Chapter 1

Introduction

Ratcheting, one of the low cycle fatigue responses, is currently being considered to be a critical issue for design and safety of structural components. Structural components which are frequently subjected to cyclic loading conditions at stress states exceeding the elastic limit of the materials, often undergo through asymmetric stress cycling. Strain accumulation induced by cyclic loading under asymmetric stress conditions is known as ratcheting (Kulkarni et al., 2003) and is considered as the average of maximum and minimum strains in a cycle (Jiang et al., 1994). Accurate prediction of ratcheting response is therefore essential as ratcheting can lead to catastrophic failure of the structures. Ratcheting deformation could accumulate continuously till fracture (Chen et al., 2004) or may get saturated with increasing number of cycles. Ratcheting is normally considered to occur in the direction of mean stress, although for ductile materials ratcheting extension gets necessarily accompanied by ratcheting contraction in orthogonal directions (Rider et al., 1995). Jiang et al. (1994) have indicated that ratcheting deformation could result in failure in tension, compression, or shear depending on the magnitude of load and initial material condition. The present investigation deals with this type of damage accumulation through ratcheting in several polycrystalline single phase metallic materials of commercial interest.

Earlier investigations on ratcheting behaviour of materials range from various metallic systems like stainless steels (Fraugas and Gaudin, 2004; Gao, 2003), carbon steels (Jiang, 1994a; Gupta, 2005), Cu alloy (Lim, 2009), Sn-Pb solders (Chen, 2005b; Chen, 2006), metal matrix composites (Kang, 2006) to polymers (Chen, 2005a; Liu, 2008). These investigations are usually directed towards developing understanding related to influence of different test parameters like mean stress (Fraugas, 2004), maximum stress (Fraugas, 2004), stress ratio (Yoshida, 1990), temperature (Kang, 2002) etc, whereas a few of these are associated with examining the effect of material behaviour like cyclic hardenability and cyclic softenability (Hassan, 1994a; Kang, 2005a). Interestingly, almost all the earlier investigations attempt to provide explanations with the consideration of mechanics of materials; the micro-mechanism of ratcheting viz. variations in material's inherent dislocation substructure due to ratcheting deformation have not been examined systematically. In this investigation, ratcheting behaviour of various metallic systems has been examined in order to acquire knowledge related to variations in their micro-mechanisms.

Existing reports suggest that accumulation of strain during ratcheting is function of the nature of the material of interest. Ratcheting deformation appears to be sub-microscopically related to the mobility of dislocations during the cyclic loading (Feaugas, 2003; Gaudin, 2004). Therefore it can be hypothesized that metals with different crystal structures and/or stacking fault energies should lead to different ratcheting behaviour. With this motivation, it is aimed in this investigation to examine ratcheting behaviour of materials with different crystal structures and/or stacking fault energies only under asymmetric stress-controlled cyclic loading tests because dislocation flow is dependent on slip systems of various crystal structures as well as on their stacking fault energies. The materials selected in this investigation are limited to only predominantly single phase materials, having 'body centre cubic' and 'face centre cubic' crystal structures. Further, variation in the dislocation sub-structure during ratcheting deformation is expected to alter the mechanical properties of the materials being investigated. The alteration of mechanical properties of materials subjected to controlled ratcheting deformation has not been suitably examined in the earlier investigations. The present study also attempts to address this issue pertaining to the variation in mechanical properties of the selected systems subjected to certain number of ratcheting cycles. The materials that can be considered to fulfill the above aims can be numerous, but considering the limitation of the time frame for this investigation, a few commercial materials have been selected considering the possible importance of ratcheting in these systems.

Stainless steel of AISI 304LN grade is extensively used in primary heat transport piping systems of advanced heavy water reactors of nuclear power plants, for which ratcheting is considered as an important deformation mechanism; the integrity of structural components subjected to seismic events is currently being considered as one of the critical issues in the design of nuclear power plants. The load fluctuations during seismic activity are usually random in nature, which eventually exceed the elastic limit of the materials being used. As a consequence strain accumulation takes place in the components, and subsequently leads to premature failure. In order to incorporate seismic factors in design, information related to the extent of strain accumulation in the plastic regime under stress controlled cyclic loading conditions must be acquired in order to achieve better integrity of components operated under seismic loading conditions. Further the structure of austenitic stainless steel is known to be metastable up on deformation, which transforms from austenite to martensite. But investigations related to both microstructural and substructural variations during ratcheting and its influence on strain accumulation during ratcheting are not available in the literature; only a single group of researchers have reported some substructural variation during ratcheting (Gaudin and Feaugas, 2004). Hence results pertaining to investigations on the ratcheting behaviour of AISI 304LN stainless steel should be of immense interest to design engineers involved with nuclear power plants.

