Graphene Oxide as a Versatile Solid Lubricant: Tribological Performance Across Ambient and Humidity-Free Environments

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ABSTRACT

Two-dimensional nanomaterials have gained significant attention as promising candidates for solid lubrication due to their exceptional tribological properties, effective from the nanoscale to the macroscale. However, the tribological performance of each material is highly dependent on specific experimental conditions, necessitating the use of different types of coating films for various applications. In this study, we propose that graphene oxide holds great potential as a solid lubricating material suitable for both ambient and humidity-free conditions, such as inert gas and vacuum environments. In ambient conditions, our findings demonstrate that graphene oxide can function as an adhesive layer, facilitating the material transfer of other 2D nanomaterials and thereby significantly enhancing durability. In contrast, under humidity-free conditions (argon and vacuum), graphene oxide exhibits an extremely low coefficient of friction (COF), ranging from 0.02 to 0.07, which is notably lower than the COF observed in ambient conditions (greater than 0.2). This study aims to scrutinize the superior tribological performance of graphene oxide and elucidate the effects of humidity on its friction and wear characteristics. Finally, we propose a potential lubrication mechanism for graphene oxide in humidity-free environments and discuss possible strategies for tailoring graphene-related materials as a universal material for solid lubrication coatings across a range of environments.

KEY WORDS

Graphene Oxide; Macroscale tribology; Solid Lubrication; Vacuum tribology

1. INTRODUCTION

The study of tribology, which encompasses friction, wear, and lubrication, is critical in mechanical systems and everyday life, as reducing friction and wear can lead to significant energy savings and enhanced durability in various applications. Solid lubricants are particularly advantageous in extreme environments where liquid lubricants fail, as well as in industries where contamination must be avoided. Two-dimensional (2D) materials, such as graphene, transition metal dichalcogenides, and MXenes, are promising for solid lubrication due to their unique layered structures and properties that facilitate material transfer, thereby lowering the coefficient of friction (COF). However, pristine graphene faces challenges in forming effective transfer layers at the macroscale due to its chemical inertness. This study introduces a graphene oxide as a versatile solid lubricant material in various environment. In ambient, graphene oxide acts as a gluing layer to enhance the material transfer of pristine graphene, significantly improving its durability. In addiation, graphene oxide exhibits super low COF in humidity/oxygen free environment. Our finidings of graphene oxide can open up the door to utilize a graphene oxide in various environments for solid tribology applications.

2. RESUILTS AND DISCUSSIONS

2.1 Graphene Oxide as a Gluing Layer to Prolong the Durability of 2D Nanomaterials in Ambient

For straightforward comparison of the tribological performances of pristine graphene (PG), graphene oxide (GO), GO-on-PG, and the substrate, the results are plotted in Figures 4(a) and 4(b). The inset of the Figure 4(a) highlights tribo-test result with the sliding distances from 0 to 400 m. This demonstrates that the simple addition of the GO layer on PG, enhances the durability by approximately 100 times, while maintaining a COF comparable to PG.

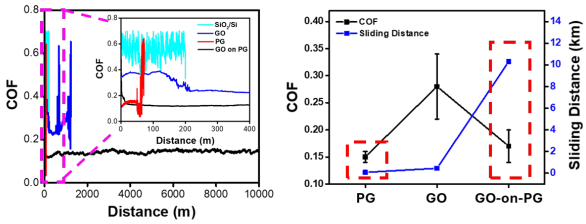

Figure 1. (a) Tribo-test results for SiO2/Si substrate, PG, GO, and GO-on-PG. The inset of Figure 4(a) shows a magnified tribo-test results up to 400 m of sliding distance. (b) Averaged COFs and sliding distances for PG, GO, and GO-on-PG.

2.2 Graphene Oxide Exhibits Super-low Coefficient of Friction in Humidity/Oxygen-Free Environments

Figure 2 shows the schematic of tribo-test under vacuum and argon environments and the tribo-test results. The results show that the COF in vacuum (0.07) and argon (0.03) environments were measured to be much lower than the COF in ambient conditions (0.17).

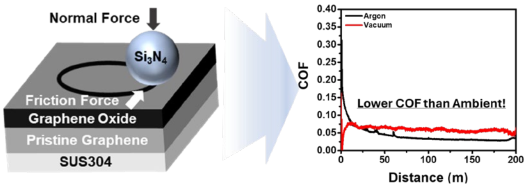

Figure 2. The schematic of tribo-test under vacuum and argon environments and the tribo-test results

Figure 3 shows the tribo-test results of GO in vacuum and argon environments. These indicate that the low COF of GO-on-PG originated from the intrinsic tribological properties of GO.

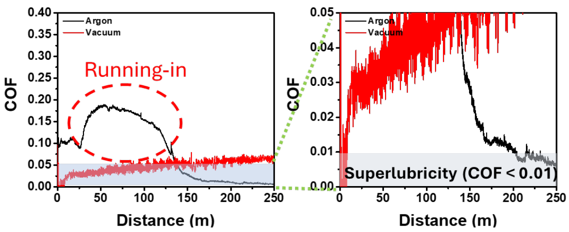

Figure 3. The tribo-test results of GO in vacuum and argon environments.

3. CONCLUSIONS

In conclusion, we revealed the potential of graphene oxide (GO) as versatile solid lubrication materials in various environments. In ambient conditions, GO acts as a gluing layer, promoting material transfer to prolong the durability of pristine graphene. In humidity/oxygen-free environments such as vacuum and argon gas, GO exhibits excellent tribological performance by achieving super-low COF in the range of below 0.01 to 0.07. We expect that our finidings of graphene oxide can open up the door to utilize a graphene oxide in various environments for solid tribology applications.

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APPENDIX

REFERENCES

1 P. Sampras and A. Agassi, How to play successfully tennis (Int. Sports Press, Timbuktu, 1998).
2 P. S. Dubois, C. Lechateau and P. Histoire, *Phys. Rev. Lett*. 62 (1993) 456.
3 L. If, S. P. Ectrum, *Proc. 1st Cross Straits Symposium on Materials, Energy and Environmental Sciences*, Fukuoka (1999) p.5.
4 W. Disney *et al*., *Int. J. of Animation* 75 (1962) 21.