Electronic Supplementary Information

Reinforcement of nanoporous lanthanum-doped zinc borate by vanadium selenide nanosheets for improved tribological activity

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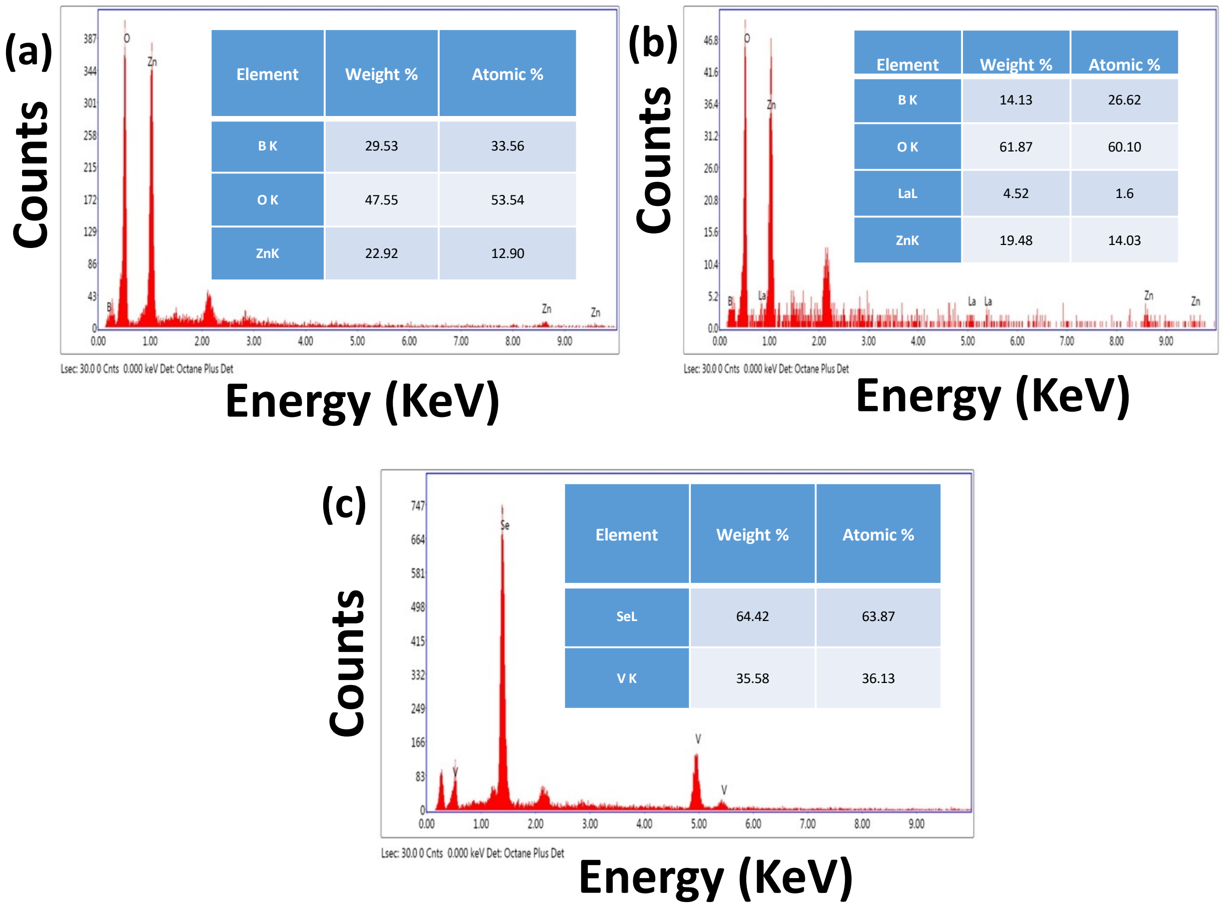