Interstitial free (IF) steels are now being extensively used in automobile industries for manufacturing different parts of car, car body etc. due to its superior formability. It can be noted that the components of a car must go through different amplitudes of cyclic loading in their service, which may be of symmetric or asymmetric type. It is therefore a critical issue and emphasis must be given to understand ratcheting and the consequent deformation behaviour of IF steels. It is known that plastic strain gets accumulated during ratcheting and thus it is expected to cause variations in materials' post-ratcheting properties. But, this expected phenomenon has not been systematically examined so far especially for IF steel. Hence attempts should be made to understand ratcheting and post-ratcheting tensile behaviour of IF steel. Aluminum alloys are extensively used in aerospace applications, and therefore one has to be concerned about the fatigue behaviour of aluminum alloys. In addition, aluminum based materials possess high stacking fault energy in comparison to AISI 304LN stainless steel or IF steel; so it will be a suitable system to reveal the role of stacking fault energy on ratcheting phenomenon. The difference in stacking fault energy between aluminum and stainless steel is wide. A system with magnitude of stacking fault energy in between that of stainless steel, IF steel and aluminum alloy would be of interest to examine the effect of stacking fault energy on ratcheting behaviour. Commercial brass is such a system which has stacking fault energy in between stainless steel and aluminum alloy having the same crystal structure. Hence, it would be of interest to examine ratcheting behaviour of all the above-mentioned materials to understand and to generalize the influence stacking fault energy on ratcheting behaviour of predominantly single phase materials.

In summary, the objectives of this investigation encompass studies on the nature of accumulation of ratcheting strain in metallic materials, supplemented by suitable characterizations of their substructural and microstructural features as well as to understand their effect on mechanical properties of a few selected materials.

1.1 Objectives

The major objectives and the pertinent work-plan to fulfill these can be broadly summarized as:

(I) To characterize microstructures and to determine related mechanical properties of the selected materials:

This part consists of (a) chemical analyses of the selected materials, (b) microstructural characterization of the materials, (c) measurement of grain size and (d) determination of their hardness and tensile properties at ambient temperature.

(II) To study the nature of strain accumulation due to ratcheting in the selected metallic materials

The major experiments to fulfill this objective are (a) investigations related to asymmetric cyclic loading tests under various combinations of stress amplitude and mean stress in order to examine the nature of accumulation of ratcheting strain at ambient temperature, (b) examination of the micro mechanisms for the accumulation of ratcheting strain through TEM studies of the sub-structural changes occurring in the materials due to asymmetric cyclic loading.

(III) To examine the variation of post-ratcheting tensile properties

The simple experiments to accomplish this objective are tensile tests of ratcheted samples of Al alloy, IF steel and brass. Post-ratcheting tensile tests have been done after 100 cycles of ratcheting deformation.

The thesis has been structured into eight chapters. The significance of the problem and the motivation behind this investigation are briefed in **Chapter-1**. Some pertinent literature background related to the current investigation has been presented in

Chapter-2. **Chapter-3** consists of characterization of the investigated materials. **Chapter-4** to **Chapter-7** include the results and discussion corresponding to the second and third objectives. An overview of the conclusions derived from this investigation has been summarized briefly in **Chapter-8** together with some proposed future work related to this area. All references cited throughout the dissertation have been compiled at the end of **Chapter-8**. Some relevant background about fatigue of materials, detailed information related to chronological development of studies in ratcheting, some typical hysteresis loops generated from ratcheting experiments for AISI 304LN stainless steel and interstitial free steel and some evidences of microvoid coalescence during tensile testing of the investigated α-brass and IF steel are compiled in **Appendix 1, Appendix 2, Appendix 3** and **Appendix 4** respectively.

DO NOT PRINT THIS PAGE

DO NOT PRINT THIS PAGE

DO NOT PRINT THIS PAGE

DO NOT PRINT THIS PAGE

DO NOT PRINT THIS PAGE