DAMAGE AND FRACTURE PROCESS IN CONCRETE A COMBINED APPROACH

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There are three distinctive theories to describe damage and failure process in concrete acting independently: continuous damage mechanics, theory of plasticity and fracture mechanics. But, the process of concrete failure appears to be too complex and combined approach become more suitable. In this paper a combined approach to the damage and fracture process in concrete is proposed, based on the all three mentioned theories. Stress state and history are pointed out as more important rather than modeling appropriate type of material in order to define the general failure criterium.

INTRODUCTION

Concrete may be considered as a composite material consisting of the three main components: the cement matrix (microporous material), the aggregates and the interface named "transition halo". Because of the highly oriented crystallized concrete in the transition zone which is the most porous part of the composite, it is considered as the weakest one. It has been established: (1) the damage appears just in this zone, even before the loading is applied; and (2) there are different types of damage (damage models) depending of stress state and history. Consequently, there are three distinguished theories to describe damage process in concrete acting independently: theory of plasticity, continuous damage mechanics and fracture mechanics. In order to find out the general failure criterium and following the ingenious starting point of Geteborgs researchers (Janson and Hult, 1977) who used to combine continuous damage and fracture mechanics as well as the interesting attempt of combining plasticity and damage mechanics (Yazdani and Schreyer, 1990) in this paper the more complex approach has been made combining all of three mentioned theories.

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Micromechanics of damage

The concrete material subjected to any kind of load conditions gives soon afterwards the nonlinear response. The nonlinearities arise from two distinct microstructural changes that advance in the material: plastic flow and development and propagation of microcracks and microvoids. On the other hand, it is well established and experimentally proved that internal microcracking take place in concrete before any load had been applied. This kind of preexisting microcracks are due the process of cement hitratation, thermal gradient or shrinkage and play an important role in the overall failure process. The majority of this microcracks are located on the aggregate-cement past interface and its presence denoted as technological damage, depends of many influencing parameters: w/c ratio, type of cement, curing procedure of the mix etc., but the most influencing one is the coarse aggregate sieve gradation. Therefore, the great effort would be made to define experimentally the exact measure of technological damage as a parameter of material.

Thus, technological damage presents the network for the future initial stress concentrators in the process of external loading. When external loads are first applied the slow moving process along the crack faces is taking place accompanied with stress concentration and crack opening displacements. Actually, fracture mode I and mode II are occur from place to place depending of state of stress and crack direction. This process is arrested at the edge of the aggregate since the cement paste has a larger toughness than the interface and further increase of loads is needed for its propagation in mesostructure. Finely, the numerous cracks different in size and orientation and randomly distributed become localized in same areas of speciment and some of them propagate, take a form and shape of macrocrack and the final state of failure is reached.

Plastic flow, by its definition for metals is induced by the dislocation moving processes along preferred slip planes. But, the plastic flow process in concrete is particular and different than in metals. The concrete material undergoes irreversible deformations due to slippage at the crack surfaces where the roughness of the cracks prevent them from closing upon unloading.

Obviously, the three types of mentioned microstructural changes interact through the process which is not explored enough (see Y. Okui, H. Horii and N. Akiyama, 1993)(1).

Thus, to reach the general failure criteria, several distinguished state of stress in the concrete material have to be considered depending of the loading nature and intensity:

State: "0"- initial (ω_0);
"I"- elastic (ε^e, ω_0 , ω_s);
"II"- elasto-plastic (ε^e, ε^p, ω_0 , ω_s);
"III"- finale (ε^e, ε^p, ω_0, ω_s, K_{Ic})

In the most general case of thermodynamical analysis, concrete material may be described by the set of parameters and internal variables: technological damage ω_0 , elastic strain tensor ε^e, damage ω_s and plastic strain ε^p. Thus, the value of thermodynamic potential $\rho\psi$ can be expressed as

$$\rho\psi = \rho\psi^e + \rho\psi^p \ \ldots\ldots\ldots\ldots\ldots \ (1)$$

We assume also that only elastic properties of material are under influence of damage. Damage in concrete material as well as the permanent strains is irreversible process which lead in permanent energy dissipation. The total rate of this energy dissipated can be expressed by the Clausius-Duhem inequality:

$$\phi = \boldsymbol{\sigma} : \boldsymbol{\varepsilon}^{(e+p)} - \rho\psi^{(e+\omega)} - \rho\psi^{p} \geq 0 \ \ldots\ldots\ldots\ldots(2)$$

However the stress conditions could be complex two damage processes are taking place the most frequently - damage provoked by tension and compression. Consequently, two the most dominant modes of cracking are identified: (1) cleavage cracking; and (2) compression cracking (Yazdani and Schroyer, 1989) (2)(Figure 1.).

In this paper we shall focus our attention to the compression mode of cracking, or more specific to the initiation, growth, propagation and interacting effects between preexisting microcracks (technological damage) and compression cracking process.

We have already described the preexisting microcracks as a randomly distributed along the grain boundary interfaces. But, besides their position, their orientation too appears to be of the great importance for their further behavior. Let us consider the crack growth process presuming the preexisting microcracks existence on the aggregate boundary interface (Figure 2.).

