Superlubricity with tetrahedral amorphous carbon coatings

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We report on the conditions on how to achieve superlubricity with lubricated hydrogen-free carbon-based coatings using various lubricants. ta-C coatings with various sp^3 ratios, as well as doped ta-C:X and ta-C:Me coatings are considered, both running against steel and in self-mated configuration. Using an oscillation model contact, we study the role of tribofilm formation and temperature in achieving superlow friction.

Keywords: DLC, ta-C, superlubricity, oleic acid

1. Introduction

Superlubricity of tetrahedral amorphous carbon coatings (ta-C) with organic lubricants is a promising tribological phenomenon with potential for very high friction reduction in future applications. The superlubric system of a ta-C/ta-C pair, lubricated with oleic acid, has been described in literature, regarding both the role of carbon surface and lubricant chemistry [1, 2].

2. Experimental

Using a laser-assisted vacuum arc process (Laserarc™) various ta-C and ta-C:X coatings have been deposited on tribological test specimen. Initial setup is a ta-C/ta-C contact with oscillation motion and oleic acid lubrication, running in boundary and mixed lubrication conditions. Then, this experimental work systematically varies parameters of the tribological system like sp^3 fraction of the carbon coating, doping elements, temperature and lubricant. Running-in behavior and tribofilm formation are studied and tested with respect to existing theories on the superlubricity phenomenon.

3. Results

In a comparative study with steel/steel, ta-C/steel, steel/ta-C and ta-C/ta-C surfaces it was found how lubricants differently interact with surfaces over time. Conventional tribofilm formation will take place on steel surfaces when lubricated with a fully additivated engine oil (Figure 1).

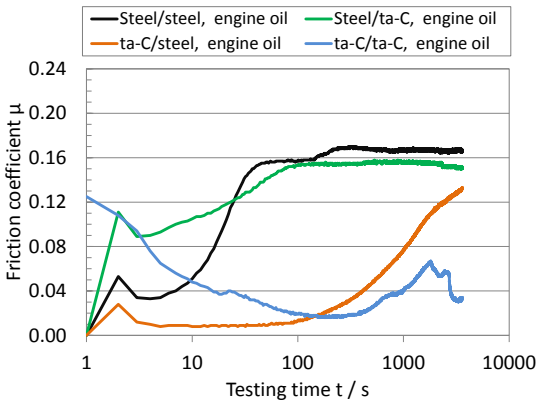

Figure 1: Friction curves over testing time with different pairs of surfaces, lubricated by engine oil. All systems involving steel surfaces form a tribofilm, followed by an increase in friction.

However, with such a tribofilm the superlubricious state is lost. In contrast, superlubricity occurs with oleic acid, whenever at least one ta-C coating is present in the contact, pointing toward a tribochemical participation of the ta-C coating (Figure 2).

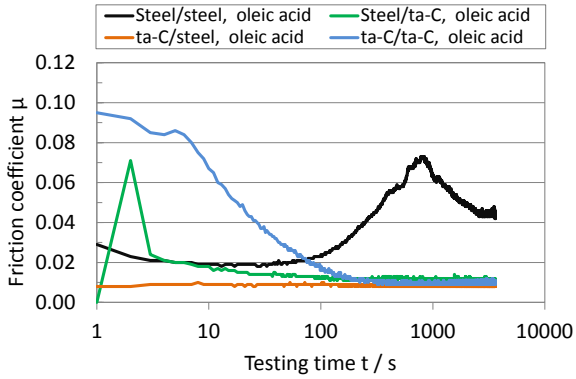

Figure 2: Friction curves over time with different pairs of surfaces, lubricated by oleic acid. All systems involving ta-C surfaces have a fast running-in process leading to superlubricity.

Further experiments demonstrate that oleic acid does not behave like a traditional friction modifier on ta-C coatings, but the double bond plays a crucial role in enabling superlubricity.
Also doped ta-C:X coatings often retain their superlubricity ability, but not for all doping elements.

4. Discussion

This works highlights that several combinations of materials involving carbon based coatings and lubricants have the capability for superlubricity. Especially a single-side coated contact can be used, which is preferred from an economic point of view, as well as a vegetable oil-based lubricant which is preferred from an ecological point of view.
However, such beneficial effects require new lubrication mechanisms apart from traditional tribofilm formation, and thus require a new design of such contacts.

5. References

[1] De Barros Bouchet, M.-I. et al. Sci. Rep. 7, 2017
[2] Kuwahara, T. et al., Nat. Commun. 10, 2019