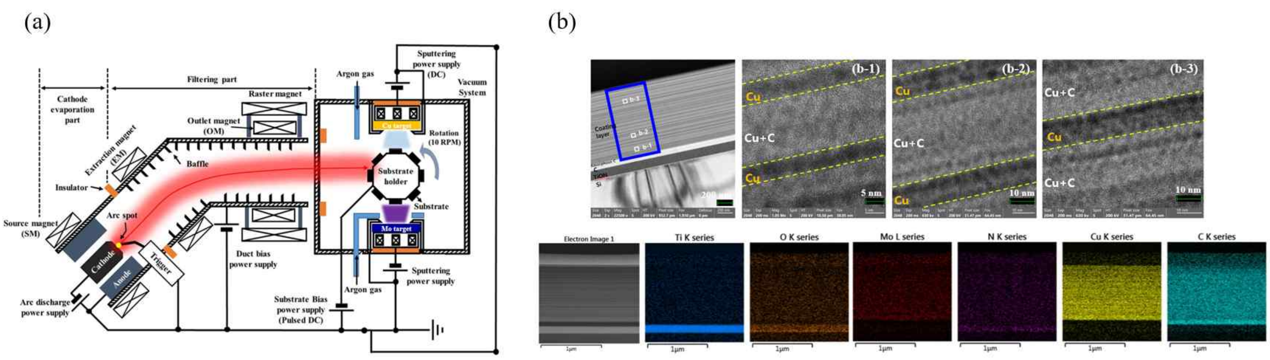

Fig. 1 (a) Schematic of the hybrid coating systems (FCVA and UBMS), and (b) microstructure and EDS data of Mo-N-Cu-taC multilayered nanocomposite coating prepared at Mo and Cu sputtering powers of 30 and 100 W, respectively.

However, Figure 2(b) shows the enhancement in the elongation, toughness, and reduce shear stress of the ta-C coating during the tensile test as a function of the transition metals and N doping. This is because the reduce the hardness and increase the ductile phase of Mo and Cu metals in ta-C coating by nanocomposite toughening and crack bridging.

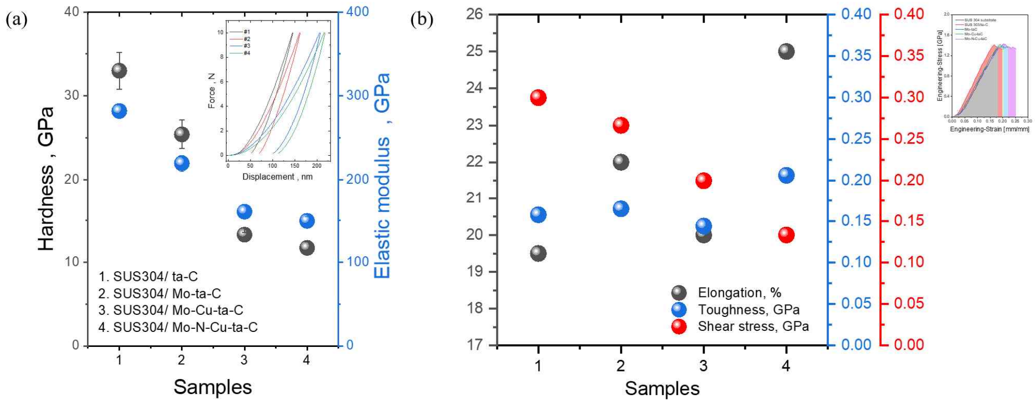

Fig. 2 (a) Mechanical properties at 10 mN of the normal force for coatings (measured using nano-indenter), and (b) elongation, toughness, and shear stress of the each samples (measured using microtensile tester).

Figure 3(a) shows the coefficients of friction (CoFs) of the pristine ta-C coating and ta-C coatings doped with Mo, Mo-Cu, and Mo-N-Cu after 24,000 cycles. The ta-C coating doped with Mo-N-Cu exhibited an average CoF of 0.24 with a very stable frictional behavior, whereas the undoped ta-C coating exhibited a CoF of 0.1. This decrease in the CoF is attributed to the increase in contact pressure due to the wear of the coating and SUS316L ball during continuous sliding (Fig. 3(a)). It was also observed that at the high hardness (> 30 GPa) of the ta-C coating causes rapid wear of the substrate, as evident from Fig. 3(b). However, doping with Mo-N-Cu, which is a ductile material, dramatically reduces the wear of the disk and substrate (Fig. 3(b)). The factors related to Mo, N, and Cu doping, such as coating structure, fracture toughness, and contact pressure were considered when evaluating the wear rate.

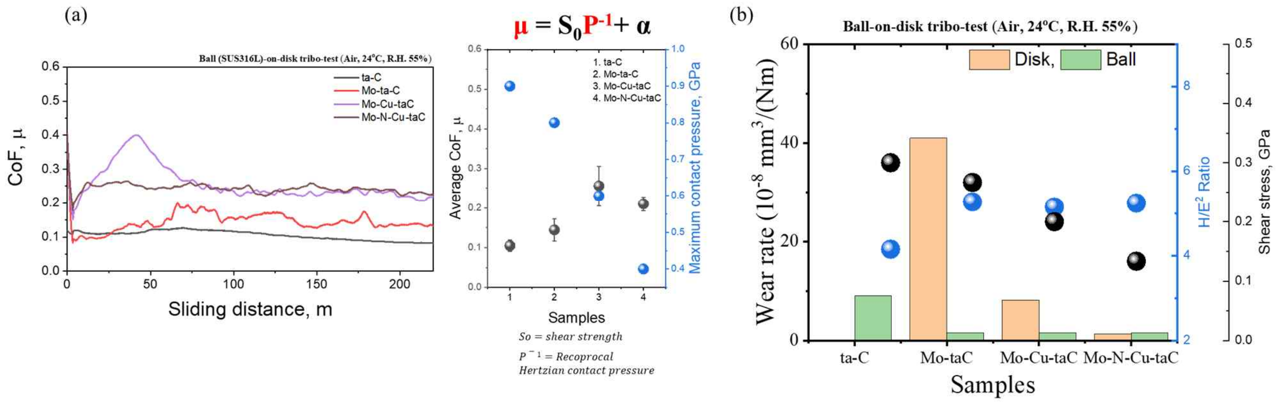

Fig. 3 (a) CoF of the different coatings sliding against an SUS316L ball; average CoF and maximum contact pressure of the different coatings. (b) Wear rates of the coated disks and SUS316L ball and H/E^2 ratios of the coatings during sliding.

4. Conclusions

An improved wear imbalance between the coating and its counterpart are important for the successful application of ta-C coatings in cryogenic environments. We successfully fabricated an optimized doped Mo-N-Cu with a 1-μm-thick ta-C coating. The fracture and wear imbalance properties of ta-C coatings were enhanced by Mo-N-Cu doping, which promoted ductile-phase crack prevention and toughening of the composite coating. The wear resistance of the Mo-N-Cu-doped ta-C coating was much higher than that of the ta-C coating. In particular, these coatings decrease the contact stress with increasing contact area.

Acknowledgments

This study was supported by the Fundamental Research Program (grant number: PNK 9920) of the Korea Institute of Materials Science (KIMS).