Chapter 1

Introduction

A large market for steels towards numerous applications in crushing machines, conveyors, screening machines, hoppers and silos, chutes and so forth specifically demands high wear resistance materials. Structural components in these applications are often directly put into service in cold formed and welded condition. Cold deforming is a pre-straining process, which changes the dislocation substructure of the metallic materials, and in turn, alters their mechanical behaviour. Extensive literature exists related to shear instabilities (Biswas, 1997), deformation substructure (Bassim, 1986), strength (Rauch, 1997), hardness (Todaka, 2007), fatigue (Hong, 2004; Kang, 2007) and fracture (Bassim, 1986; Chen, 2003; Qiu, 2005; Sivaprasad, 2000) to understand the structure-property relations of cold formed materials. But there is lack of organized attempt to understand wear behaviour of materials in pre-strained or cold formed condition. The current investigation is also aimed in this direction. In order to fulfill this gap, the present investigation aims to examine sliding wear behaviour of a series of plain carbon steels in pre-strained condition.

Structural components also consist of various types of weld joints, which are frequently subjected to wear and tear when put into service. A weld joint comprises base metal, heat affected zone (HAZ), and weld metal. The HAZ of a mild steel weldment is further categorized into four sub-zones, sub critical (SCHAZ), inter critical (ICHAZ), fine grain (FGHAZ), and coarse grain (CGHAZ), in order of their locations from the base metal to the weld metal (Easterling, 1993) with each sub-zone exhibiting its characteristics microstructure (Lancaster, 1993; Easterling, 1993). The role of microstructure on the mechanical properties of the sub-zones is known (Liu, 2002; Kim, 2001) to some extent. For example, fracture toughness of the CGHAZ has been reported to be significantly lower compared to its adjacent FGHAZ for weld-joints fabricated from low carbon–manganese steels (Kumar, 1999; Dolby, 1979). However, any systematic investigation related to the wear behaviour of this gradient microstructure is lacking.

It is well documented that sliding wear is governed by abrasion, adhesion, and delamination (Stachowiak, 1993). One of the basic manifestations of abrasion and adhesion is the process of fragmentation of material under sliding contact which leads to the formation of wear debris. The formation of fragments during sliding wear is the result of increased dislocation density, which increases the level of lattice energy; mis-orientation boundaries are created to reduce this lattice energy which leads to the formation of fragments (Panin, 2002). On the other hand, the process of delamination is caused by nucleation of voids, their growth and subsequent coalescence in a severely strained material during sliding (Fleming, 1977). The initiation of voids during delamination is mainly due to dislocation/dislocation or dislocation/twin interactions, and void formation around hard inclusions (Terheci, 2000). Since these mechanisms are predominantly governed by dislocation substructure, it is expected that pre-straining of material will have considerable effect on sliding wear behaviour of the material. In this work, therefore, an emphasis is laid on examining the influence of tensile pre-strain on wear behaviour of a few plain carbon steels.

Increase in the degree of pre-straining or cold working on materials generally increases their hardness and tensile strength. On the other hand, it is widely known that the volume worn per unit sliding distance is inversely proportional to the hardness of the material in sliding wear (Archard, 1956). Thus, it is natural to expect that pre-straining will enhance the wear resistance of materials. On the other hand, since the microstructural constituents govern the hardness of a material, it is obvious that a gradient microstructure like that in weld joint should lead to variation in wear rate across its profile.

The work of Biswas and Kailas (1997), however, indicates that in spite of higher hardness, wear of titanium is greater than that of copper. This observation has been elucidated by Biswas and Kailash (1997) in terms of the strain rate response of these metals, as reflected in their stress-strain characteristics. The works reported by Wang *et al.* (1999a) has shown that the microstructure of a material plays a more important role than its initial hardness on its sliding wear characteristics. They have supported their postulations with the evidence that the wear resistance of lamellar pearlitic structure of 52100 and 1080 steels is higher than that of the martensite structure in dry sliding, even though the hardness of the former is lower than that of the latter. The work done by Wang *et al.* (1999a) have attributed the difference in wear resistance of the various microstructures to emerge from different possibilities like thermal stability of the microstructure, resistance to plastic deformation, and resistance to nucleation and propagation of microcracks. On the other hand, it is also known that the wear behaviour is a system response rather than the response of only the characteristics of a specific material (Kato, 2000). So the influence of the microstructure of a material on its wear rate would also depend to some extent on the selection of the system. Thus, it is difficult to predict a-priori the nature of the influence of pre-strain and gradient microstructure on sliding wear characteristics of metallic materials.

Examination of the wear behaviour of variously cold formed low, medium, high carbon steels, and weld joints is the major content of this thesis. Cold deformation on the steels was applied by tensile pre-straining and the maximum magnitude of pre-strain was kept limited within the uniform elongation of the selected steels. A series of pin-on-disk wear tests were carried out in the severe wear regime of the steels. The severe wear regime was initially evaluated for each of the steels by determining their wear rates at different loads for a fixed sliding speed. The wear experiments were supplemented by studies related to tensile behaviour of the pre-strained material, hardness measurements on specimens before and after the wear tests, SEM observation of the worn out surfaces and examination of sub-surface cracks. The inherent aim for the overall investigation is to reveal the influence of pre-strain and gradient microstructure on wear behaviour of plain carbon steels.

In order to achieve variations in the proportion of ferrite and pearlite contents, i.e., in the proportions of the microstructural constituents of the steels, the materials selected for this investigation are plain carbon steels with varying carbon contents of 0.15, 0.22, 0.38, 0.47, 0.64, and 0.82wt%. To examine the mechanical behaviour of the steel with gradient microstructures, single pass butt-weld joints were fabricated from a low carbon-manganese steel (0.14%C-1.1%Mn) blanks of approximately 10 mm thick and size 150mm×400mm using metal active gas (MAG) welding process. All mechanical tests on these steels were carried out on annealed samples except that for weld joints.

The major objectives of this investigation and some pertinent details to fulfill these objectives are categorized into five modules as given below:

Module 1: To characterize the microstructure and to evaluate hardness and tensile properties of the selected plain carbon steels in unstrained condition.

This module incorporates (a) determination of the amount and distribution of various phases in the microstructure, (b) estimation of cleanliness, (c) measurement of ferrite grain size, (d) determination of hardness, and (f) evaluation of tensile properties.

Module 2: To evaluate hardness and tensile properties of the investigated steels in pre-strained condition.

This module incorporates (a) determination of hardness of the steels, and (b) evaluation of tensile properties of the selected steels at different pre-strain levels.

Module 3: To determine the transition load for mild to severe wear for the steels.

This module includes (a) determination of transition loads for mild to severe wear for the selected steels by conducting wear test at different loads but at a fixed sliding speed.

Module 4: To examine the wear behaviour of pre-strained steels at the selected loads in severe wear regime.

This module consists of (a) assessment of the effect of microstructural constituents on wear behaviour, (b) understanding the possible wear mechanisms; and (c) correlation between wear and other mechanical properties of pre-strained plain carbon steels.

Module 5: To examine wear behaviour of the different sub-zones of a weld-joint.

This module of the investigation consists of (a) comparison of the wear behaviour of the different sub-zones of weld-joints under identical test conditions, and (b) understanding the wear behaviour of gradient microstructures.