where τ^* is the limiting shear imposed by the shear strength of the solid as computed from the measured HEL, σ_H, and ν is Poisson's ratio for the solid. It is convenient to define a *shear strength offset*

$$\sigma^* \equiv \tfrac{4}{3}\tau^* \tag{7}$$

in a like manner to the shear stress offset σ_τ.

In this paper the high pressure region above the HEL will be examined to determine the magnitude of the *shear stress offset*, σ_τ, and its relation to the *shear strength offset*, σ^*. Previous theoretical and experimental studies have indicated the basis for two radically different relations between σ_τ and σ^*. These relations are developed for *elastic-plastic solids* and what will be called *elastic-isotropic solids*.

(b) *The elastic–plastic solid*

The theory of plasticity has been adapted to the uniaxial strain configuration in studies by Wood[9] and Fowles[10]. One result which may be extracted from this work is that under ideally plastic deformation

$$\sigma_\tau = \sigma^*, \qquad \sigma_\tau > \sigma_H; \tag{8}$$

that is, the shear stress offset is independent of pressure and equals the shear strength offset which is a fixed property of the solid. For the elastic–plastic solid the magnitude of the shear stress has no inherent effect on the properties of the solid and the solid can be characterized as having a constant shear strength.

The elastic–plastic solid has very attractive features since it is particularly simple in concept both theoretically and phenomenologically and the numerous static studies of plastic flow and deformation can be used as a guide for the shock deformation. Furthermore, the microscopic theories of dislocation motion in solids have been successful in explaining many aspects of plastic flow under static conditions and similar dislocation theories have been successfully pursued under shock loading. This provides a fundamental basis for understanding the response of solids to large anisotropic compressions and second-order effects involving small changes in σ_τ. In addition, rate effects observed in shock experiments may be described in terms of the dislocation theory.

Since the initial experimental confirmation of elastic-plastic response of aluminum by Fowles[10] in 1961, several experimental investigations have demonstrated that a number of metals respond to shock loading as elastic–plastic solids[11–18]. In addition a recent examination of the fixed point phase transition pressures measured under hydrostatic and shock conditions indicated that the elastic–plastic model correctly correlated the shock and static results for a number of metals [19]. Although numerous deviations to the elastic–plastic response of metals have been noted, such as different HEL values than predicted from static measurements[20, 21] and unloading paths[22] not predicted by elastic plastic response, it appears likely that they can be explained in terms of modifications to the basic theory.

Confirmation of the elastic plastic model is particularly gratifying since HEL values can be routinely measured experimentally and the HEL value can be used to calculate σ_τ if elastic–plastic response correctly describes the solid. Furthermore a recent survey of HEL values[20] indicates that shear strength effects are not negligible in many instances.

Unaware of the simplicity of the elastic–plastic response, crystalline quartz chooses to respond to anisotropic compressions in a radically different fashion, thereby raising questions as to the generality of the elastic–plastic response, and the calculation of σ_τ from the measured HEL values.

(c) *The elastic–isotropic solid*

Shock experiments on single crystal quartz revealed an unexpected and dramatically different response than that observed for metals. Neilson and Benedick[23] conducted experiments in which X-cut quartz was shock-loaded at high pressures and the resulting piezoelectric outputs were measured. Interpretation of these piezoelectric outputs required that quartz exhibit an unusually large HEL and a state of zero piezoelectric polarization in the high pressure region above the HEL. The piezoelectric response of quartz to isotropic compression is zero; hence, zero polarization requires $\sigma_\tau = 0$. This observation led Wackerle[24] and Fowles[25] to perform shock compression measurements on crystalline quartz which, when compared with Bridgman's hydrostatic data, showed that even though σ^* was unusually large, that $\sigma_\tau = 0$ for stresses greater than the HEL. The manner in which quartz suffers this loss of shear strength seems inexplicable within the theory of plasticity and classical dislocation mechanics. Unlike the elastic–plastic solid which has a fixed characteristic shear strength, the elastic–isotropic solid suffers a catastropic loss of shear strength when a critical shear stress is exceeded. The magnitude of the shear stress alters the shear properties of the solid.

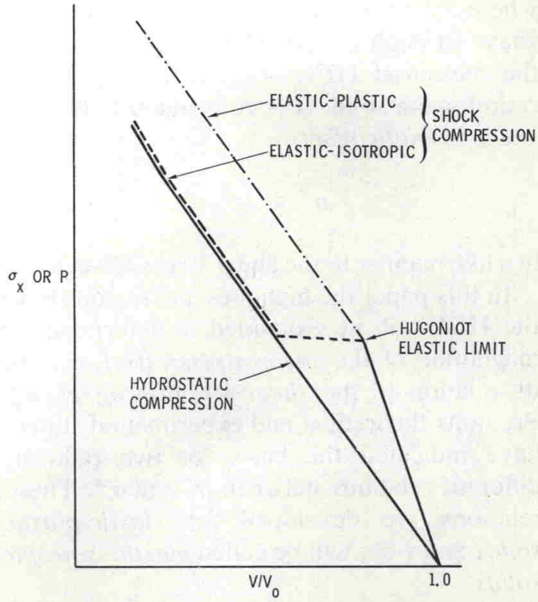

Fig. 1. Principal features of the two simplest models for the compressional behavior of solids under shock compression. The elastic–plastic solid exhibits a constant shear stress offset from the hydrostatic curve for stresses greater than the HEL. On the other hand, the elastic–isotropic solid exhibits no shear stress offset. Unlike the elastic–plastic solid, the shear strength of the elastic–isotropic solid is irreversibly reduced by the shear stress accompanying uniaxial strain.

The phenomenological difference between the elastic–plastic solid and the elastic–isotropic solid is demonstrated in Fig. 1. Unlike the elastic–plastic response which shows a constant offset from the isotropic compression curve above the HEL, the elastic–isotropic response shows no offset. If the process by which the loss of shear strength occurs does not alter properties of the solid, the hydrostatic compression curve and shock compression curve will be the same in regions where the shock heating is negligible.

In contrast to the situation for metals, the generality of the loss of shear strength has not been systematically explored. It has been suggested[26, 27] that the elastic–isotropic response may be typical of 'brittle' solids but little systematic attempt has been made to verify this characterization.

Recently, Ahrens *et al.*[28], reported shock-compression measurements on a high-density polycrystalline Al_2O_3 and concluded that Al_2O_3 responded as an elastic–plastic solid. This was subsequently confirmed by Munson[29]. Since polycrystalline Al_2O_3 is a brittle solid this observation is not consistent with the early predictions of the response of brittle solids. Further complicating the question, McWhan[30] reported static compression measurements on quartz with X-ray techniques and found that the shock data and the high pressure static data showed a small, 1 per cent offset in volume. Thus, at the present time we have no consistent basis for predicting the shear stress offsets of solids other than metals and are faced with a fundamental unknown in the mechanical response of solids to large anisotropic compressions.

The present study of the shock compression of single crystal Al_2O_3, sapphire, was under-