CHAPTER-1

CHAPTER 1

INTRODUCTION

Tribology, coined by H Peter Jost (1966), is the study of surfaces having relative motion and interacting with each other. The core of tribology is understanding how these interactions work and finding technical solutions to the interfacial phenomena. The familiarity of friction, wear, and lubrication and their application in human history date back to 3000 BC or before (Dowson, 1979). Leonardo da Vinci's sketches from the late 15th century have revealed many of the fundamental laws of friction, including the proportional relation between normal and limiting friction forces, as well as friction tests that closely resemble the current ASTM standard led friction and 4-ball test geometries, which have been the subject of extensive scientific study. However, understanding friction and wear and concepts that explain the underlying mechanisms took several centuries. Amonton (1699) proposed that tiny spheres cover the surfaces, and the angle of contact between the spheres of contacting surfaces results in the friction coefficient. His assumption, however, restricted the motion always to the top of the spheres. Between 1750 and 1850, rapid technological changes happened due to the industrial revolution alongside social and economic developments. An important work during this period was by Charles Augustin Coulomb in 1781, who derived friction formulas based on his experiments. Yet until the late 19th century, relatively little knowledge of friction was gained. Osborne Reynolds' landmark work, published in an article on hydrodynamic lubrication in 1886, sparked a slew of further studies aimed at enhancing the interaction between two contacting surfaces, which have continued to this day. Reynolds proved that even at very low sliding speeds, the hydrodynamic pressure of liquid employed between sliding surfaces prevented contact between the surfaces, which helped in designing journal bearings to high-end sophistication.

Tribology, a multidisciplinary discipline of research and technology, finds widespread applications in chemistry and material science, solid mechanics and physics in lubrication problems in engineering, ergonomics, business economy, and management, among other fields (Dašić et al., 2003) and has significant economic implications for any country. Jost & Schofield (2006) indicated that with annual tribological losses in energetic and economic wastes, U.K. could have saved approximately £500 million per year (1.5% of GDP), and the U.S. could have more than $16 billion per year by better tribological practices. In other words, 1/3 of the world's primary energy consumption (of which about 20% in automobiles, 9% in aviation piston engines and (1 ½ -2) % in turbojet engines) and 80% of equipment failure resulting in a significant loss. It has also been reported that the Austrian industry could save from 1.1 to 1.9 billion euros per year by emphasising research and the continuous use of tribological practices. (Troyer & Fitch, 2001).

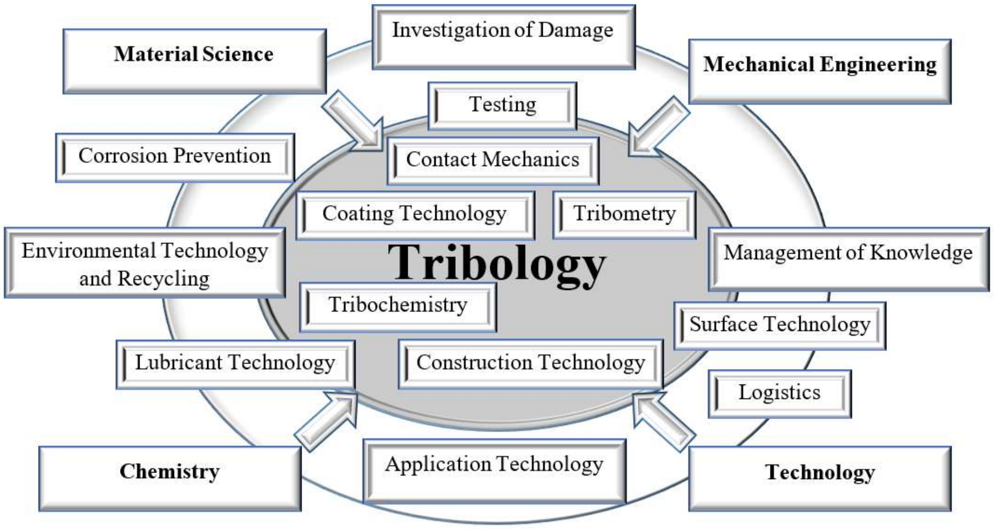

Fig. 1.1 Graphical representation of the multidisciplinary notion of tribology in relation to other sciences. (Dašić et al., 2003)

According to an estimate, the cost of friction and wear in India is estimated at around Rs. 78.67 billion, and severe wear and poor lubrication are responsible for 55–60% of equipment damage**.** (Singh et al., 2013) Even after 50 years, only around a tenth of these savings have been achieved globally, yet this modest amount demonstrates enormous energy savings on a wide scale. Economic perspectives and long-term reliabilities (i.e., energy and matter savings) oriented the scientific and technological communities towards the need for strategies on wide diffusion of tribology and the training of high-quality tribologists whose principal research goal is to minimize and eliminate losses due to friction and wear in the applications where mating surfaces are involved.

