CHAPTER ONE

1.1 BACKGROUND AND JUSTIFICATION

Modern technological progress demands the use of materials at increasingly higher temperatures. One of the critical factors in considering such applications is creep behaviour.

The successful introduction of advanced high performance materials for aero engines, steam turbines and chemical plants offers the prospect of improved thrust to weight ratios, higher operating temperatures and greater fuel efficiency. However, for critical applications, safety and reliable component integrity are paramount. Yet, before such materials can be considered for applications requiring component lives of many thousands of hours, their long term behaviour under load at elevated temperatures must be assessed and understood: Major cause for concern is creep or creep rupture.

Creep is defined as time dependent strain occurring under a stress which is lower than the yield point. As the temperature increases, the strength of most materials decreases and elongation may continue for a long time before fracture occurs. The temperature above which continuing slow deformation can be observed differs in different materials. The continuous plastic flow of a material during creep can eventually result in large plastic deformations and significant modification to the microstructure of the material, and may terminate in fracture by creep rupture.

Existing parametric techniques needed to predict reliable long term creep properties are mostly complex, time consuming and expensive. For many applications, it may be useful to be able to estimate the creep properties of a material from simpler testing procedures such as tensile tests, which are relatively simple, cost effective and less time consuming compared to conventional creep tests. Tensile tests would be most useful where there is a need to test many alloys where only limited facilities are available.

The high temperature strength of materials and their deformation at elevated temperatures are affected by several factors. Dislocation may move out of their glide planes by thermally activated cross slip, since the mobility of atoms and the equilibrium concentration of vacancies increase with temperature. Diffusion controlled processes become more important at higher temperatures. The mobility of dislocations is thus increased, because they can climb more easily at a higher temperature. New deformation mechanism comes into play with the operation of different slip systems at the grain boundaries.

Fundamentally, the rate controlling mechanism of creep deformation at low temperatures does not, however, differ from that of normal plastic deformation, e.g., as observed during tensile testing[1]. In both cases all the strain is due to thermally activated deformation, the only difference being that the activation is stress assisted to a much greater extent during a regular tensile test at ambient temperatures. Recovery causes reductions in strain hardening, whereas the glide process concurrently tends to increase the strain hardening.

In polycrystalline solids a number of mechanisms in creep deformation and fracture often compete with one another, complicating the ability to predict creep. Among these, the principal mechanisms for fracture are void growth and coalescence and, in the case of high strength alloys, microstructure degradation such as precipitates coarsening. The three major deformation mechanisms are; plasticity controlled by glide of dislocations through an obstacle field, power law creep controlled by climb of dislocations over obstacles and diffusion creep under the influence of a stress-induced chemical potential difference[2]. For some metals at relatively high stresses and low temperatures, the rate controlling mechanism is often regarded as dislocation glide through an obstacle field, which may be provided by forest dislocations or precipitates. At higher temperatures and lower stresses, the rate controlling process becomes dislocation climb rather than glide. At intermediate stress and temperature, conditions between the glide (plasticity) and climb (power law creep) exist. This intermediate behaviour is known as power law breakdown. Power law breakdown is usually described by empirical equations or may be described by a combination of glide and power law equations.

In low alloy steels the major mechanism responsible for microstructure degradation is coarsening of the carbide precipitates[3-4]. The mechanism of solute hardening presents some problems. An extension of the precipitation-hardening model to individual solute atoms may, at best, apply to very dilute solutions when only interstitial solutes cause any appreciable strengthening. Randomly dispersed substitution solute atoms do not act as discrete obstacles when they are in concentrated solution, but interact with dislocations cooperatively[5]. For the evaluation of kinetics in alloy steels where complex structures of carbide precipitates and dislocation tangles as a result of the quenching process, recovery could be attributed both to carbide growth and to tangled dislocations re-arrangement and annihilation.

Some work has been done on the subject of unified constitutional theory describing the plastic deformation of metals and alloys with each mechanism of deformation described by flow kinetics and evolution kinetics[6]. The flow stress is ascribed to be a function of the temperature, deformation rate, and a parameter, which characterises the mechanical structure of the material. The structure parameter corresponds to a certain configuration of dislocation structure and determines the mechanical state of the materials. However, most studies on the mechanical behaviour of precipitate-hardened alloys have been concerned with deformation behaviour under steady state conditions usually using creep tests. The work hardening of such materials beyond the yield point where the steady state behaviour cannot be assumed has not been studied to such an extent. Furthermore, most work has focused on theoretical issues with little work been done on the practical aspects. An example of extensive practical work involves predicting long-term creep from short-term creep results using extrapolation techniques involving extensive experimental data. Cases under review include the theta projection[7] and the damage mechanics approach[8]. There are theories that attempt to predict creep results from tensile tests but in most cases require information on transient responses for their application[9-10]. Such measurement involving flow stress changes due to sudden changes in strain rate or temperature tend to be difficult to perform and can lead to ambiguous results, since they are subject to machine stiffness and response characteristics. One of the possible reasons for requiring such a result is that recovery rates tend to be accelerated for material under stress as compared to unstressed material[12].

Low alloy ferritic steels of the type Cr-Mo-V used in this study are used extensively throughout power generating plant for steam chest, casings, covers, boiler tubes etc. The operating temperature range of such components is fairly high. Generally, these alloys are in hardened state and tertiary creep, controlled by micro structural degradation predominate. This is due to the degradation of the microstructure produced during the initial hardening treatment and may take the form of precipitate coarsening and or recovery of forest dislocation structures. For such alloys, it should be simpler to describe creep than in the case of pure metals where primary and secondary, as well as tertiary creep may contribute significantly to behaviour. Thus it may be useful to be able to estimate creep properties of such alloys from simpler testing methods such as tensile tests. However, it is well established that under the influence of an applied stress, processes such as precipitate coarsening tend to be accelerated. In the case of alloy steel, it has been shown that hardness tests carried out on interrupted creep specimens were softer than on unstressed material under similar temperature/time conditions[11].

It is desirable to carry out tensile tests at different temperatures and strain rates in order to determine material parameters for use in kinetic equations describing deformation. Furthermore, tests on furnace-aged specimens will be carried out to quantify softening due to material degradation and formulate evolution expression. This, together with the kinetic equation will be used to determine creep curves.

1.2 OBJECTIVES

The scope of the study was to develop a unified approach describing tensile and creep behaviour with the aim of trying to predict creep behaviour from the fewest possible tensile and creep results using flow and evolution kinetics. The specific objectives where:

- To characterise the kinetic model approach to give an estimate of `rupture life and the shape of the creep curve when tertiary creep predominates.

- To determine the mechanical behaviour and the influence of recovery and other softening mechanisms on creep.

1.3 THESIS OUTLOOK

The report comprises six chapters. The first chapter introduces the topic and the justification for the project. The objectives of the project are also stated with a brief theory on what has already been done by other researchers in line with the stated objectives.

In Chapter Two, a general theory of the topic is introduced and discussed. An integrated approach is assumed highlighting the various mechanisms in play and their corresponding equations under specific conditions. Four empirical approaches are outlined and discussed, emphasising their merits and demerits with respect to the present study.

Chapter Three outlines the experiments conducted and the equipment used for each test.

Chapter four deals with various tests conducted and data manipulation techniques adopted to analyse the result.

Chapter five deals mainly with data analysis. Modelling techniques adopted are outlined and models discussed in line with the data acquired from the experiments. An attempt is made to use data obtained in this study in the internal stress model.

Chapter Six deals with the discussion and conclusion.