

CHAPTER SIX

6.1 DISCUSSION

Creep in polycrystalline materials has many mechanisms defining it. Key mechanisms relevant to this study have been outlined and dealt with in the above sections. The basic processes of creep occur at the atomic and macroscopic levels; which become relevant in the materials research and development. At the macroscopic level the solid is considered as a continuum with mechanistic and continuum mechanics model developed. Prominent on the list are the deformation and evolution kinetics. The constitutive law encompasses all; providing an economic means for the experience of relations among strain, stress, temperature, the characteristic material quantities, and their variations with deformation, temperature and time. A physically based constitutive law was sought that can be expressed in practical engineering terms, economical to test, able to use materials data banks and can be processed with computer aided programmes. The kinetics fully satisfies these demands for time and temperature dependent plastic deformation processes.

The thrust of the study was to evaluate the correlation of creep and tensile data of a low alloy Steel. Different sets of test were conducted to determine relevant material parameters. Tensile tests at different temperatures and strain rates were used to determine materials parameters in kinetic equations describing deformation. Test of furnace aged specimens were used to quantify softening due to material degradation and to formulate a structure evolution expression. This, together with the kinetic equation was used to determine creep curves.

In this study four other methods are discussed giving their merits and demerits. Three are found not to be applicable to this study, mainly because of the non-duplicability of data and as a result of differences in test requirements and deformation mechanisms. Furthermore, some of the approaches are based on extrapolation techniques which are

predominately based on mathematical methods or time temperature parameter. Techniques like the θ -projection might be suitable for alloys with long term stability. However, ferritic steels are unstable during long term service.

6.1.1 Plastic Deformation

In describing the plastic deformation, many empirical and semi-empirical relations are used.

The modified equation by Dorn was used to determine the material parameters and to predict flow characteristics. Two sets of mechanisms were observed (see Figure 4.1). At low temperature and high stress (above 550MPa) dislocation by glide mechanism was investigated. At higher temperatures and low stress (below 550MPa), some form of power law creep was observed. Glide mechanism was investigated using equation (5.33), Material parameters σ^* , n and activation volume v , were calculated using equation (5.33). Value of σ^* used was the same for both plastic deformation and the softening kinetics. σ^* was assumed to be constant in both instances.

Micro-analysis of the test specimen showed no visible sign of coarsening. This is indicative of the fact that at the test temperature and during the time allowed for the test, dislocation climb was the major recovery mechanism. At lower temperatures and stress, creep deformation should occur in principle. The creep rate, however, is so small that it is beyond the resolution of the creep machine.

It can be stated quite generally that when viewed critically, ideal steady state creep is rarely observed, as has been emphasized repeatedly³. Nonetheless, and depending on how significant the deviations from steady state creep are, it is common practice to assume for the sake of simplicity that in such cases the creep behaviour can be described

approximately in terms common creep rate instead of steady state creep rate. The creep rates calculated from the creep curves were minimum creep rates for creep curves for the different sets of test precisely for the above reasons.

The value of activation energy observed for creep for this alloy is in line with the processes which could be related to self diffusion. Measurement of activation energy in the power law breakdown regime often gives values which exceed that of self diffusion. This is some times taken to indicate that the recovery process differs from that of climb-controlled creep. Some of the difference, however, may reflect the temperature dependence of the shear modulus, which has a greater effect when the stress dependence is greater (in the exponential region). In equation (5.35), the use of only two parameters n and α to describe three quantities is not in itself satisfactory; n describes the power law, α prescribes the stress level at which the power law breakdown occurs, and n and α describe the strength of the exponential stress dependence. α was taken as 10 in this study to give a straight line plot. Lacking any physical model, it must be considered fortuitous that any set of n and α can correctly describe the behaviour over a wide range of stresses.

6.1.2 Recovery kinetics

The rate of recovery increases with increasing temperature, as in other thermally activated processes. Finding an activation energy for a given process may throw light on the mechanism or mechanisms by which the process occurs. In some instances it has been found experimentally that several activation energies apply within the recovery range of a single specimen, which implies that different processes of mechanism predominate in different parts of the range.

