Creep Lec 5

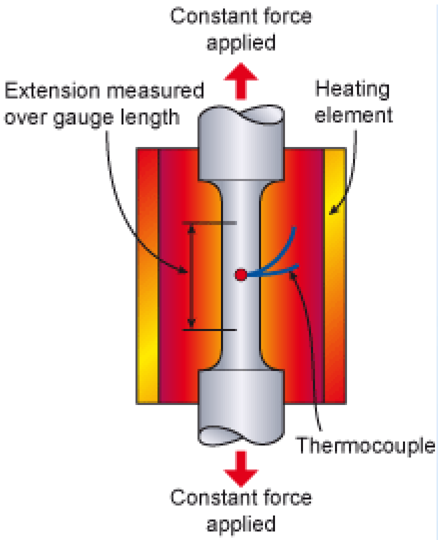
Materials are often placed in service at **elevated temperatures** and exposed to **static mechanical stresses** (e.g., turbine rotors in jet engines and steam generators that experience centrifugal stresses, and high-pressure steam lines).

Deformation under such circumstances is termed **creep**. Defined as ***the time-dependent and permanent deformation of materials when subjected to a constant load or stress***, creep is normally an **undesirable phenomenon** and is often the limiting factor in the **lifetime of a part**.

It is observed in all materials types; for metals it becomes important only for temperatures greater than the recrystallization temperature about **0.4Tm** (Tm absolute melting temperature). Amorphous polymers, which include plastics and rubbers, are especially sensitive to creep deformation.

Creep Behavior

A typical **creep test** consists of subjecting a specimen to a **constant load** or stress while maintaining the **temperature constant**; deformation or strain is **measured and plotted as a function of elapsed time**. Most tests are the constant-load type, which yield information of an engineering nature; constant-stress tests are employed to provide a better understanding of the mechanisms of creep. Figure below is a schematic representation of the typical constant-load creep behavior of metals.



Upon application of the load there is an instantaneous deformation, which is totally elastic. The resulting creep curve consists of **three regions**, each of which has its own distinctive strain–time feature. **Primary or transient creep occurs first**, represented by a continuously decreasing creep rate; that is, the slope of the curve diminishes with time. This suggests that the material is experiencing an **increase in creep resistance** or **strain hardening**, *deformation becomes more difficult as the material is strained*.

For **secondary creep**, sometimes termed **steady-state creep**, the rate is constant; that is, the plot becomes linear. This is often the stage of creep that is of the **longest duration**. The constancy of creep rate is explained on the basis of a balance between the competing processes of **strain hardening** and **recovery**. Recovery being the process whereby a material becomes softer and retains its ability to experience deformation.

Finally, for **tertiary creep**, there is an acceleration of the rate and ultimate failure. This failure is frequently termed rupture and results from microstructural and/or metallurgical changes; for example, grain **boundary separation**, and the formation of **internal cracks**, **cavities**, and **voids**. Also, for tensile loads, a **neck** may form at some point within the deformation region. These all lead to a decrease in the effective cross-sectional area and an increase in strain rate.

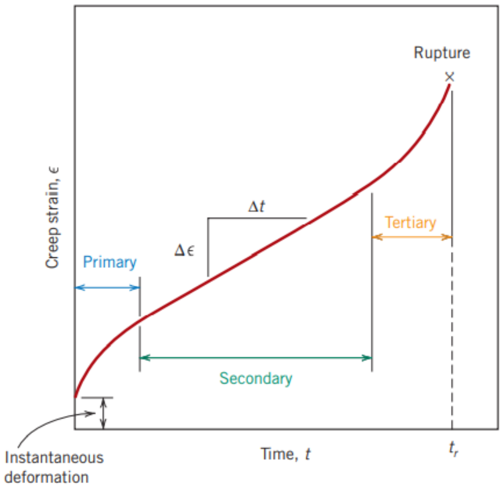


Figure 8.28 Typical creep curve of strain versus time at constant load and constant elevated temperature. The minimum creep rate $\Delta\epsilon/\Delta t$ is the slope of the linear segment in the secondary region. Rupture lifetime t_r is the total time to rupture.

For metallic materials, most creep tests are conducted in uniaxial tension using a specimen having the same geometry as for tensile tests. On the other hand, **uniaxial compression tests are more appropriate for brittle**

materials; these provide a better measure of the fundamental creep properties in as much as there is no stress amplification and crack propagation, as with tensile loads. Compressive test specimens are usually right cylinders or parallelepipeds having length-to-diameter ratios ranging from about 2 to 4.

Possibly the most important parameter from a creep test is the slope of the secondary portion of the creep curve, this is often called the minimum or **steady-state creep rate.** It is the engineering design parameter that is considered for long-life applications, such as a nuclear power plant component that is **scheduled to operate for several decades**, and when failure or too much strain are not options.

