Tribological contact-induced transformations of carbon materials

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Carbon-based solid lubricants are excellent options to reduce friction and wear, especially by the carbon capability to adopt different allotropes forms. These materials are sheared on the contact along with debris and contaminants to form tribolayers that govern the tribosystem performance. Using a specific Raman analysis on the tribolayers, the contact-induced modifications in the crystalline structure of different allotropes of carbon-based solid lubricants tested under various dry sliding conditions were quantified. The results indicate an increase in the point and line defects density until a saturation value, regardless of initial tribosystem conditions.

Keywords: carbon nanostructures, tribolayer, Raman spectroscopy, defects.

1. Introduction

Carbon-based lubricants are versatile materials for tribological uses due to their high availability and different nanostructures [1,2]. Although the tribological behaviour of these materials is well known, the processes that these materials undergo due to the tribological phenomena and the influence of these processes on their tribological performance is still uncertain. The objective of this study is to quantify the defects changes of several sp2 carbons to characterize their degradation process due to the tribological contact. A new Raman analysis technique allows disentangling the contribution of point and line defects [3] and enables new insights into the nature of tribolayers produced by carbon-based solid lubricants.

2. Methods

Dry sliding tribotests at ambient atmosphere were performed on ball-on-flat (BF) and cylinder-on-flat (CF) configurations. The carbon-based lubricants used were carbide-derived carbons from B_4C-Cr_3C_2 (CDC 1300 and CDC 1500) and SiC (αSiC-CDC and βSiC-CDC), crystalline graphite (GR), multilayer graphene (MLG), and carbon nanotube films (CNT 600 and CNT 700) (Table 1). WLI measured wear rates. Solid lubricants and tribolayers were analyzed via FEG-SEM and Raman spectroscopy.

Table 1: Different carbon materials studied in this work

Id.	Form of introduction to the tribo-system
CDC 1300 CDC 1500 GR	Impregnated in the porosity of sintered steel (BF)
MLG	Drop-casting AISI 1020 steel surface (CF)
αSiC-CDC βSiC-SiC	Solid lubricant nodules in the bulk of self-lubricating sintered composites (CF)
CNT 600 CNT 700	CNT film on the AISI 1005 steel surface (BF)

3. Results

The tribopairs presented COF ranging from 0.08-0.12; additionally, the wear rates were between $2.70x10^{-5}$ (αSiC-CDC) to $13.2x10^{-5}$ (CNT 600) mm³/Nm on the specimens and $0.01x10^{-6}$ (CNT 700) to $1.12x10^{-6}$ (CDC 1500) mm³/Nm on the counter-bodies. Therefore, self-lubrication behaviour was observed for all tribosystems in dry conditions. A comparison between the initial and final crystallite sizes of carbon allotropes is presented in Figure 1(a). Point defects are shown in Figure 1(b), which correspond to vacancies and impurities present in the tribolayer due to the energy dissipated during the test.

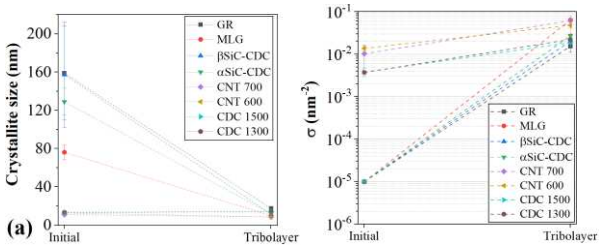

Figure 1: Quantification of defects before and after the tests (a) Crystallite size (b) Point defect density.

4. Discussion

GR initially had the largest crystallite size and lowest point defect densities along with αSiC-CDC, βSiC-CDC, and MLG followed by the CNTs and CDC 1500 and CDC 1300. The more ordered materials had a defect density around 10^{-5} nm^{-2}, while CNT and CDC had defect densities in the order of 10^{-3} to 10^{-2} nm^{-2}. The solid lubricants crystalline structure is quickly degenerated by the tribocontact action. In fact, the tribolayers become rich in nanocrystalline carbon, regardless of the initial condition or test setup used. The point defect density on the tribolayers also falls in the 10^{-2} to 10^{-1} nm^{-2} order of magnitude for all the materials tested. These findings show that, for carbon materials, the crystalline nanostructure is not the main factor that should be considered when analysing their tribological performance. It was observed that as the tribological reactions forming the tribolayers turn these allotropes into very similar nanocrystalline carbons with a high defect density reaching a threshold around the 10^{-2} nm^{-2} order of magnitude, no matter their initial crystalline structure.

5. References

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