DAMAGE PROCESS ANALYSIS IN CONCRETE UNDER COMPRESSION

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Concrete can be considered as a composite material consisting of three main components: cement matrix, aggregates and interface, named "transition halo". Bacause of the highly oriented crystallized concrete in the transiotion zone which is the most porous part of the composite, it is consodered as the weakest one. It has been established: (1) damage appears just in this zone even before the loading is applied, and (2) there are diferent types of damage (damage models) depending on state of stress and history. Thus, three distinct microstructural changes exist in concrete material: (1) preexisting microcracks; (2) plastic flow and (3) microcraking development. In the paper, particular case of uniaxial compression is considered using a combined approach of the three well established, but highly idealised theory: continouse damage mechanics, theory of plasticity and fracture mechanics.

INTRODUCTION

The main problem in concrete material fracture analysis and modeling is a luck of continuum transition between the state of non-loaded (non-strained) medium (which is supposed to be medium "intact") to the loaded (strained) medium. Namely, it is well known fact that the concrete material contains so called preexisting microcracks before it is exposed to the loading conditions. The nature and origin of the microcracks is explained by the process of concrete shrinkage and steep temperature gradient during concrete strengthening and named by the author of this paper as a "*technological damage*". The preexisting microcracks are randomly distributed through the concrete material and their volume and number depends of the many parameters (sieve gradation, maximum grain size, humidity maintaining etc.) but their presence is precisely located in the transition zone just on the grain boundary. Thus, the concrete material is "apriori" homogeneous with the microdiscontinuities randomly distributed through its volume before any external load is applied. This has to be the base ground for any further mesomechanical considerations of the stress, strain and damage in concrete material, as it was pointed out by Krajcinovic and Sumarac (1).

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A combined approach is introduced in concrete material fracture analysis based on the fundamental work of Janson and Hult (2), and suggestions of Yazdani and Schreyer (3).

Uniaxial compression of concrete material.

Let us analyze stress–strain curve for concrete material under uniaxial compression test. Roughly speaking, three clearly distinguished parts of the curve can be observed (Fig. 1). Part OA corresponding to the elastic material response, AB – describing elasto-plastic response, and BC – relieving and failure. By increasing of load to the point A, under idealized conditions of perfectly undamaged material, usually brings no any damage to the concrete material. The strain is small (the part of the curve (OA) is very steep) and completely reversible. However, preexisting *technological damage* in the real concrete material, might be considered as a system of microcracks mostly located on the grain boundaries. Most of the microcracks directed perpendicularly to the stress orientation have no any or neglecting influence on the further damage propagation process (Fig. 1.a and d). The only deformation effect for this type of microcracks is a crack closure (¨sponge¨ effect) and it makes concrete material to be softer. The global strain is greater (part of the curve (OA) less steep), but still completely reversible, since the elastic energy is stored without any dissipation. Some of the microcracks might propagate along the grain boundaries but they are arrested at the age of aggregate facet since the cement paste has larger toughness than the interface.

Further increase in the applied loads (section AB) is particularly stimulated for those microcracks oriented in the stress direction or at angle θ with respect to the axial direction. Exposed to uniaxial compression the microcracks will have shear stress t_n acting on its faces. Consequently, at this level of loads they begin to propagate into the cement matrix. This crack propagation is designated as a *crack kink* and usually takes place in the direction of axial stress. This is the most delicate moment in concrete material deterioration process being the microcracks begin to interact with one another forming the network of internal microcracks in composite (localization phenomena). The nature and the manner of this interaction is not jet explicitly expressed, though the problem has been considered introducing interaction field theory by Okui, Horii and Akiyama (4). According to D. Fanela (6), concerning uniaxial compression, the problem is closely related with the mean free distances between the adjoining aggregates.

Besides, this is not the only interaction process which is taking place in concrete material at this level of loads. Simultaneously, interaction between plastic strain (flow) and microcracks (damage) occurs. Plastic flow results as a consequence of dislocation processes along preferred slip planes. Considering those deformation energetically, the two kind of energy imparted by a given increment of external load can be distinguished: (1) the energy stored as an elastic strain energy, and (2) the energy partially dissipated through the plastic flow and increase of the microdefects density. Subsequently, the interaction forms a network of internal damage in the concrete material.

The loads reaching or close to the point B, brings the strong strain localization, the network becomes unstable forming macrocracks and soon after that (section BC) the total material failure take place causing axial splitting of the spacemen.

Basic thermodynamics equations.

To describe the constitutive relations for concrete material a modified continuum model may be applied. The internal energy is described by the following expression:

$$U = U(\mathbf{e}, w_o, T, H, \mathbf{q}) \quad \text{.......} \quad (1)$$

$$\mathbf{q} = \mathbf{q}(k, g) \quad \text{.......} \quad (2)$$

Technological damage is described by the crack density tensor introduced by Kachanov, M.(4) and suitable for geometrical description not only of cracks but also of any kind of "surface type" defects.

