The efficiency of a mechanical device is strongly reduced due to friction and wear between moving surfaces. Friction and wear are therefore, always undesirable in such applications as these adversely affect the functionality of the mechanical device and limit its life-span. Lubricants play an important role towards reduction in friction and wear between sliding surfaces by interposing a thin film. Over the years, various categories of lubricant additives have been employed for various purposes. To protect the engineering components from wear and tear, antiwear, antifriction and extreme pressure additives have been used in lubricant. This category of lubricant additive contains huge amount of sulfur, phosphorous, halogens and metal contents. Among these lubricant additives, zinc dialkyldithiophosphates (ZDDP) are being frequently used as excellent multifunctional lubricant additives in lubricant industries.

For the last two decades there has been a growing trend towards greener lubricant additives driven by several environmental legislations. As environmental legislations become more stringent, it is increasingly important and urgent to find a substitute that is more environmentally friendly. It is also recognized by lubricant industries and research institutes that there is a need to review which materials and lubricant additives should be used to enhance the synergistic interaction between them. Therefore, the need of hour is to replace the ZDDP-based lubricant additives because of high amount of Sulfated Ash, Phosphorous and Sulfur (SAPS) contents which cause toxicity to aquatic wildlife, adverse effects to human-health and poisoning of automotive exhaust.

In view of the above, development of sulfur, phosphorous-free antiwear additives which are cost-effective, environment friendly in nature and capable to reduce both friction and wear has become a major concern for the energy efficient tribological applications. To implement the conceived idea, the present work was undertaken where different categories of antiwear additives; Schiff bases and their synergistic formulation with organoborate ester, Copper (II) benzoylhydrazones, Stearic acid modified-$CaCu_{2.9}Zn_{0.1}Ti_4O_{12}$ nanoparticles (SCCZTO) and $TiO_2$-reinforced-B-N-codoped-MRG nanomaterials have been prepared and their tribological properties have been evaluated. The thesis has been divided into following heads: Introduction, Experimental details, Results & Discussions, Summary and References.

**Chapter 1** comprises of introduction which covers basics of tribology in terms of friction, wear and lubrication. In addition to this, a concise historical review of ongoing and the past research on lubricant additives has also been incorporated in this section. The scope and objectives of the present investigation have been highlighted at the end of this chapter.

**Chapter 2** describes of the experimental details including materials used, testing methodologies and the instrumentation which have been used to characterize the additives as well as lubricated surfaces. Quantum chemical calculations were performed using density functional theory (DFT) method to correlate the experimentally obtained results of antiwear additives with the theoretical ones.

The results and discussion of the experimental data have been spread over four chapters from 3 to 6. **Chapter 3** presents synthesis and characterization of a series of SAPS-free Schiff bases derived from condensation of 4-aminoantipyrine with benzaldehyde, salicylaldehyde, *p*-methoxybenzaldehyde and *p*-chlorobenzaldehyde. The tribological behavior of Schiff bases has been evaluated in absence and presence of borate ester (Vanlube 289) in paraffin oil using four-ball tester. These metal, sulfur and phosphorous free formulations provide excellent tribological and environment friendly compatibilities when used as additive in paraffin oil. Being ashless, these antiwear lubricant additives have potential to find applications in various automotive industries in improving machine efficiency. The pronounced tribological performance of these blends is due to their synergistic action via formation of donor-acceptor complex between nitrogen-boron which facilitates the formation of durable tribofilm preventing direct metal-metal contact. Among all of the constituents of tribofilm (BN, $B_2O_3$ and $Fe_2O_3$/$Fe_3O_4$) on worn surface, boron nitride is mainly responsible for their synergistic behavior which has been confirmed with the help of XPS and EDX studies. The role played by boron nitride may be because of its layered structure. The SEM and AFM studies suggest that the surfaces generated through these blends are much smoother in comparison to ZDDP/BE/base oil. Among the studied Schiff base additives, the best antiwear and load carrying properties are exhibited by AAPM which are very well supported by the theoretical studies using density functional method.

