CHAPTER 1

INTRODUCTION

The essential requirements of any engineering system are its efficiency, long life and reliability. Relative sliding motion between the components/links of engineering system is the genesis of friction which leads to loss of material from both components, which is termed as wear, may affect its life, reliability and efficiency. Most of the times, machine failure occurs due to the wear i.e. gradual loss of material from the rubbing surfaces due to mechanical action, not due to fracture. The failure due to wear is rarely catastrophic, but it hampers the efficiency of the system due to increased power losses and oil consumption and leads to replacement of components. It, therefore, becomes imperative that the parts having relatively sliding motion with respect to each other be designed to minimize the wear. During rubbing of the two surfaces some fundamental changes occurs in the contacting surfaces, determining the nature of frictional force and the process of wear. The study of the complex phenomena which occurs during rubbing and need to minimize material/energy losses in mechanical systems has generated large interest among the research community in the science of friction, wear and lubrication known as “Tribology”. Tribology is not only limited to reduction in the friction and wear, rather the philosophy behind this is to minimize the human effort and cost by adopting environmental friendly practices.

The economic importance of the tribology can be gauged by the latest worldwide energy consumption reports (Holmberg et al, 2017), which states that a whopping 23% of total energy accounts for tribological contacts, whereas implementation of advanced tribological practices save more than 400000 million euros per year. Hence, it becomes imperative to be aware of different aspects of losses occurring due to tribological interactions and devise measures to stop them. It can help us to save our resources, energy and economic losses directly and indirectly. Direct savings can further be categorized into; Primary: Saving the energy by friction reduction. Secondary: Saving energy which is needed to fabricate the new parts; Tertiary: saving energy on material content while replacing the worn components whereas. Indirect saving accounts for life of machinery.

The liquid lubricants are extensively used between the sliding surfaces to reduce friction and wear, however, these are usually toxic and not readily biodegradable and thus cause substantial damage to the environment. Also, it is not always possible to use the lubricants in every sliding condition due to various limitations. The use of external lubricants can be eliminated by designing self-lubricating composite materials possessing the ability to attain low friction and wear at the contact surfaces without any external supply of lubrication during sliding. The metal matrix composites reinforced with various self-lubricating particles such as graphite, molybdenum disulfide are being used as self-lubricating materials for various engineering applications. Composite material is manmade combination of two or more materials which are physically distinct, chemically dissimilar and possess different properties. The topologically continuous material is termed as matrix, while discontinuously distributed phase is known as reinforcement. The reinforcement phase can have different geometrical characteristics and different scales ranging from micron to nano, which govern the properties of the composite material. Since the beginning of the development of the composite materials, researchers have been trying the different combinations; with or without solid lubricants, to achieve the desired tribological properties. Hence, alternative approaches like surface modification (coatings) or development of self-lubricating composites materials have emerged as viable options to provide effective lubrication in such conditions in order to minimize friction and wear.

However, between these two the self-lubricating composites are the best alternative as they provide adequate and effective lubrication for an extended period of time in comparison to coatings due to their limited life.

A lot of work has been done on aluminum, copper, magnesium, nickel, titanium matrix composites containing a variety of hard/soft reinforcements or a combination of them. Copper and its alloys are widely used for making wires and cables, automobile industry, heat exchanger and in rapid heat conduction. However, low hardness and strength, low friction properties and wear resistance of copper restricts its application in the components invbolving sliding contacts. These short comings can be overcome by reinforcing copper with suitable hard or soft lubricating material. Studies conducted on its tribological behavior suggests that a variety of reinforcements (MoS_2, WS_2, h BN, Al_2O_3, SiC, ZrO_2, CNT, Ag and graphene) and their combinations have been used by several researchers to enhance the mechanical and tribological properties of copper. The well-known solid lubricants like graphite, molybdenum disulfide, *h*-BN having lattice layered structure have been extensively used as reinforcement because they provide easy shearing property at the sliding interface with consequent reduction in both friction and wear. Apart from reinforcements, the processing technique also plays a vital role in governing the mechanical and tribological properties of composites as uniform dispersion, interfacial bonding and structural stability depends upon the processing technique adopted for fabrication of the composites. However, it is not only the reinforcements that are responsible for improvement in tribological performance, but the processing techniques also plays a vital role, since uniform dispersion, interfacial bonding and structural stability depends upon them, in governing the mechanical and tribological properties of composites. In view of the widespread use of copper it has been selected as the matrix to synthesize self-lubricating composites and to explore their tribological potential.

