6

Brittle Damage Mechanics of Rock Mass

6.1 Introduction and Objective

In this chapter, special aspects of brittle damage mechanics are considered, related to the various frameworks by which the behavior of a brittle damaged material can be postulated, still considering the damaged medium as a global continuum. The basic framework of CDM is recalled, stressing the concepts of effective stress and the ways of introducing coupling between damage and brittle behavior. Particular attention is paid to problems related to initial or induced anisotropy and the unilateral character of the brittle damage. Coupling between damage and plasticity is not discussed herein. The materials concerned are rock, concrete, considered initially isotropic and composite, in particular ceramic matrix composites. Some specific models are developed, taking into consideration scalar damage variables for initially anisotropic brittle materials.

Chaboche et al. [6-1] considered only small perturbations and isothermal conditions for anisotropic brittle materials. The total strain $\varepsilon$ is assimilated with the elastic strain and the damage processes are considered time-independent. We do not discuss the difficult problems related to instabilities by localization and therefore describe only the first stages of damage, before conditions become critical.

Determination of elastic parameters of brittle solids in the function of the concentration, shape, size and orientation of micro-cracks is an important part of micro-mechanical damage models. In the last two decades this problem has been addressed by many authors [6-2~6]. In all of these cases the elastic brittle parameters were estimated within the framework of Mean Field Theories (MFT). The primary objective studied by Krajcinovic et al. [6-7] was to provide additional data defining the influence of micro-cracks on the elastic parameters of brittle solids. More specifically, this study will address the dependence of the elastic parameters on the orientation of micro-cracks, i.e., defect induced anisotropy. This will provide a necessary background for a forthcoming study focused on micro-crack concentrations, for which mean field
Theories are inadequate. The complementary case of prescribed macro-strains was considered in Nemat-Nasser and Hori [6-5]. Additionally, the considerations will be restricted to two-dimensional continua in [6-7].

The other important investigation of brittle damage mechanics is intended to generalize the damage model, presented earlier by Chow and Yang [6-8, 6-9], for brittle anisotropic materials to cover the nonlinear damage behaviors of brittle composite laminates. A general form of constitutive relations describing the nonlinear damage response of brittle unidirectional composite lamina is first introduced and then expressed in such a way that it can be readily incorporated in the analysis of brittle laminates. The earliest investigation is limited to symmetric laminates without discontinuity. Brittle laminates are thin and the free edge effects are not considered. Therefore, in the case of in-plane uniform loading, each layer in the brittle laminate, as well as the laminate itself, will be regarded as in a state of plane stress. With the method due to Tsai and Hahn [6-10], the constitutive equation of the brittle laminate with damage is determined from those of its constituent parts. The damage process in the brittle laminate is analyzed and the comparisons between the experimental observation and predictions are discussed in [6-11].

There are classes of quasi-brittle solids where cracks tend to follow tortuous paths when the local stress or strain conditions for the crack propagation are satisfied. Examples are ceramic objects, where micro-cracks are intergranular and concrete, where cracks emanate from weak interfacial bonds, propagate through the mortar phase and go around aggregate particles that act as energy barriers. During the process of micro-cracking, material grains are severed leaving the strained solid as “damaged”. Such a process alters the elastic modulus and can lead to a strong material anisotropy. Yazdani and Karnawat [6-12] presented a study which is the effect that damage, in a given direction, might have on the solid’s strength and ductility in other orthogonal directions. This becomes of particular interest in ceramics, rocks and concrete since micro-cracks are not planar, nor do they propagate along perfect planes.

In [6-13] Sadowski mentioned that: The existence of cracks, pores and other defects within solids diametrically changes the material response due to the applied load. Many effective continuum models have been proposed to estimate mechanical properties of materials [6-5~9]. In the case of semi-brittle ceramics, a small amount of plasticity also influences the total material response [6-14~15]. The aim of his work was to follow the two-dimensional, quasi-static deformation process (tension-compression) of semi-brittle ceramics. The mechanical response of polycrystalline continua, weakened by a set of slits, was modeled by application mean field theories [6-2~4]. According to the experimental results of MgO [6-16~18], a limited plastic flow is also created by dislocation motion within the range of grains of the representative volume element. Micro-cracks are initiated by Zener-Stroh’s mechanism and propagate mainly intergranularly along grain boundaries (zig-zag cracks), leading to final failure of the brittle material.