When external load is applied the preexisting microcrack is affected by the action of shear stresses arising from the crack faces to face slipping and friction.

$$\tau = \sigma \sin\theta \cos\theta - \mu \cos^2\theta \ \ldots\ldots\ldots\ldots \ (3)$$

At the same tame significant displacements are taking place in transverse direction defined by the value of Poisson's ratio ν. However, we should keep in mind that

Poisson's ratio value is not a constant and vary throughout the damaging process. The microcrack growth along the interface from the initial value of length $2a_0$ to D and than is stopped by the higher value of material toughness (Fig. 2.b). Further increase of loads leads to kink crack propagation throughout the cement matrix. The length of the kink cracks increase in a stable manner with loads increasing until two or many of these cracks (along the same direction) interact mutually causing the total axial splitting (failure) throughout the material (Fanela A. D., 1990) (3).

Combined approach

To define and to explain the fracture process in general and for the any kind of material the researchers are mostly inclined to define at first the model of the material which should be considered (brittle, brittle-ductile, ductile etc.). However, the same kind of material subjected to different environmental conditions and to different stress states and levels, responds on different manners. Thus, we should escape to define the materials as a model but to consider the particular stress state of material.

In our case, the concrete material as a composite continuum with isotropic damage distribution should be treated combining all three theories in the most general case. Thus, the general homogenized behavior of heterogeneous material can be described by a mixed mode (J.M. Berthelot and J.L. Robert,1990)(3) (Figure 3). The test curve can be divided into three regions depending of the different phases of material behavior. In the phase 1 the material response to load is linear. Continuous damage mechanics is appropriate to apply at this level taking in account parameter of the technological damage. In the phase 2 damage and microcracks development take place and continue until cracking become highly localized in some area of specimen. Also, already described plastic permanent strains interact and coincide with the cracking. Thus, combined continuous damage mechanics and theory of plasticity approach is the most convenient to describe this process. In phase 3 the main dominant crack is formed accompanied with sudden drop of load intensity and failure of specimen.

Instability conditions of the one single macrocrack need to be considered in the framework of fracture mechanics principle. But, the main assumption of the fracture mechanics is that the medium around the crack must be mechanically intact. Since, this is not the case in the concrete material for the phase 3 where the main crack propagate through the medium which is already damaged and cracked, a combined fracture and damage mechanics approach have to be considered.

Experiment

The uniaxial compression test has been caring out and the final results will be presented and discussed at the conference.

The main purpose of the experiment is not merely to follow development of the entire damage and fracture process in concrete but to tray to find out the interrelation between several types of concrete deterioration affected by the technological and external loading conditions. The particular attention is focused to the assessment of the technological damage value as a parameter of material.

Conclusions

Damage and fracture process in concrete is a very complex problem to be considered in the frame of one single theory.

Combined approach of the three distinguished theory: continuous damage mechanics, theory of plasticity and fracture mechanics is the closest to the real nature of the phenomena.

SIMBOLS USED

ω_0 =initial or technological damage
ω_s =damage induced by load
ε^e =elastic strain
ε^p =plastic strain
K_c =stress concentration factor
σ =stress
ρ =mass tensity

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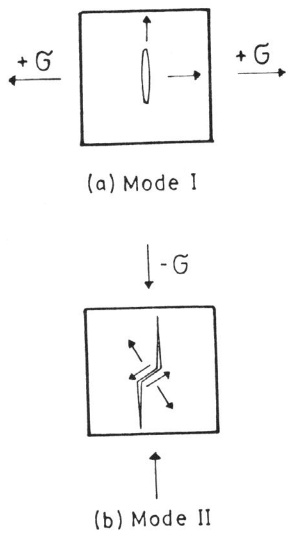

Figure 1. Failure modes
(Yazdani, S., and Schreyer)

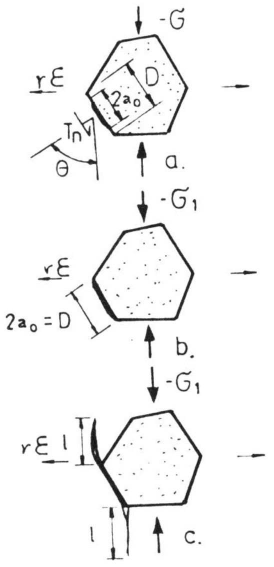

Figure 2. Crack propagation
in compression (Fanella, A.D.)

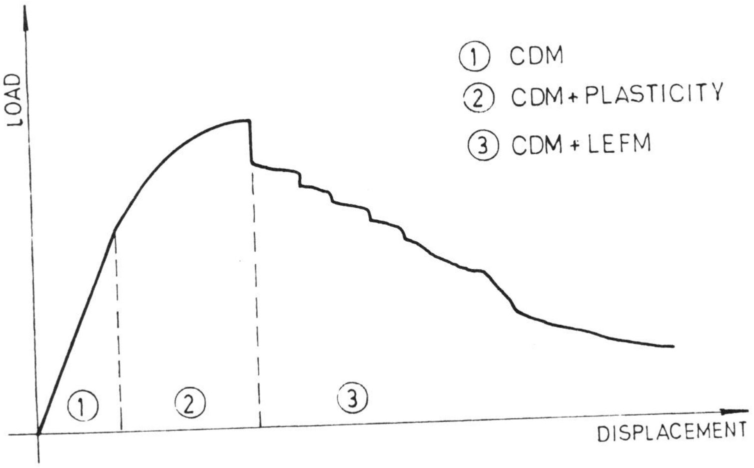

Figure 3. Characteristic strain states
(Berthelot, M.J, and Robert, J.L.)