Fig. S1 EDX spectrum of, (a) ZB, (b) LZB and (c) VSe_2

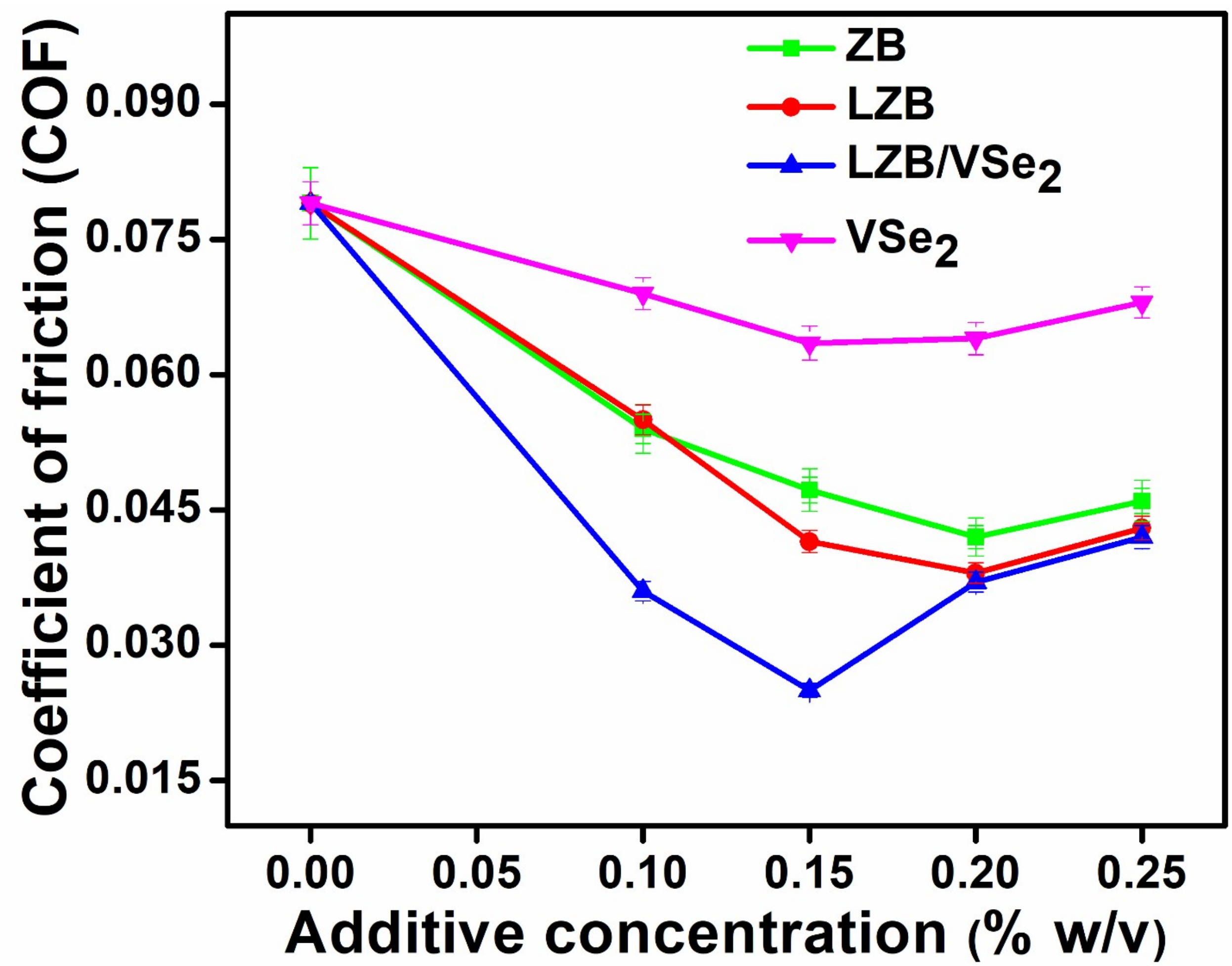

Fig. S2 Variation of coefficient of friction (COF) vs. additive concentration

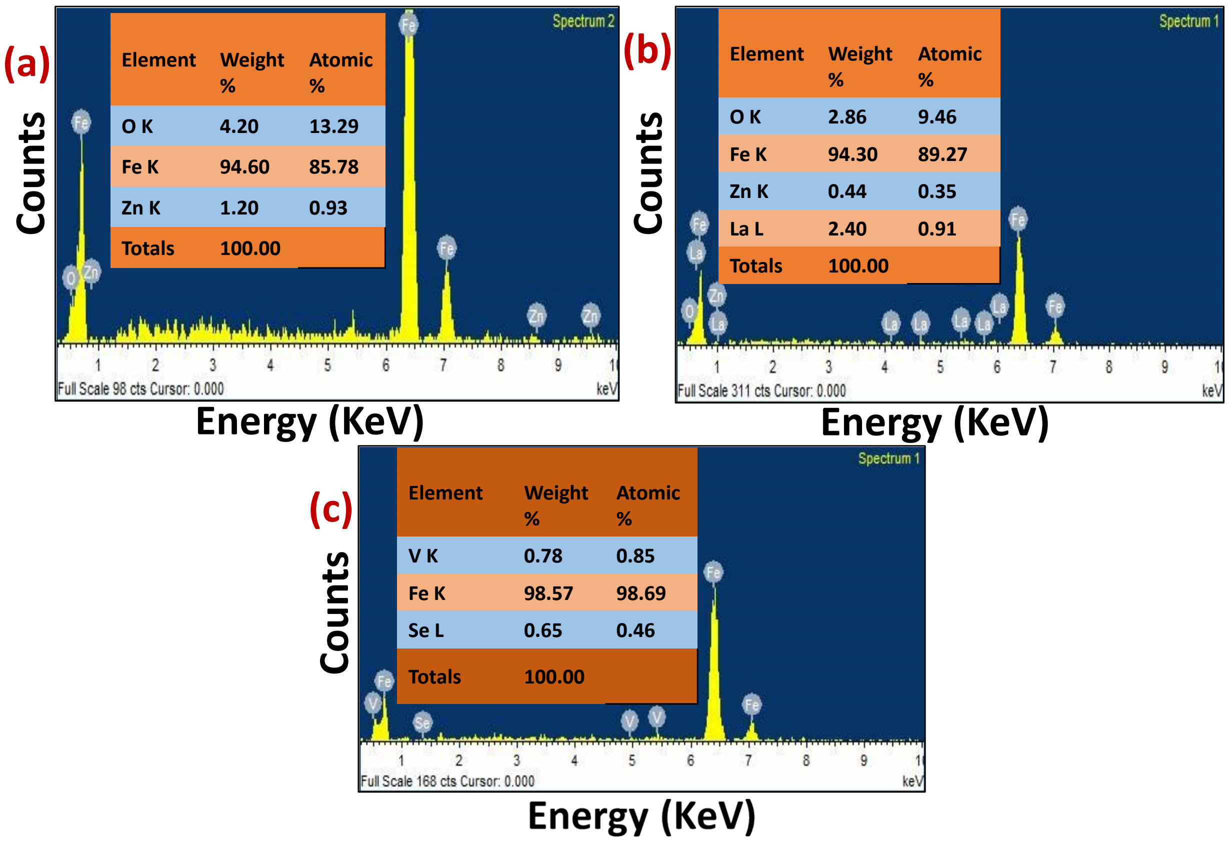

Fig. S3 EDX spectrum of wear track of steel surface lubricated with (a) ZB, (b) LZB and (c) VSe_2

Table S1. Surface roughness parameters obtained from the digital processing software of AFM (Nanosurf-basic Scan-2) for different additives after the antiwear test.

Surface roughness parameter	Sq (nm)	Rq (nm)	Sa (nm)	Ra (nm)	Sy (nm)	Ry (nm)	Sp (nm)	Rp (nm)	Sv (nm)	Rv (nm)	Sm (pm)	Rm (pm)
PO	626	919	488	771	4363	3255	2611	2060	-1752	-1195	129	-129
ZB	212	270	167	229	1245	977	752	517	-492	-459	162	157
LZB	152	156	118	129	964	565	532	255	-431	-309	145	148
VSe_2	490	516	411	421	2192	1897	1126	964	-1065	-933	136	134
LZB/VSe_2	63	44	49	36	485	194	289	78	-196	-115	108	132

Where, S = Areal roughness, and R = Linear roughness parameters).

