ME102: Subunit 3.3.5: Creep Deformation

Creep is the slow, permanent deformation that occurs in materials under small loads. Hence, it is not observed in typical short-duration laboratory tests, but can be an important factor in the longevity of equipment and specimens made of many types of materials. Creep can occur in all materials, but is much more dramatic near the melting point of a given material. The ratio of the T/T_m, where T is the ambient temperature and Tm is the melting point of the material (both expressed on an absolute temperature scale) is called the *homologous temperature*. Significant creep can occur for homologous temperatures of 0.3.

The main problem posed by creep is that materials may fail when exposed to long-term stress value that is much less than that required for short-term failure. In other words, some things do not hurt if they happen for just a little while, but over the long term they may cause great damage.

The time over which deformation occurs is usually separated into three regimes, as illustrated in the figure below, which plots accumulated strain versus time for a constant stress.

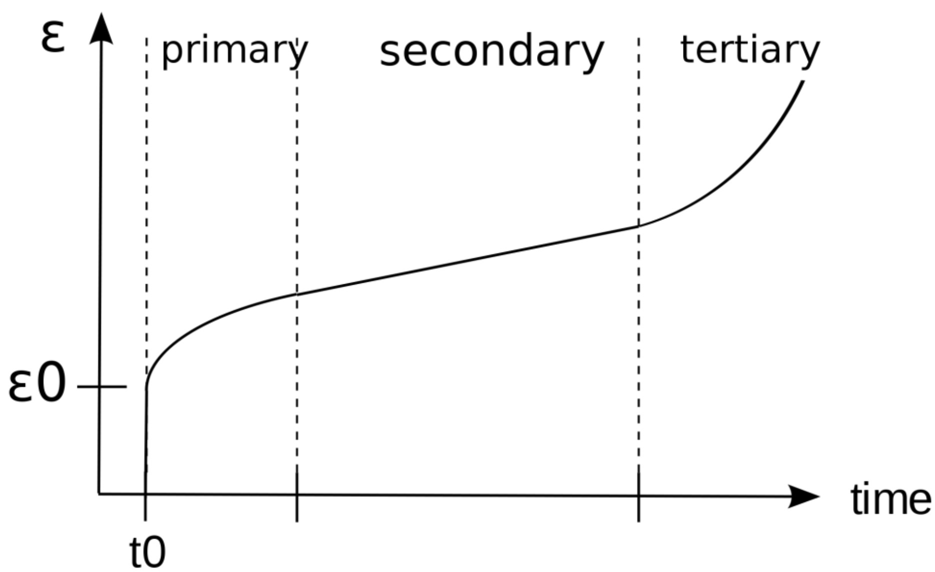

Figure 1. Accumulated strain versus time. Figure submitted to Wikimedia Commons by **Strafpeloton2** under the **Creative Commons** **CC0 1.0 Universal Public Domain Dedication**. The original version is available **here**.

A key feature to note is that during the secondary time period, the strain increases at an almost constant rate; hence, this period is generally the simplest and best understood. The primary period involves initial elastic deformation and work hardening. In the tertiary period, material failure eventually occurs.

The mechanisms by which creep occurs generally fall into two categories: diffusion creep and dislocation creep. Both involve the random, thermal motion of features in the material assisted by applied stress. They differ by the types of motions that they consider. Diffusion involves the random, thermally activated motions of particles (for example, atoms or molecules). Microstructure in the material—for example, cracks, grains, or holes—modify the types of motions that take place and provide sensitivity to applied stress.

These two mechanisms for creep allow some intuitive grasp of the observed temperature and stress-dependence of the creep rate ($d\varepsilon/dt$). The temperature dependence is generally found to follow an Arrhenius expression ($d\varepsilon/dt = c \exp(-E/RT)$, where c is a constant, E is an activation energy, R is the gas constant, and T is absolute temperature). The stress (σ) dependence of creep rate is often found to follow a power-law expression like $d\varepsilon/dt = c\,\sigma^n$, where c is another constant and n is usually greater than 1 and less than 10, depending upon creep mechanism. Creep rate is also observed to be inversely proportional to d^b, where d is the grain size of the material and b is another exponent. A general creep-rate equation summarizes the above observations and can be written as

$$\frac{d\varepsilon}{dt} = \frac{C\sigma^n}{d^b}\exp\left(-\frac{E}{RT}\right)$$

This sort of equation is useful for understanding and modeling the behavior of a particular material. The parameters in the equation are generally found from experiments with a piece of the material at several different known stresses and temperatures. You will learn more about estimating the parameters in such equations in the Saylor Foundation's ME205: Numerical Methods for Engineers and ME301: Measurement & Experimentation Laboratory.