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Short communication

Wear prevention behaviour of nanoparticle suspension under extreme pressure conditions

A. Hernández Battez[a,*], R. González[a], D. Felgueroso[a], J.E. Fernández[a], Ma. del Rocío Fernández[a], M.A. García[b], I. Peñuelas[a]

[a] University of Oviedo, Department of Mechanical and Civil Engineering, Ctra de Castiello s/n, 33204 Gijon, Spain
[b] University of Oviedo, Department of Material Science and Metallurgical Engineering, C/ Independencia 13, 33004 Oviedo, Spain

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Abstract

This work presents and discusses the extreme-pressure behaviour of nanoparticle suspensions in a polyalphaolefin (PAO 6). CuO, ZnO and ZrO_2 nanoparticles were dispersed at 0.5, 1.0 and 2.0 wt.% in PAO 6 using an ultrasonic probe during 2 min and EP properties were obtained using a Stanhope Seta Shell Four-Ball EP Lubricant Tester according to ASTM D2783. The ball test material was AISI 52100 steel of 12.7 mm diameter, with a hardness of about 65 HRC. The wear scar diameter (WSD) was measured with an optical microscope and scanning electron microscopy (SEM) and energy dispersive spectrometry (EDS) analysis of the worn surface highlighted a number of conclusions: all concentrations of nanoparticles improved the EP properties of PAO 6; CuO nanoparticles exhibited the best EP behaviour and ZrO_2 the worst; CuO and ZnO suspensions showed better results at 0.5% and 2.0 wt.% of nanoparticles, respectively, while ZrO_2 behaved identically regardless of nanoparticle concentration; all results were analysed according to the nanoparticles' size and hardness, and their deposition on wear scar surface.
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1. Introduction

Friction and surface damage caused by high temperatures and pressures can be reduced by applying extreme pressure (EP) and antiwear (AW) additives. These tend to be sulphur-, chlorine- and phosphorous- containing compounds designed to react chemically with the metal surfaces, forming easily sheared layers of sulphides, chlorines or phosphides, and thereby preventing severe wear and seizure [1].

The application of inorganic nanoparticles has been the focus of particular research attention for some 25 years. The tribological properties of LaF_3 [2], graphite [3], polytetrafluoroethylene (PTFE) [4], MoS_2 [5], TiO_2 [6–8], $La(OH)_3$ [9], PbS [10], lanthanum borate [11], titanium borate [12], zinc borate [13], ferric oxide [14], ferrous borate [15], Ni [16], $CaCO_3$ [17] and ZnO [18] nanoparticles used as oil additives have all been investigated in that time. Results show that they can deposit on the rubbing surface and improve the tribological properties of the base oil. Micron particles of a certain hardness have also been reported to lead to abrasive friction [19]. The results observed by Xue et al. [8] and Dong et al. [17] also point to nanoparticles displaying good friction and wear reduction characteristics even at concentrations below 2 wt.%.

Copper oxide nanoparticles with a diameter of 10–40 nm have also been tested recently as an additive in cutting fluids [20]. Transfer and adhesion of the micellar particles accelerated surface modification, self-reducing and forming of a fine copper tribofilm that reduced the coefficient of friction, the extent of direct contact between the cutting tool and the workpiece, the temperature in the cutting zone and hence tool wear.

This paper uses a four-ball machine to study the extreme-pressure behaviour of CuO, ZnO and ZrO_2 nanoparticle suspensions in a polyalphaolefin (PAO 6), and scanning electron microscopy (SEM) and energy dispersive spectrometry (EDS) to analyse wear scar surfaces. Taking into account the results obtained by Pawlak et al. [20] and Cambiella et al. [21], some of the potential applications of these nanoparticles as additives in

* Corresponding author. Tel.: +34 985182669; fax: +34 985182433.
E-mail address: aehernandez@uniovi.es (A. Hernández Battez).