Sq = root mean square height, Rq = root mean square line

Sa = Arithmetical mean height, Ra = Arithmetic mean line

Sy = Maximum height of the surface, Ry = Maximum height of the profile

Sp = Maximum peak height, Rp = Maximum profile peak height

Sv = Maximum valley depth, Rv = Maximum profile valley depth

Sm = Mean width area, Rm = Mean width line

1. Experimental details

1.1. Instrumentation used for Characterization of the Synthesized Additives

For studying morphological features of the additives, scanning electron microscopy/high resolution scanning electron microscopy (HR-SEM) using FEI-Nova Nano SEM 450 and transmission electron microscopy (TEM)/high-resolution transmission electron microscopy (HR-TEM) using FEI-Tecnai-G2 electron microscope were carried out. FTIR spectra were recorded on a *Thermo Scientific* Nicolet iS5 FTIR spectrometer. X-ray diffraction (XRD) (Rigaku Miniflex 600, XRD-System) using Cu-Kα_1 radiation (λ=1.54˚A) and X-ray photoelectron spectroscopy (XPS) (PHI 5000 Versa Probe II, FEI, Inc.) were employed for investigation.

1.2. Antiwear Testing

The lubricating base oil, neutral liquid paraffin oil (Qualigens Fine Chemicals, Mumbai, India) having specific gravity 0.82 at 25 ^{o}C, kinematic viscosity, at 40 ^{o}C and 100 ^{o}C, 30 and 5.5 cSt respectively, viscosity index 122, cloud point -2 ^{o}C, pour point -8 ^{o}C, flash point 180 ^{o}C and fire point 200 ^{o}C, was used without further purification.

The balls of 12.7 mm diameter made of AISI 52100 steel alloy possessing hardness 59-61 HRc were utilized for tribological tests. Before and after each test, balls were rinsed well with *n*-hexane and then properly air-dried.

The prepared admixtures were sonicated for 1 hour at RT. The antiwear tests of the synthesized additives were carried out with the help of a Four-Ball Lubricant Tester (Ducom Instruments Pvt. Ltd., Bangalore, India) followed by ASTM D4172. At first, concentration optimization tests were carried out for base oil with and without different concentrations of the studied additives according to ASTM D4172 norms (applied load, 392 N; sliding speed, 1200; rpm, temperature, 75 ^{o}C). All tribological tests were conducted at the optimized concentration (0.15% w/v) under similar conditions. Step loading test was conducted in accordance with ASTM D5183 standards. After the running-in period is over under the test conditions (applied load, 392 N; sliding speed, 600; rpm, temperature, 75 ^{o}C and optimized concentration (0.15% w/v), increments of 98 N load were added after every 10 min until the seizure of tribo-surface was noted. In general, all the tribological testing was repeated 3 times.

1.3. Tribological Parameters

For each experiment arithmetic mean of the diameter of each ball (d_1, d_2 and d_3) was taken as given by equation **1**. The three stationary balls were not disturbed while taking the readings and the wear scar diameter was taken by Image acquisition system.

1.3.1. Mean wear scar diameter (MWD)

$$d = \frac{d_1 + d_2 + d_3}{3} \qquad \text{S1}$$

1.3.2. Frictional power loss

Frictional power loss

In the antiwear test, the frictional power loss is calculated as per eq (1).

$P = T.\omega$ eq.(1)

Where, P = Frictional power loss ($N.m.s^{-1}$),

T = Frictional torque (N.m) = F.r,

Where, F is Frictional force, r is friction radius = 0.14434 (inch) = $3.662 x 10^{-3}$ (m)

ω = angular velocity (rad/s) = $2\pi n/60$, where n = 1200 rpm,

F = Frictional force = μN,

Where, μ is coefficient of friction, N is the contact load on the three balls (N)

N = 1.22475p, where p is actual applied load = 392 (N)

Substituting all the values in eq. (1), The frictional power loss

$P = 221*\mu$ (watt) eq.(2)

1kWh = 3.6 MJ eq.(3)

1.4. Analysis of Wear Track

(SEM) with Energy-dispersive X-ray spectroscopy (EDX) was applied for providing surface magnified images of wear scar of 12.7 mm diameter steel balls and elemental compositions of tribofilm formed on the wear scar respectively using a scanning electron microscope (ZEISS SUPRA 40 electron microscope). A contact mode atomic force microscope (Model no. BT 02218, Nanosurf easyscan2 Basic AFM, Switzerland) was used to investigate the roughness of the worn surfaces with the Si_3N_4 cantilever (Nanosensor, CONTR type) having a spring constant of approximate 0.1 Nm^{-1} and tip radius more than 10 nm. X-ray photoelectron spectroscopy (K-alpha X-ray photoelectron spectrometer) was used for analyzing the chemical composition of the tribofilm formed on the worn surface.