Supplementary Information (SI)

Preparation of a highly effective lubricating oil additive — ceria/graphene composite

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SI1. AFM images of GO

Fig. S1 shows the AFM images of GO which was observed by a Nanoscope IIIa multimode AFM (Veeco, USA) in tapping mode. Based on the section analysis, the thickness of GO sheets is determined to be ~0.8 nm. The theoretical value of a perfectly flat sp^2-carbon atom network is 0.34 nm, while it is natural that the thickness of monolayer GO flakes is larger than 0.34 nm. According to the work reported by Kulkarni *et al.*, the thickness of monolayer GO flakes is 0.87 ± 0.09 nm,[1] indicating that the GO synthesized in this work is monolayer.

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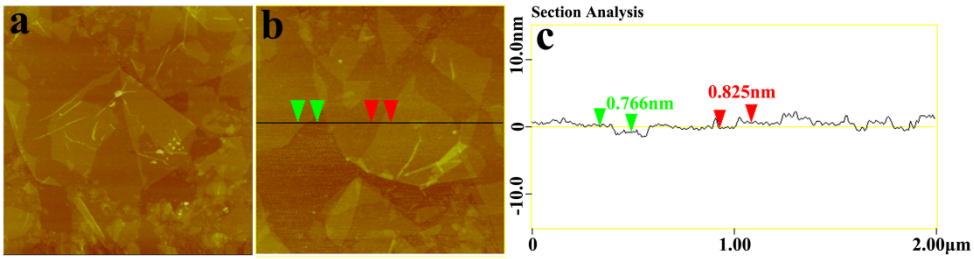

Fig. S1 AFM images of GO (a, b) and the corresponding section analysis (c). The scanning area of (a) is 5 × 5 μm^2 and (b) is 2 × 2 μm^2.

SI2. Average particle size variation of COGNCs and graphene with time

The dispersion states of COGNCs and graphene in the base oil were monitored by measuring their average particle size using the Malvern Zetasizer Nano 3600 dynamic laser scatter instrument. Note that the particle size measurement on this instrument is based on the assumption that the particles are spherical, so the instrument is unable to give the absolute sizes of COGNCs or graphene sheets. Nevertheless, the measurements over time provide a means of monitoring dispersion stability. As shown in Fig. S2, the particle size of COGNCs increases a little after a long period of settling time (240 min), while that of graphene increases greatly to twice of the original. Moreover, the particle size of graphene is much larger than that of COGNCs at initial time in spite of the identical ultrasonic pretreatment, indicating that graphene sheets are easier to aggregate. It also reflects that CeO_2 nanoparticles serve as spacers to prevent the graphene nanosheets from restacking and increase the stability of exfoliated graphene sheets.

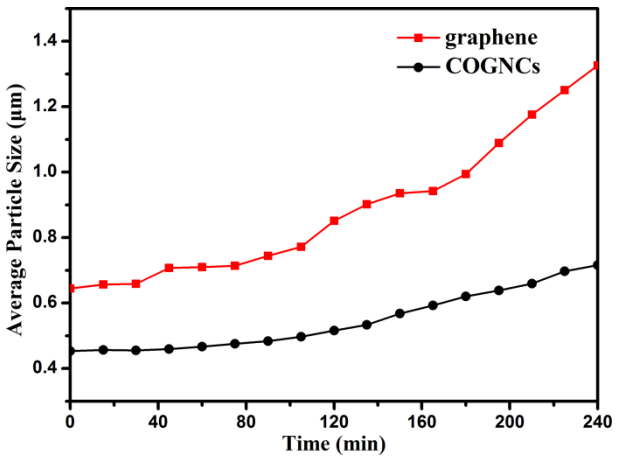

Fig. S2 Dispersion stabilities of COGNCs and graphene in the base oil, characterized by measuring average particle sizes over a long period of time.

SI3. Elemental composition analysis of various wear tracks on the steel discs

Table S1 Mass concentration of elements on the worn surfaces of steel discs performed with base oil and base oil containing various additives.

Types of lubricating oil	Mass concentration (wt%)						
	C	O	Fe	Cr	Ce	S	P
Base oil	–	–	98.88	1.12	–	–	–
Oil with CeO_2	–	–	98.86	1.14	–	–	–
Oil with graphene	14.22	1.71	82.80	1.27	–	–	–
Oil with COGNCs	18.90	2.30	77.52	1.16	0.12	–	–
Oil with mixture of CeO_2 nanoparticles and graphene	15.17	1.90	81.66	1.26	–	–	–
Oil with graphite	14.14	–	84.48	1.39	–	–	–
Oil with ZDDP	3.67	–	94.63	1.39	–	0.22	0.09

Reference

1 D. D. Kulkarni, S. Kim, M. Chyasnavichyus, K. Hu, A. G. Fedorov and V. V. Tsukruk, *J. Am. Chem. Soc.*, 2014, **136**, 6546−6549.