The mechanical contact between surfaces is complicated, and multiplex sets of microscopic interactions occur while sliding against each other arising friction and wear. A surface is a geometric boundary between a solid and its surroundings, and its interactions are determined by the contacting materials as well as the surface geometry. The shape of the surface of an engineering material is determined by its manufacturing history and the characteristics of the parent material. (Bhushan, 1996; Thomas, 1982; Whitehouse, 1994). The solid surfaces are rough when examined on a microscopic scale, with asperities of variable amplitudes and spacing defining the roughness. The irregularities are inherently present, creating the texture over the surface in the form of roughness and waviness. The solid surface itself has multiple zones in addition to surface variations. These zones are critical because their properties might differ significantly from those of the bulk material. (Bhushan, 2013). Since tribology is related to surface and near-surface regions, the surface texture commands the extent of contact area, contact stress and lubricant paths. The geometrical and topographical properties of the surfaces, the materials, and the working conditions, such as loading, temperature, atmosphere, type of contact, etc., in which they are made to move against each other, are responsible for the interactions between surfaces. The tribological characteristics of a system depend on the surrounding atmosphere and all mechanical, physical, chemical, and geometrical features of the contact between the surfaces. As a result, the tribological system in which friction and wear are considered has its own peculiarities.

Lubricants are used to minimise friction and wear between rubbing surfaces, and this is evident from an estimated use of 40 million tonnes of liquid lubricant which is used annually as indicated by Mang & Dresel, (2007). The biggest issue, however, is the disposal of hazardous lubricants and additives that create a threat to the environment. On the other hand, coatings are used to improve the substrate's surface properties without changing the bulk materials' properties. It reduces friction and wear by increasing the hardness and improving the surface finish. One of their limitations is the adherence of coatings to the substrate, which permits the interactions of chemical bonds between the layers. Also, coatings have a limited lifetime and are not suitable for all applications. (Shi et al., 2014)

An intentional modification of surface topography has effectively minimised friction and wear under dry and lubricated circumstances during the last seventy years. A number of texturing techniques, such as pattering by coating, mechanical removal, chemical etching, focused beams, and laser surface texturing, have evolved based on processing time, process control, cost, and environmental friendliness. However, Additional processing expenses are incurred as a result of surface texturing, which must be justified by the benefits received. Artificially generated micro features have been shown to have a big impact on sliding behaviour, lowering friction, reducing wear, and improving lubrication processes. The micro features act as entrapment for debris under dry sliding, whereas these act as a reservoir and create a hydrodynamic effect in lubricated conditions, especially for conformal contacts. Hamilton et al. (1966) and Anno et al. (1968) published the first experimental evidence of improvement in friction tribological performance of a system by texturing. However, the pioneering work by Etsion et al. (1999) on laser surface texturing (LST) is regarded as the renaissance of this research topic, wherein they reported a 40-45% reduction in friction after texturing of piston rings. A number of other studies (Yu et al., 2010; Rosenkranz et al., 2014; Schneider et al., 2017) have also reported a significant reduction in friction due to textures. Since then, much courtesy has been paid to surface texturing in the research community working in the field of tribology. Among the various texturing techniques, Laser Surface Texturing (LST) has been shown to be fast, less time-consuming, clean to the environment and affords easy controllability of the shape and size of textures. The tribological performance of the materials processed by LST has been reported to be significantly affected by the morphologies of textures like shape (circular, spherical, elliptical, triangular etc.), size and aspect ratio. Furthermore, it has been argued that the array of dimples on the surface also plays a major role in controlling friction. The density of dimples becomes significant as the spiral arrangement of micro-dimples has a greater and more stable number compared to a radial array for the same contact area. Under dry contact, cavities are likely to help by entrapping wear debris and reducing the real area of contact. In the last two decades, numerous experimental and computational research has been published in an attempt to determine the optimum morphology of textures in terms of possible friction and wear reduction, understanding the underlying mechanisms of surface texturing. However, there is still a lot of scope of exploration in this area of research.

The present work aims to advance the knowledge of the correlations among the dimple shape, aspect ratio, density, array, and tribological performance of textured bearing steel at various loads and speeds under both dry and lubricated conditions. In view of this, the present study has been carried out to understand the effect of shape, density and array of dimples on the friction and wear behaviour of bearing steel. Laser surface texturing has been used to create circular and bi-triangular dimples having two different densities, i.e., 7% and 20%, on circular disc-shaped specimens. The tribological behaviour of the textured surface has been examined by conducting friction and wear tests under unidirectional sliding against a pin of the same material having a conformal contact on a pin-on-disc tribometer. The tribological performance of textured surfaces has been studied under “dry contact” and “single drop” lubrication at different loads and speeds. The untextured steel disc has been taken as a reference specimen for the purpose of comparison. The tribological performance of untextured surfaces, textured with circular and bi-triangular dimples, has been compared under dry as well as lubricated sliding conditions. The present results are expected to provide a better understanding of the effect of the shape of the dimple under various input conditions and help to utilise the potential of texturing for a wider spectrum of tribological applications in which there is relative sliding under conformal contact.