Studies on Some Nanomaterials as Wear and Friction Modifiers

THESIS SUBMITTED IN PARTIAL FULFILLMENT FOR THE AWARD OF DEGREE

DOCTOR OF PHILOSOPHY

By

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Dedicated to

my

loving family

&

Prof. R. B. Rastogi

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Alok Kumar Singh

Research Scholar Department of Chemistry

List of Notations, Symbols, and Abbreviations

μ	Coefficient of friction
P	Frictional Power loss
AFM	Atomic force microscopy
ASTM	The American standard of testing machine
BDC	1,4- Benzene dicarboxylic acid
BV	Bismuth Vanadate
CNMs	Carbon nanomaterials
CNTs	Carbon nanotubes
COF	Coefficient of friction
CQDs	Carbon quantum dots
CS	Carbon spheres
EDS	Energy Dispersive X-ray Spectrometry
FE-SEM	Field emission-scanning electron microscopy

FTIR	Fourier transforms infrared spectroscopy
GO	Graphene oxide
GQDs	Graphene quantum dots
g-C_3N_4	Graphitic carbon nitride
h-BN	Hexagonal boron nitride
h	Hour
LZB	Lanthanum doped zinc borate
MBV	Molybdenum doped bismuth vanadate
min	Minute
MoS_2	Molybdenum disulfide
MWD	Mean wear scar diameter
MWV	Mean wear scar volume
NPs	Nanoparticles
NTs	Nanotubes
N-ZnO	Nitrogen doped Zinc Oxide
PO	Paraffin Oil
PEG	Polyethylene glycol

PO	Paraffin oil
QDs	Quantum dots
rGO	Reduced graphene oxide
SAED	Surface area electron diffraction
SDS	Sodium dodecyl sulfate
SEM	Scanning electron microscopy
TEA	Triethylamine
TEM	Transmission electron microscopy
UV-Vis	Ultraviolet visible Spectroscopy
VSe_2	Vanadium diselenide
WS_2	Tungsten disulfide
XPS	X-ray Photoelectron Spectroscopy
XRD	X-ray diffractometer
ZB	Zinc Borate
ZDDP	Zinc dialkyldithiophosphate
ZIF	Zeolitic imidazolic framework
ZnO	Zinc oxide

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Preface

Heat release via friction between the mating surfaces causes energy losses and wear. Friction and wear are reduced when a lubricant is supplied between the proximate moving surfaces. Nanomaterials are preferred as lubricant additives over traditional organic chemicals because of their small dimensions and quick tribological action. Nanosheets, a 2D material, play a vital function in lubrication, referring to their minimal value of the coefficient of friction and ease of shearing in a sliding motion. To address the limitations of nanosheets during lubrication, such as repiling of nanosheets, agglomeration, poor adhesion to the surface, inadequate dispersibility in the base oil, insufficient wear and friction diminishing properties, and last but not least, awful load-carrying ability, functionalization of nanosheets is performed. In the present research, different 2D nanosheets and their non-covalent functionalized nanocomposites with other nanomaterials have been synthesized to enhance the tribological behavior using their synergistic effects. The thesis is divided into the major heads; Introduction, Experimental procedures, Results & Discussions, Summary, and References.

In **Chapter 1**, introduction, the term "Tribology" was initially explicitly introduced concerning mechanical systems durability. The phenomena of friction, wear, and lubrication were elaborated. Further, the types of lubrication, lubricants, and their classification, have been discussed. Different categories of additives, in general, and antiwear/antifriction additives, in particular, have been described. A detailed literature survey regarding nanomaterials in tribology, like quantum dots, nanoparticles, nanorods, nanotubes, various 2D nanosheets, and their nanocomposites, is presented in this section. The problem has been addressed and defined in detail. Finally, the aims and objectives of the current investigation have been outlined.

The **Chapter 2** includes instrumentation techniques such as powder X-ray diffraction (p-XRD), Fourier Transform infrared spectroscopy (FTIR), scanning electron microscopy (SEM)/high resolution scanning electron microscopy (HR-SEM), energy-dispersive X-ray spectroscopy (EDX), transmission electron microscopy (TEM)/high-resolution transmission electron microscopy (HR-TEM), electronic absorption spectroscopy (UV/visible), and X-ray photoelectron spectroscopy (XPS) for characterization of the synthesized lubricant additives as well as lubricated mating surfaces. The characteristics of base lube paraffin oil (PO), details of the test sample (steel balls), experimental procedures for the tribological tests, ASTM D4172, ASTM D5183, and brief information about various tribological parameters such as coefficient of friction (μ), mean wear scar diameter (MWD), load-carrying capacity and frictional power loss have also been included in this chapter.

Conclusions obtained from the experimental data and their outcomes have been discussed in chapters 3 to 6.

Chapter 3 contains the synthesis of N-doped Zinc oxide (N-ZnO) nanorods, g-C_3N_4 nanosheets, and the nanohybrid N-ZnO/g-C_3N_4. Characterization and Morphologies of the as-prepared nanorods/nanosheets and their nanocomposite have been investigated. The tribological performance of these nano additives has been assessed. As anticipated, the nanohybrid shows marvelous tribological activity among all tested additives.

Chapter 4 comprises the synthesis of manganese-based Metal-Organic Framework bulk Mn-MOF (B) and ultrathin Mn-MOF (U)). These were characterized thoroughly, and their tribological activity has been evaluated. Undoubtedly, MnMOF(U) performed much better than Mn-MOF (B).