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Mussel-inspired improvements in the wear resistance of graphene

Sulin Chen[1)], Zhewei Huang[1)], Bin Shen[1)*]

[1)] School of Mechanical Engineering, Shanghai Jiao Tong University, Shanghai, 200240, China
*Corresponding author: binshen@sjtu.edu.cn

Graphene has exhibited superior friction properties at the nanoscale, but its relatively weak adhesion to the substrate still limits its durability. In the present study, we showed the effective enhancement effect of the mussel adhesive protein (MAP) on the graphene-substrate adhesion. Compared with the graphene on bare substrate, the normal load threshold at the edge of graphene with MAP doubled, and the surface friction further decreased by an extent of ~40%. This strategy of improving the graphene-substrate adhesion via MAP offers an avenue for the development of effective and reliable graphene-based solid lubricants for engineering applications.

Keywords (from 3 to 5 max): tribology, MAP, graphene, wear

1. Introduction

Graphene, a two-dimensional atomic solid lubricant, exhibits superior friction properties at the nano-scale due to its extremely high mechanical strength, wear resistance, and outstanding lubricity in a variety of environments. However, at the macro-scale, the challenge of enhancing the adhesion of graphene film to the substrate still limits the durability of its lubricity. Step edge of graphene is much more fragile than the interior zone during sliding, which can be the key mechanism that limits the overall wear resistance of graphene[1]. The strategy of improving the graphene-substrate adhesion via mussel adhesive protein (MAP) offers an avenue for the development of effective and reliable graphene-based solid lubricants for engineering applications.

2. Methods

The Gr/MAP film was fabricated by alternatively adsorption of MAP and graphene sheets on the SiO_2/Si substrate (Figure 1a). The MAP solution for adsorption was prepared by diluting the concentrated liquor (50 mg/ml, Biopolymer Products AB, Sweden) with 1 wt% citric acid to a concentration of 1 mg/mL, and the pH was about 2.4. The MAP film was obtained by immersing the SiO_2/Si substrate in aqueous MAP solution for 2 min. Then the sample was gently rinsed with pure water to remove the loosely attached MAP and dried in air at room temperature. Once the water on the sample surface is dry, we transfer the mechanically peeled graphene to the sample surface immediately.

3. Discussion

We measured the lateral forces for the graphene sheet with and without MAP layer (~0.5 nm) in a set of AFM scanning tests under various normal loads. The friction for both samples exhibits a linear increasing tendency as the increased normal load (Figure 1b). The slope of the friction-load curve represents the coefficient of friction. It is calculated as 0.01 for the graphene on bare silicon substrate and 0.006 for the Gr/MAP film. Obviously, far from increasing the surface friction, the soft MAP underneath further enhances the friction reducing effect of graphene.
To examine the wear resistance of graphene, we perform

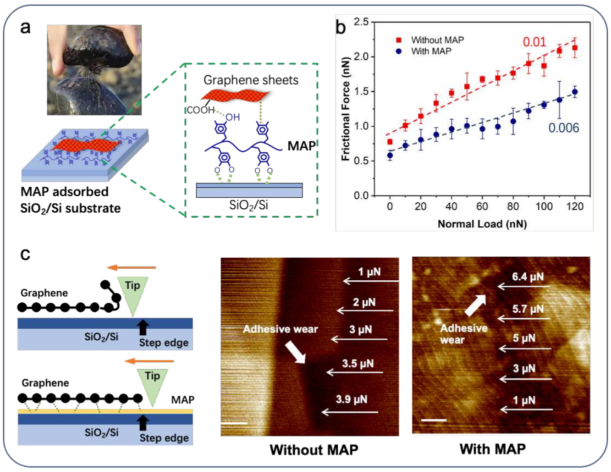

Figure 1: (a) Schematic diagram of Gr/MAP film; (b) friction force as a function of the applied normal load for AFM Si tip sliding on graphene with and without MAP; (c) wear-resistance of graphene at the step edge.

scratch tests across the step edge of monolayer graphene under a set of normal loads. Figure 1c shows the topography images of graphene after the scratch tests. For the graphene sheet without MAP, damage occurs at the edge as the load increases to 3.5 μN. As for the graphene with MAP, adhesive wear occurs under the load of 6.4 μN. This normal load threshold is almost twice as high as that measured on the graphene without MAP.
It is well known that MAP can interacts with silica surface by forming hydrogen bonding[2]. On the other hand, the catechol of MAP interacts strongly with the basal plane of the graphene sheets through π-π overlap. By increasing the adhesive strength of graphene to the substrate with MAP, the surface friction is reduced and the wear at the graphene edge is effectively suppressed.

4. References

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