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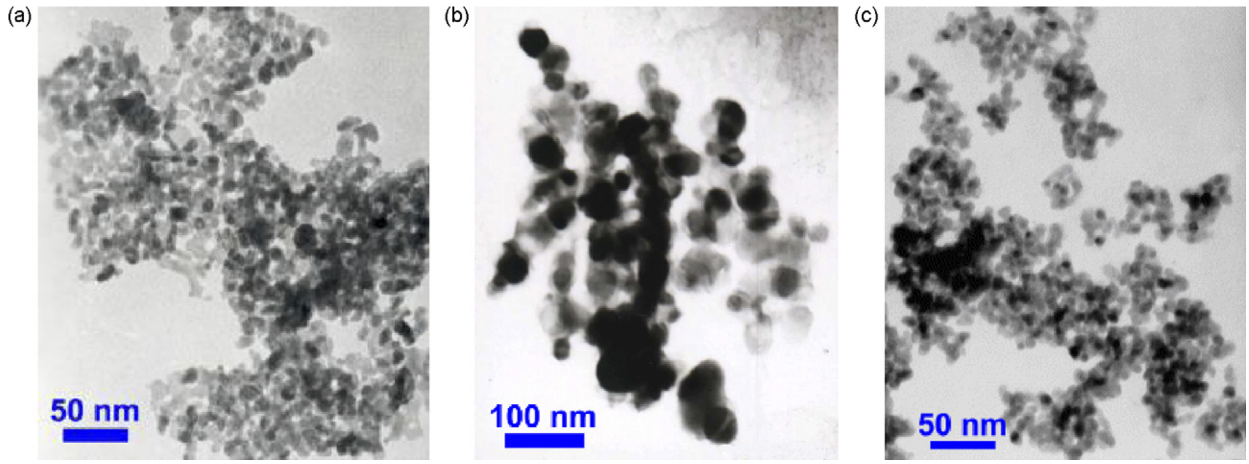

Fig. 1. Micrographs of nanoparticles: (a) ZnO, (b) CuO and (c) ZrO_2.

a polyalphaolefin can be found in metalworking fluids and also in lubricants for gearboxes.

2. Experimental details

2.1. Nanoparticles and lubricant

The main properties of the nanoparticles and lubricant are listed in Table 1. CuO, ZrO_2 and ZnO nanoparticles, Fig. 1, were separately dispersed in the lubricant in concentrations of 0.5–1.0–2.0 wt.% using an ultrasonic probe for 2 min.

2.2. Extreme pressure test machine and procedure

All test-section components were cleaned ultrasonically with heptane for 3 min, rinsed in ethanol and dried with hot air before and after tests. The test machine used for extreme pressure tests (ASTM D 2783) was a Stanhope Seta Shell Four-Ball E.P. Lubricant Tester with a drive shaft speed of 1470 rpm. The 12.7 mm diameter test balls with a roughness of $R_a = 0.035$ μm used in this study were made from AISI 52100 steel with a hardness of 65 RC (Table 1). In this technique, one steel ball under load is rotated against three steel balls held stationary in the form of a cradle while immersed in the lubricant. A series of 10 tests of 10-s duration are carried out at increasing loads until welding occurred, Fig. 2. The first run was made at an initial load of 490 N and the additional runs were carried out at consecutively higher loads according to the standard method: 617, 980, 1235, 1568, 1960, 2450, 3087 N... until welding occurs. If ten loads have not been run when welding occurs, the total was brought to ten by assuming, according to the standard, that loads below the last nonseizure load (LNSL) produce wear scars equal to the compensation scar diameter. The wear scar diameters (WSD) in the stationary balls were measured using a Nikon PFX optical microscope, provided with a Nikon F-301 CCD camera, and plotted against the applied load. From the EP results, the following parameters were obtained: initial seizure load (ISL), weld load (WL) and load-wear index (LWI). Repeatability and reproducibility were verified according to ASTM D2783 recommendations.

2.3. Hertz line

The Hertz line was obtained by plotting the Hertz scar diameter against the load. The Hertz scar diameter (d_h) is the average diameter of an indentation caused by the deformation of the balls under static conditions.

2.4. Compensation line

The compensation line was obtained from a plot of the compensation scar diameters against the applied load. The compensation scar diameter is the average diameter of the wear scar on the stationary balls, caused by the rotating ball under an applied load in the presence of lubricant, but without causing either seizure or welding.

2.5. Last nonseizure load (LNSL), initial seizure load (ISL) and weld load (WL)

The last nonseizure load is the last load at which the measured scar diameter is not higher than 5% above the compensation line.

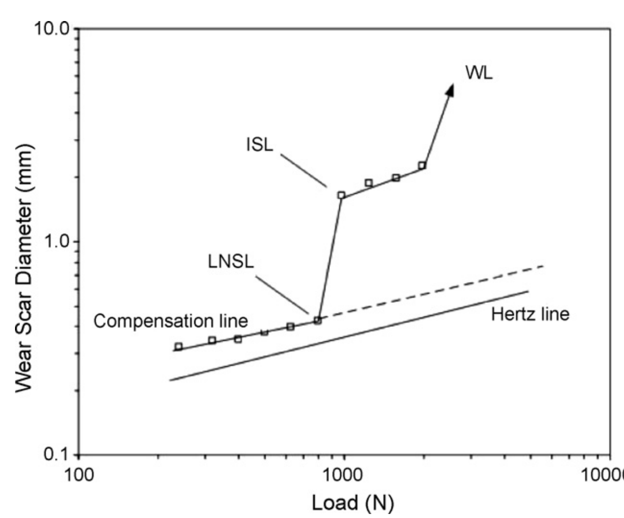

Fig. 2. Example of a wear-load curve obtained from the extreme pressure tests.

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