On the other hand, for many relatively short-life creep situations (e.g., turbine blades in military aircraft and rocket motor nozzles), time to rupture, or the rupture lifetime is the dominant design consideration.

Thus, a knowledge of these creep characteristics of a material allows the design engineer to ascertain its **suitability for a specific application**.

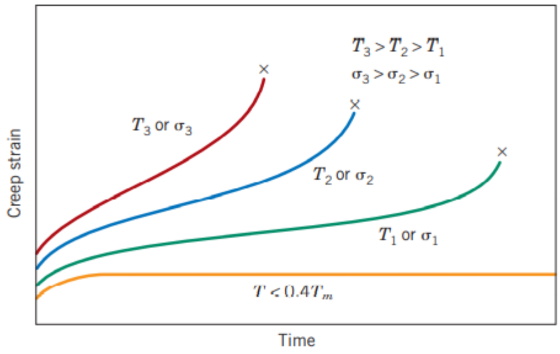


Figure 8.29 Influence of stress σ and temperature T on creep behavior.

Stress and Temperature Effects

Both **temperature** and the level of the **applied stress** influence the creep characteristics. At a temperature substantially below 0.4Tm, and after the initial deformation, the strain is virtually independent of time. With either ***increasing stress or temperature***, the following will be noted:

(1) the instantaneous strain at the time of stress application increases,

(2) the steady-state creep rate is increased,

(3) the rupture lifetime is decreased.

The results of **creep rupture tests** are most commonly presented as the logarithm of stress versus the logarithm of rupture lifetime. For some alloys and over relatively large stress ranges, nonlinearity in these curves is observed. Empirical relationships have been developed in which the steady-state creep rate as a function of stress and temperature is expressed. Its dependence on stress can be written

$$\dot{\epsilon}_s = K_1 \sigma^n$$

here K_1 and n are material constants. Clearly, one or two straight line segments are drawn at each temperature, now, when the influence of temperature is included,

$$\dot{\epsilon}_s = K_2 \sigma^n \exp\left(-\frac{Q_c}{RT}\right)$$

where K_2 and Qc are constants; Qc is termed the activation energy for creep.

Several theoretical **mechanisms** have been proposed to explain the creep behavior for various materials; these mechanisms involve **stress-induced vacancy diffusion, grain boundary diffusion, dislocation motion, and grain boundary sliding**.

Alloys for High-Temperature applications

Several factors affect the creep characteristics of metals. These include:

1. melting temperature,
2. elastic modulus,
3. grain size.

In general, the higher the melting temperature, the greater the elastic modulus, and the **larger the grain size**, the **better a material's resistance to creep.** Relative to grain size, smaller grains permit more grain boundary sliding, which results in higher creep rates. This effect may be contrasted to the influence of grain size on the mechanical behavior at low temperatures. Stainless steels and the super-alloys are especially resistant to creep and are commonly employed in high-temperature service applications.

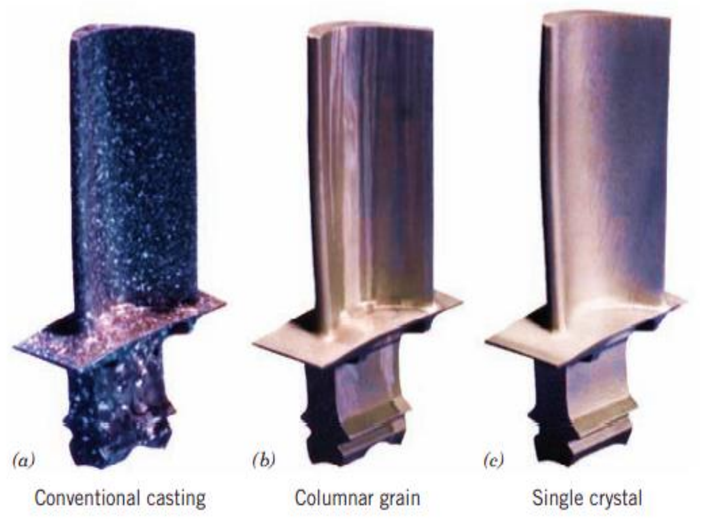


Figure 8.33 (*a*) Polycrystalline turbine blade that was produced by a conventional casting technique. High-temperature creep resistance is improved as a result of an oriented columnar grain structure (*b*) produced by a sophisticated directional solidification technique. Creep resistance is further enhanced when single-crystal blades (*c*) are used. (Courtesy of Pratt & Whitney.)

The creep resistance of the superalloys is enhanced by **solid-solution alloying** and also by the formation of precipitate phases. In addition, advanced processing techniques have been utilized; one such technique is directional solidification, which produces either highly elongated grains or single-crystal components.