$O_2 = \quad 0.144\ [6.13\ (T_2 - 298) + 2.99/2\ (10^{-3})(T_2^2 - 298^2) - 0.81/3\ (10^{-6})(T_2^3 - 298^3)]$

The sum is equal to –61,393 cal/mole, and the cubic form (Eq. 9.2.1.7) becomes

$$0 = 22.137\ T_2 + 0.00516\ T_2^2 - 5.13\ (10^{-7})\ T^3 - 68365$$

The solution to the cubic equation has three roots (determined graphically or solved numerically), one of which lies between reasonable values of 2000 to 5000°K. The graphical solution gives the explosion temperature for ANFO as 2204°K.

Detonation Pressure: The equation of state for explosive gases produced by detonations must define the temperature-pressure-volume relationships at high temperatures and pressures. Many equations of state for nonideal gas pressure calculations are proposed (Cook, 1958; Fickett and Davis, 1979; Mader, 1979; Johansson and Persson, 1970). These solutions require the use of large hydrodynamic computer codes and the knowledge of empirically derived constants from high-pressure experiments. A simple expression used to estimate pressure is the covolume equation of state:

$$P\,(V_e - \alpha) = n\,R\,T \qquad (9.2.1.9)$$

where V_e is specific volume of the explosive (inverse of ρ explosive density), T is explosion temperature in °K, n is the number of gas moles, and R is the gas constant, 82.06 cm^3-atm/mole-°K. Covolume α is a measure of the actual volume of gas molecules. Pressure is thus related to the inverse of P – α, or free volume. Experimental values of a are given by Cook (1958) as a function of ρ and approximated by,

$$\alpha = e^{-0.4\rho} \times 10^3\ \text{cm}^3/\text{kg} \qquad (9.2.1.10)$$

Example 9.2.1.8. Calculate the detonation pressure for ANFO.

Solution.

Given 1 kg of ANFO mixture,

$$n = 43.285\ \text{mole}$$
$$T = 2204\ °\text{K}$$
$$\rho = 0.85$$
$$\alpha = 711.8\ \text{cm}^3/\text{kg (from Eq. 9.2.1.9)}$$
$$V_e = (1000\ \text{g/kg})/(\rho) = 1176.5\ \text{cm}^3/\text{kg}$$

$$\text{Pressure, } P = \frac{(43.285\ \text{moles})(82.06\ \text{cm}^3\text{-atm/mole-°K})(2204°\text{K})(14.7\ \text{psi-atm})}{(1176.5\ \text{cm}^3/\text{kg} - 711.8\ \text{cm}^3/\text{kg})}$$
$$= 0.247 \times 10^6\ \text{psi (1.7 GPa)} \qquad (9.2.1.11)$$

For explosives that are not oxygen balanced such as TNT, experimental data for n are required and vary widely among experimentalists. Cook (1958) among others gives experimental data for TNT.

Example 9.2.1.9. Calculate the detonation pressure for TNT.

Solution.

Given 1 kg of TNT,

$$n = 23\ \text{moles}$$
$$T = 4100°\text{K}$$
$$\rho = 1.59$$
$$P = 1.1 \times 10^6\ \text{psi (7.57 GPa)}$$

which agrees with experimental results.

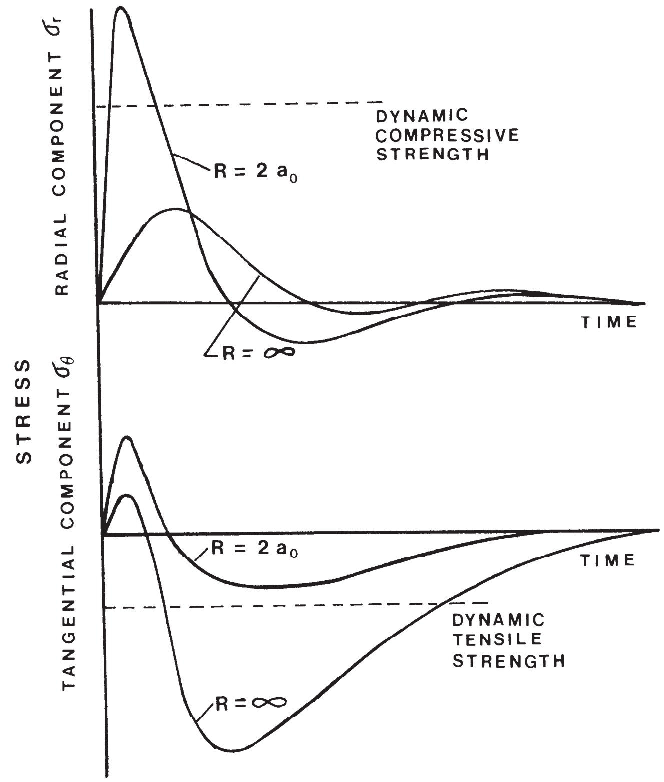

Fig. 9.2.1.6. Generalized stress vs. time for radial and tangential components of stress at two distances R from the borehole center (a_o = original borehole radius).

9.2.1.3 Blasting Practices

The use of explosives to break rock requires the proper selection of explosives and blasting devices, the careful design of borehole patterns, loading characteristics, and delay blasting sequence, and the control of ground vibration, airblast, and flyrock. Efficient blast designs produce the desired particle size distributions and placement of muckpiles for ease of rock removal and handling.

Rock Breakage Using Explosives: There are a number of theories used to describe rock fragmentation by blasting (Winzer and Ritter, 1980; Anon., 1987a). Two broad areas of breakage mechanisms include (1) the role of stress waves generated from the explosive detonation (shock) force, and (2) the role of borehole pressures created by the detonation gas products.

Effect of Stress Waves—The theoretical treatment of explosively generated stress waves is given by Kutter and Fairhurst (1971), Rinehart (1975), and Mohanty (1985). Upon detonation within a borehole, a shock wave is generated and travels into the rock, quickly decaying in peak pressure amplitude and dispersing in shape as the wave travels away from the borehole. The cylindrically divergent wave carries both a radial and tangential stress component whose stress time histories are shown, idealized, in Fig. 9.2.1.6. The response of the rock adjacent to the borehole