A set of tests was carried out on specimens that had been furnace aged at different temperatures for various time periods for use in an expression

describing structural evolution. Creep curves were determined numerically by combining kinetic and structure evolution equations. Equation (5.32) was most suited.

The kinetics of recovery as reviewed by Bever¹⁰⁶ pointed out that any simple formulation of the rate of recovery is at best an approximation. Since the cold worked state is complex and non-uniform on a fine scale, a single parameter cannot describe this state adequately, and any rate equation in terms of a single parameter is unlikely to represent the kinetics of recovery for more than a restricted range.

The recovery process is thought to be the growth of the dislocation network to generate link lengths of sufficient length to act as dislocation sources¹⁰⁶ and the rate controlling processes is the growth of the overall network¹⁰⁸. General for this class of alloys the recovery process occurs under a stress $(\sigma_a - \sigma_o)$. In this study the recovery term is associated with $\frac{J}{\sigma_o}$, the material state stress. The creep rate and recovery have similar stress dependence with the stress and temperature dependence similar to that predicted by recovery theory. A much needed comparative analysis of data of this work with studies utilising internal stress models have not been possible, mainly because of the unavailability of data on internal stress values. However, if it is assumed that changes in internal stress were negligible for the duration of the test, the tensile data could be used to determine creep curves of a similar nature as the ones arrived at in this study especially during the secondary creep rate when the internal stress would be expected to be nearly equal to the applied stress. However, for this class of material, it is the tertiary creep that is extensive and It can be stated as a rule that when viewed critically, ideal steady state creep is rarely observed, as has been emphasized repeatedly.³ Therefore any result obtained would be of limited use.

6.2 CONCLUSION

To date there have been several suggestions for the rationalization of creep data. These proposals have often evolved from empirical equations for the stress dependence of secondary or steady state creep rate.

It has been shown that reasonably good estimates of the creep behaviour of the low alloy steel used in this investigation in which tertiary creep dominates can be calculated from tensile yield stress values. The steady state creep rate and the recovery rate have similar stress dependencies, as observed by the researchers discussed in a previous section of this thesis. The scheme is based on the Dorn equation which has been modified to give equations (5.27), (5.33) and (5.37). These equations have many advantages for the engineer since:-

- test methods used are simpler and are cost effective and that data manipulation is simpler and quicker,
- simple architecture of the equations with a relatively small number of parameters involved,
- simple relation of parameters to the microscopic properties or processes and
- clear recipes for parameters evaluation, which, in combination with an evaluation strategy, can substantially simplify parameter identification.
- equations contain parameters that can be measured easily in the laboratory
- equations can be used immediately to simplify the task of evaluating new engineering materials with some modifications

- approach gives the theorist a different vantage point from which to view deformation processes

Furthermore, existing empirical methods by the Estrin-Mecking, Damage Mechanics, θ - projection are unable to provide a simple approach that can describe a complete creep curve with ease. θ -projection and Damage Mechanics generally involve extensive practical work involving considerable data to predict long-term creep from short-term creep results using extrapolation techniques. In many cases these theories require information on transient responses for their application⁹⁻¹⁰. 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 material¹².

The Internal Stress Model on the other hand could be used in this class of alloy used if the following assumptions hold:-

- tests durations are short with no change in macrostructure, especially during the secondary creep rate.
- tests conducted at high stress, low temperature regimes.

Thus it could be assumed that change in internal stress during the test period is negligible, with the rate determining event in general being similar and the creep deformation mechanisms been assumed to be essentially the same. In general, the deformation mechanisms are essentially the same for a range of microstructures from pure metals to complex alloys⁹³⁻⁹⁵. The method should be applicable to

other materials provided that the three assumptions made during this analysis apply.

- First, the power law creep/breakdown equation can be normalized with reference to a material state stress, which varies with age, rather than normalizing with respect to the modulus of elasticity as is usually the case for describing steady state deformation.
- Secondly, the material state stress is the same in equations describing deformation by different mechanisms in this case glide and climb.
- Thirdly, it was assumed the acceleration of recovery processes can be accounted for by adding the applied stress to the internal state stress in the equation describing structural evolution.