5. Creep and Viscoplasticity

In this chapter we consider time-dependent inelastic deformations of isotropic metals and include thermal effects. We consider creep, thermoplastic and viscoplastic models. After the introduction in Section 5.1, we give the fundamental characteristics of creep and thermoplastic models in Section 5.2 and of a viscoplastic model in Section 5.3.

In Sections 5.4 and 5.5 we develop computational procedures for stress integration for the material models described in Sections 5.2 and 5.3. The computational algorithms are implicit and represent applications of the governing parameter method of Section 4.2. General 3-D deformation conditions are considered, as well as the special conditions of shell, beam and pipe deformations. A number of solved examples show the computed material response in typical engineering conditions.

5.1 Introduction

In Chapters 3 and 4 we considered plastic deformations of metals; that is time-independent inelastic deformations. The main assumption was that the deformation occurs *instantaneously* with the application of the load. The load (strain) level was the measure of the external action on the material, and time was a fictitious parameter. However, it is known from experiments that after the initial plastic deformations of a material, the *plastic flow can continue* with the development of time-dependent inelastic strains. These effects are to some degree present in many materials, but they may or may not be significant, depending on the physical conditions under which the material is loaded.

It is considered that there are generally two types of time-dependent (mathematical model) inelastic deformations, *creep* and *viscoplastic deformations*. These two types of inelastic deformations are governed by different constitutive laws. However, some materials, for example metals at elevated temperatures, exhibit creep and viscoplastic phenomena simultaneously. It is not possible to experimentally distinguish between these two types of inelastic deformations, and their separation has been an analytical convenience.

Both creep and viscoplastic deformations are important in the cases of long-term material loading and are pronounced at elevated temperatures.

Many structural parts are exposed to high temperatures and loading over long time intervals (e.g., elements of power plants, gas turbines, pressure vessels, etc.). It is necessary to formulate material models to adequately describe the material characteristics in these conditions, and to have numerical procedures to predict the material response.

There is, however, a fundamental difference in the character between creep and viscoplastic flows. Namely, under constant stresses (above a level that depends on the material and temperature), creep deformations *progress* while viscoplastic deformations *diminish* with time. The creep models assume that the creep deformations increase with time leading to a possible material rupture. On the other hand, the viscoplastic models are based on an overstress assumption, according to which the stress point in the stress space is outside the yield surface and moves toward the yield surface with time. The viscoplastic flow continues until the stress point reaches the yield surface. A stress relaxation occurs in both types of deformations and has the same character. Note that a viscoplastic constitutive law may be reduced to a creep law, if the yield stress is taken to be zero (see Section 5.3.2).

We will describe these two types of inelastic deformations in the next two sections. The constitutive descriptions are macroscopic, phenomenological in character, as for the description of the time independent plastic deformations in Chapter 3.

The methods of analysis that include thermo-elastic-plastic and creep deformations were first of an analytical type and were applicable to simple deformation and loading conditions, Finnie and Heller (1959); Penny and Marriott (1971); Odquist (1974); Kraus (1980). The traditional creep models have been further modified by introducing anisotropic creep behavior, based on the potential theory of creep, Brown (1970); Rees (1983). Later, with the progress of numerical methods, especially the finite element method, numerical procedures have been developed that can be used to realistically predict the response of very complex structures (Bathe 1999, 2001a). Included in these response predictions are also phenomena related to damage, fatigue due to cyclic loading, and fracture, which, however, we do not consider in this book.

5.2 Creep and Thermoplastic Material Models

In this section we first describe some basic temperature effects on material behavior, and then introduce commonly used material models for creep and thermoplastic deformations of metals (e.g., Penny and Marriott 1971; Kraus 1980).

Figure 5.2.1 shows schematically the influence of temperature on a uniaxial stress-strain relation. It can be seen that Young's modulus and the yield stress of the material *decrease* with the temperature *increase*. A detailed de-