There are many processing techniques available, each one of them has its own limitations. However, powder metallurgy has been proved to be the most appropriate route to produce superior quality products over the last few decades. It is a solid state processing, which allows to process the components having dissimilar physical and chemical properties e.g. melting temperature, density difference, difference in coefficient of thermal expansion, high reactivity etc. It also offers other advantages like uniform dispersion, improved structural stability, good surface finish, dimensional control and a good bonding between matrix and reinforcement. The main drawback of conventional sintering processes is that it is a bit time consuming, so, the advanced processes like spark plasma sintering (SPS) and microwave sintering are being used due to save time and energy. Moreover, it has also been observed that properties of the product fabricated by these techniques are also superior to those fabricated by conventional sintering techniques. Spark plasma sintering offers some advantages like less time consumption, avoids grain coarsening, provides good densification due to internal heat generation, heating and cooling rate can be controlled and above all the materials with dissimilar properties. Hence, in the present study SPS has been used to fabricate the composites.

Graphene, a revolutionary 2D material having honeycomb lattice structure and high tensile strength, also known as the best conductor of heat and electricity (Mohan et al., 2018 and Chee et al. 2016), is an attractive material which can be reinforced into copper matrix to enhance its mechanical and tribological properties without compromising its electrical conductivity. MoS_2 is an excellent solid lubricant, which is being widely used in composites either singly or in combination with other solid lubricant. Since, the research on a combined effect of MoS_2 and graphene in copper is still evasive, it would be good to analyze the behavior of copper based composites containing a combination of these two lubricants which are expected to improve hardness, wear resistance while simultaneously providing low frictional properties. The other approach which is gaining attention in the research community is to synthesize a hybrid of reduced graphene oxide (rGO) grafted with MoS_2 i.e. rGO-MoS_2 and then use it as a reinforcement in the metal matrix. A number of researchers have reported the improvement in performance of the lubricant by using rGO-MoS_2 hybrid as an additive. Hence, it would be reasonable to explore its potential as a solid lubricant in metal matrix composites.

In light of the above, the present study has been carried out to synthesize the copper based hybrid composites containing either a hard phase (Cu-Fe-Al_2O_3), a combination of hard and solid lubricant (Cu-Fe-Al_2O_3 -MoS_2) and a hard phase plus a combination of solid lubricants (Cu-Fe-Al_2O_3 -MoS_2-*h*-BN) using spark plasma sintering and to examine their tribological performance apart from exploring the presence of any synergetic action between MoS_2 and *h*-BN in enhancing the regime of effective solid lubrication. The study is also aimed at fabricating the copper based composites containing different amounts of novel rGO-MoS_2 hybrid material synthesized through hydrothermal process, as a reinforcement and to explore their fiction and wear characteristics under dry sliding conditions. In order to determine the optimum sintering parameters and optimum concentration of reinforcement, the effects of sintering temperature and amount (wt. %) of rGO-MoS_2) on mechanical and tribological properties of Cu/rGO-MoS_2 are also slated to be examined.

In summary, the present study has been carried out to explore the tribological performance of copper based composites containing either a combination of hard phase and solid lubricants or a novel nano rGO-MoS_2 hybrid synthesized via spark plasma sintering. The knowledge base generated through this study is expected to provide a better understanding of the Cu-rGO-MoS_2 composite and may help utilize its potential as a future material for tribological applications.