Investigation of the Lubricity of Graphene Coatings on the Macro Scale

Alex Joanis[1,2], Jonathan Pont[2], AKM Newaz[2], California Polytechnic State University[1], San Francisco State University[2]

Background & Objective

The lack of out of plane bonding in graphene, a 2-dimensional allotrope of carbon, suggests that it can be used as a coating to reduce atomic scale friction. The lubricating properties of graphite, a material composed of multiple layers of graphene, are well known and utilized in industry. The application of graphene lubricants, as opposed to graphite lubricants, is an area still under study. Other researchers have experimentally demonstrated graphene's ability to reduce drag between few-layer graphene and other materials by studying nanoscale friction with scanning probe microscopes.[2] However, none have reported on whether this nanoscale reduction in drag is observable when a graphene-coated macroscopic object is considered. Here we have performed an experiment to observe the lubricating properties of graphene on the macro scale by measuring time of flight of a few-layer graphene coated macroscopic metal sphere through a column of liquid.

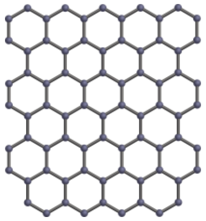

Figure 1.[1] Graphical representation of single-layer graphene.

Materials & Equipment

- High Speed Camera: Casio EXILIM HS EX0ZR1700
- Thermo Scientific Lindberg/Blue M Mini-Mite Tube Furnace
- Nickel Spheres: 3.0mm Diameter, GoodFellow NI006840
- Principal Test Liquid: Glycerol (Reagent Grade)

Methods

Sample Preparation via Chemical Vapor Deposition (CVD)

1. Nickel spheres underwent oxide removal inside a tube furnace at 1100°C and under 35 sccm of hydrogen gas for 100 minutes.
2. Control samples were removed from the furnace after oxide removal. Graphene samples were exposed to 35 sccm of methane and 2 sccm of hydrogen for 70 minutes at 1025°C.
3. Samples were cooled under 100 sccm of Argon.

Drop Tests

1. A 2-liter graduated cylinder was filled to volume with glycerol. A marked scale was taped to the graduated cylinder as well.
2. A high-speed camera was pointed at the glycerol, set to capture video at 240 frames-per-second.
3. Nickel spheres were dropped from the surface of the glycerol, and the fall was recorded with the camera.
4. Using video-viewing software, exact frames at which spheres reached specific areas in the frame of the video were recorded.
5. From these frame numbers, frame rates, and distances as expressed by the scale, the speed of the sphere through glycerol was calculated.

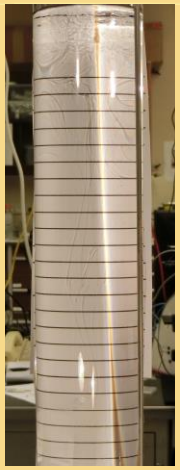

Figure 2. 2L graduated cylinder filled with glycerol, marked for scale.

Calculations

$$\text{Time Elapsed Between Two Frames} = \frac{Frame_A - Frame_B}{Framerate}$$

$$Velocity = \frac{(\text{Distance at Frame } A - \text{Distance at Frame } B)(\text{Frame Rate})}{Frame_A - Frame_B}$$

Results

We were not able to achieve consistent, reproducible results in comparisons between control and graphene coated nickel spheres. In one case, the average time required for a nickel sphere to travel across a set distance increased by 3% after being coated with graphene. This result suggested an increase in drag. In another case, comparing two similar but non-identical nickel spheres, the average time required to travel across a set distance decreased by 2.6%. This result suggested a decrease in drag.

Velocities and total time through the recorded region for other, less viscous liquids such as isopropanol and deionized water showed even less distinction between control and graphene coated samples.

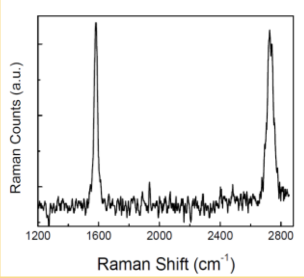

Figure 3. Raman shifts for a nickel sphere after undergoing CVD growth.

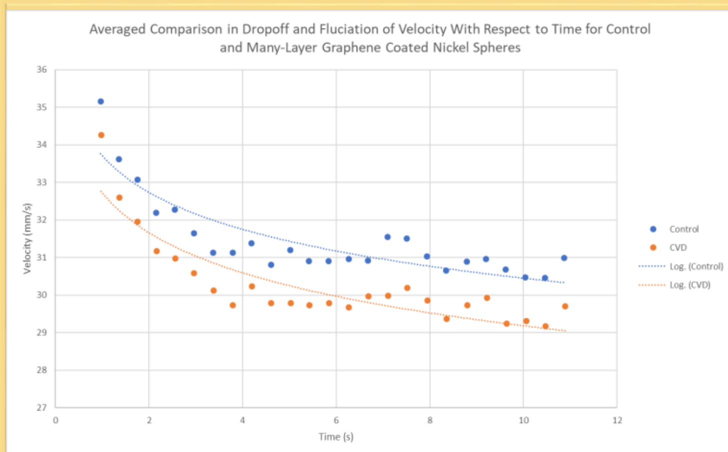

Figure 4. Although the averaged velocities suggests a slight decrease in velocity for coated spheres falling through a column of liquid, isolated tests with single spheres gave varied, inconsistent results. The data points on this graph make up an averaged 15 CVD few-layer graphene drop tests and 10 control sphere drop tests. Many more tests were performed, but were omitted because they were incompatible for the purpose of averaging with these data points. Overall, some drop tests indicated small increases in velocity for a few-layer graphene nickel sphere, while others indicated small decreases in velocity.

Discussion

Based on our findings, we were unable to observe a consistent and significant difference in the motion between graphene coated and uncoated control samples. Future studies on the application of graphene's properties as a lubricant for the purpose of macro scale drag reduction would likely require more sensitive instruments. We believe that the rotation of the sphere to bring its center of gravity to its lowest point as it falls through the glycerol is heavily impacting the reproducibility of our results. The resolution of the camera we used for this study was not great enough to detect the rotation of the sphere as it falls. We believe that, in order to accurately measure the drag on metal spheres as they fall through a liquid, we would have to model the tumbling motion of those spheres as they fell. Because of the difficulties we faced in creating reproducible results, we did not explicitly calculate drag. Instead, we used total time, velocities, and rates of acceleration/deceleration as indicators of change in drag.

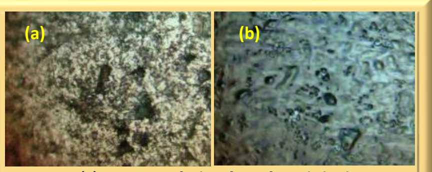

Figure 5. (a) 111x magnified surface of a nickel sphere, before undergoing graphene growth and (b) 111x magnified surface of a nickel sphere with few-layered graphene.

Poor graphene coatings on the rough surface of the nickel spheres may also have affected our results. Coatings may have degraded quickly as spheres underwent multiple drop tests. The initial (pre-drop test) quality and smoothness of graphene coatings may also have been a source of inconsistent results. The nickel spheres we worked with had rough surfaces, which would have theoretically disrupted the growth of 2-dimensional graphene. Future work should also investigate the quality of graphene films grown by CVD and whether other methods of deposition would be more appropriate for studies of this nature.

References

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2. Kawai, Shigeki, et al. "Superlubricity of Graphene Nanoribbons on Gold Surfaces." *Science* 351.6276 (2016): 957-61. *Science*. American Association for the Advancement of Science, 26 Feb. 2016. Web.

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