**Chapter 4** contains the synthesis, characterization and tribological investigations of a series of N-substituted benzoylhydrazones derived from condensation of substituted aromatic carbonyl compounds with benzhydrazide and their copper (II) complexes in paraffin oil using four-ball lubricant tester. The Schiff base copper (II) complexes exhibit excellent antiwear and load carrying ability which are even much better than those of ZDDP/Schiff bases at 1% w/v concentration. The pronounced tribological performance of the complexes is due to their large surface coverage which in turn, facilitates the formation of durable tribofilm preventing direct metal-metal contact. Among all of the constituents of tribofilm (decomposed nitrogen, CuO, $Cu_2O$ and $Fe_2O_3/Fe_3O_4$) on worn surface, CuO and $Cu_2O$ are mainly responsible for their excellent tribological behavior which has been confirmed with the help of XPS analysis. The SEM and AFM studies suggest that the surface generated in presence of complexes is much smoother in comparison to ZDDP/Schiff bases/base oil under various test conditions. Out of the studied Schiff bases, H-Sbh exhibits better antiwear and load carrying properties than H-Abh. Similarly, $[Cu(Sbh)_2]$ proves to be superior antiwear additive over $[Cu(Abh)_2]$. Theoretically calculated values for various molecular orbital indices including the energy of frontier molecular orbitals ($E_{HOMO}$ and $E_{LUMO}$), energy gap ($\Delta E$), $\Delta E_1$, $\Delta E_2$ and dipole moment have been used as the criteria to investigate the interactions between lubricant additives and metal surface. These interaction parameters based on density functional theory support very well the experimentally observed tribological behavior.

**Chapter 5** addresses the synthesis and characterization of $CaCu_{2.9}Zn_{0.1}Ti_4O_{12}$ nanoparticles (CCZTO) and stearic acid (SA) modified SCCZTO nanoparticles of varying size 60, 80 and 90 nm and evaluate their tribological properties. The stearic acid capped nanoparticles could be well dispersed without agglomeration in paraffin oil. These blends effectively enhanced the antiwear properties of base oil in order of decreasing particle size. The overall, running-in and steady-state wear rates of SCCZTOs nanoparticles except -12h have been found to be lower than ZDDP. The load bearing ability of the SCCZTOs nanoparticles was found to be far better than ZDDP and paraffin oil alone. Surface analysis by SEM and AFM also supports the observed tribological behavior of SCCZTOs nanoparticles. The EDX analysis of wear track shows presence of C, Ca, Cu, Zn, Ti, O and Fe elements in the tribofilm whereas

XPS spectra revealed chemical form of these elements as -C(O)O-, C-C/C-H moieties; CaO; CuO, $Cu_2O$; $TiO_2$ and $Fe_2O_3$. EDX and XPS analyses support the mechanism of wear through nano bearing as well as process of tribosinterisation.

**Chapter 6** illustrates the microwave synthesis of few layered thick reduced graphene oxide (MRG), B-MRG, N-MRG, B, N-co-doped-reduced graphene oxide (B-N-MRG) and $TiO_2$-reinforced-B-N-MRG ($TiO_2$-B-N-MRG) nanomaterials. These have been successfully characterized by various states of the art techniques like Raman, powder XRD, SEM with EDX, HRTEM and XPS. As novel lubricant additives, the as-prepared B-N-MRG and $TiO_2$-B-N-MRG nanomaterials possess appreciable dispersion stability in paraffin oil. Friction and wear characteristics of these nanomaterials were evaluated using four-ball lubricant tester at optimized concentration (0.15% w/v). The observed tribological results show that B/N/B-N doped MRG and $TiO_2$-reinforced MRG exhibit tremendous reduction in MWD (from 0.733 to 0.366 mm) and COF (from 0.0756 to 0.0564) values and appreciable enhancement in load carrying ability from 1078 to 1470N. In addition to this, studied additives exceptionally reduced the steady-state wear rate in the range of 64-98%. SEM and AFM studies revealed that there is some pad-like deposition on the sliding surfaces lubricated with B-N-MRG and $TiO_2$-B-N-MRG which may be the consequence of *in situ* formed tribofilm preventing metal-metal contact. The XPS analysis of tribofilm formed on the surface lubricated with $TiO_2$-B-N-MRG confirmed the presence of graphitic carbon, boron nitride and tribosintered $TiO_2$ nanoparticles. Above results suggest that the synthesized B-N-MRG and $TiO_2$-B-N-MRG nanomaterials are the potential candidates to be developed as SAPS-free antiwear lubricant additives under boundary lubricating conditions. Despite its low thickness, MRGs have improved anti-frictional properties and imparted relatively high wear resistance that makes them attractive materials for various applications in tribology.