According to the first low of thermodynamics (energy balance):

$$dW + dQ = dU + dD \quad \text{.......} \quad (3)$$

Gibbs free energy (GFE):

$$G(\mathbf{s}, w_o, T, H, \mathbf{q}) = s : e - U + Th \quad \text{.......} \quad (4)$$

Clausius-Duhem inequality:

$$dG(s, w_o, T, H, q) - e{:}ds - dD > 0 \quad \text{.......} \quad (5)$$

Forth order compliance tensor (C):

$$C(w) = C_0 + C(w_0) + C(D) \quad \text{.......} \quad (6)$$

$$\frac{\partial G(\sigma, T, H, q)}{\partial\sigma\partial\sigma} = C(\omega) \quad \text{.......} \quad (7)$$

Flexibility and stress tensor are related by G:

With the integration of this equation, the total strain tensor is identified:

$$e = C(w_0){:}s + e^i(q) = e(w_0) + e^i(q) = e(w_0) + e^i \quad \text{.......} \quad (8)$$

$$e = e^e + e^i(q) \quad \text{.......} \quad (9)$$

$$e^i(q) = e^w(q) + e^p(q) \quad \text{.......} \quad (10)$$

In the same time, at this level of load, a modified fracture mechanics consideration can be involved. Thus, for series of cracks with the configuration shown in Fig. 3., Horii and Nemet-Nasser (6) and Fanela, D. (7) introduced the stress intensity factor at the crack tips:

$$K_{IC} = \frac{T\cos\theta}{\sqrt{b\sin(\frac{\pi l_{eff}}{b})}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (11)$$

and subsequently the relating failure stress in uniaxial compression:

$$\sigma_{uc} = \frac{K_{IC}\sqrt{b}}{D_M F(\theta)\cos\theta} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (12)$$

$$F(\Theta)=\sin\Theta_1\cos\Theta_1 - \cos\Theta_1 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (13)$$

$$\theta_1 = arctg[(3\mu + \sqrt{9\mu_2 + 8} / 4] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (14)$$

This kind of interaction derived from the many experiments could be the main characteristics of the final state of concrete material failure process.

Summary and Conclusions

A failure process in plain concrete material subjected to uniaxial compression stress is considered. The concrete material is assumed as "a priori" non-homogenous (disordered) continuum containing microcracs and microvoids (technological damage) in the state before any external load is applied.

Deformation process is characterized by microcracks, plastic flow and macrocracks development depending of the stress rate and history. The process is experimentally investigated by the scanning electron microscopy. Consequently, a combined approach of damage mechanics, theory of plasticity and fracture mechanics is proposed based on the internal variable theory of thermodynamics. Three kinds of interactions are identified as a crucial for the final state of failure: microracks, microcracks-microflows and series of kink cracks interaction.

SYMBOLS USED

ε_e = strain tensor

q = internal state vector

ω_0 = technological damage

T = temperature (C ^{o})

H = entropy

k = damage induced by load

γ = hardening plasticity parameter

G = Gibbs free energy

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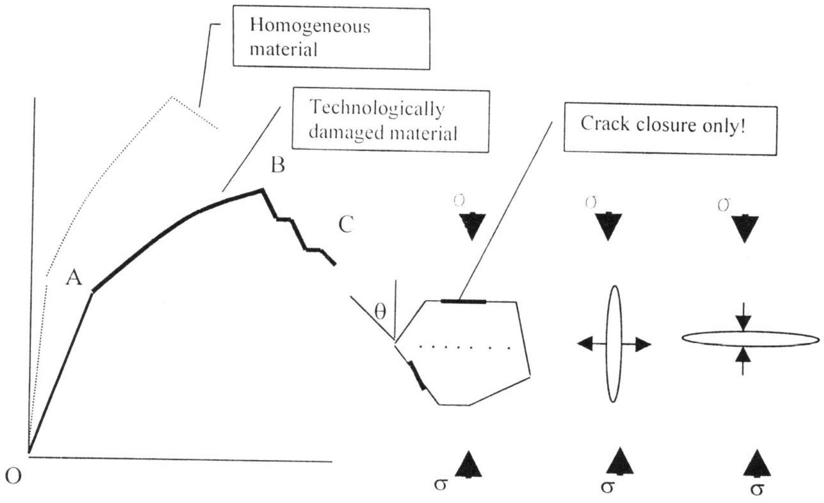
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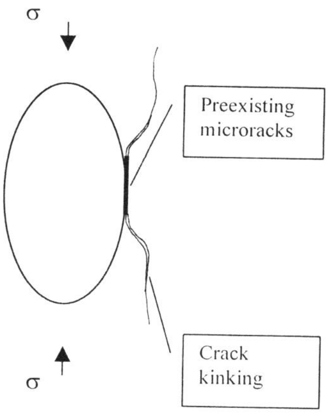
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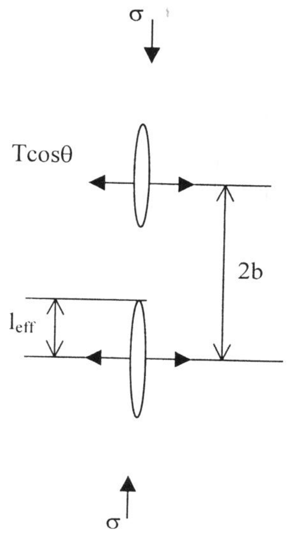
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