$$V_k = \sigma \left(\frac{1}{C} \right)^{\frac{1}{p}}$$

(19.104.12)

$$V_m = \frac{1}{p}$$

Material Model 106: Elastic Viscoplastic Thermal

If LCSS is not given any value the uniaxial stress-strain curve has the form

$$\sigma(\varepsilon_{eff}^p) = \sigma_0 + Q_{r1}(1 - \exp(-C_{r1}\varepsilon_{eff}^p)) + Q_{r2}(1 - \exp(-C_{r2}\varepsilon_{eff}^p)) \\ + Q_{\chi 1}(1 - \exp(-C_{\chi 1}\varepsilon_{eff}^p)) + Q_{\chi 2}(1 - \exp(-C_{\chi 2}\varepsilon_{eff}^p)) \qquad (19.106.1)$$

Viscous effects are accounted for using the Cowper-Symonds model, which, scales the yield stress with the factor:

$$1 + \left(\frac{\dot{\varepsilon}_{eff}^p}{C} \right)^{1/p} \qquad (19.106.2)$$

Material Model 110: Johnson-Holmquist Ceramic Model

The Johnson-Holmquist plasticity damage model is useful for modeling ceramics, glass and other brittle materials. A more detailed description can be found in a paper by Johnson and Holmquist [1993].

The equivalent stress for a ceramic-type material is given in terms of the damage parameter *D* by

$$\sigma^* = \sigma_i^* - D(\sigma_i^* - \sigma_f^*) \qquad (19.110.1)$$

Here,

$$\sigma_i^* = a(p^* + t^*)^n (1 + c \ln \dot{\varepsilon}^*) \qquad (19.110.2)$$

represents the intact, undamaged behavior. The superscript, '*', indicates a normalized quantity. The stresses are normalized by the equivalent stress at the Hugoniot elastic limit (see below), the pressures are normalized by the pressure at the Hugoniot elastic limit, and the strain rate by the reference strain rate defined in the input. In this equation *a* is the intact normalized strength parameter, *c* is the strength parameter for strain rate dependence, $\dot{\varepsilon}^*$ is the normalized plastic strain rate, and,

$$t^* = \frac{T}{phel} \qquad (19.110.3)$$

$$p^* = \frac{p}{phel} \qquad (19.110.4)$$

where T is the maximum tensile strength, *phel* is the pressure component at the Hugoniot elastic limit, and p is the pressure.

$$D = \sum \Delta \varepsilon^p / \varepsilon_f^p \qquad (19.110.5)$$

represents the accumulated damage based upon the increase in plastic strain per computational cycle and the plastic strain to fracture

$$\varepsilon_f^p = d_1 (p^* + t^*)^{d_2} \qquad (19.110.6)$$

where d_1 and d_2 are user defined input parameters. The equation:

$$\sigma_f^* = b(p^*)^m (1 + c \ln \dot{\varepsilon}^*) \le sfma \qquad (19.110.7)$$

represents the damaged behavior where b is an input parameter and, *sfma,* is the maximum normalized fracture strength. The parameter, d_1, controls the rate at which damage accumulates. If it approaches 0, full damage can occur in one time step, i.e., instantaneously. This rate parameter is also the best parameter to vary if one attempts to reproduce results generated by another finite element program.

In undamaged material, the hydrostatic pressure is given by

$$p = k_1 \mu + k_2 \mu^2 + k_3 \mu^3 \qquad (19.110.8)$$

where $\mu = \rho / \rho_0 - 1$. When damage starts to occur, there is an increase in pressure. A fraction defined in the input, between 0 and 1, of the elastic energy loss, β, is converted into hydrostatic potential energy, which results in an increase in pressure. The details of this pressure increase are given in the reference.

Given *hel* and the shear modulus, g, μ_{hel} can be found iteratively from

$$hel = k_1 \mu_{hel} + k_2 \mu_{hel}^2 + k_3 \mu_{hel}^3 + (4/3) g (\mu_{hel} /(1 + \mu_{hel}) \qquad (19.110.9)$$

and, subsequently, for normalization purposes,

$$p_{hel} = k_1 \mu_{hel} + k_2 \mu_{hel}^2 + k_3 \mu_{hel}^3 \qquad (19.110.10)$$

and

$$\sigma_{hel} = 1.5(hel - p_{hel}) \qquad (19.110.11)$$

These are calculated automatically by LS-DYNA if p_{hel} is zero on input.