‘Transient thermal creep’ of concrete: intrinsic behaviour or structural effect?

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Abstract

The aim of this study is to model the damage mechanisms of concrete and to investigate the behavior of concrete specimens when they are simultaneously subjected to a constant compressive load and to high temperature. To show the structural effect of such loading, numerical simulations of the experimental tests carried out by Holst [1] have been performed.

Keywords: Transient thermal creep; Thermal damage; Multi-scale model; High temperature; Micro macro approach

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1. Introduction

Experimental studies show an important influence of the temperature on concrete behavior. Figure 1 shows the total strain of concrete samples heated under a constant compressive load given by Holst [1], several levels of compressive load were tested, from 0% up to 60% of the compressive strength of concrete. Several authors explain these observations by an additional strain, called transient thermomechanical interaction strain or transient creep strain [2,7,8].

In our opinion, these test results do not reflect an intrinsic material behavior, but should be considered as a structural behavior of concrete due to the thermal damage at the mesoscopic scale. To show the structural effect of such loading, numerical simulations of the experimental tests carried out by [1] have been achieved. Using the digital-concrete FE model (DC) [4], and the damage model MODEV [5], both implemented in the general FE code SYMPHONIE.

2. Modeling of concrete at high temperature

The approach proposed to model concrete behavior at high temperature, is based on the multi-scale homogenization of concrete using the digital-concrete model. Several scales of modeling are taken into account, ranging from the cement paste to the concrete material [6]. Thus, the concrete is considered as a combination of three materials: cement, mortar, and concrete. Each material is considered on its specific scale, and homogenization is needed on each scale to go to the following upper one. Figure 2 shows the basis of this approach. The mechanical and thermal characteristics of cement paste and sand aggregates are conjointly introduced into the DC model in order to homogenize

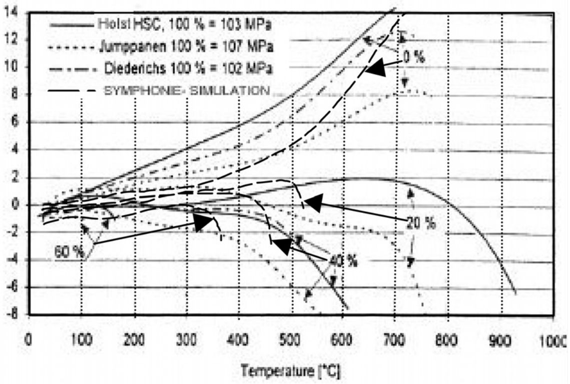

Fig. 1. Model response for coupled thermal and mechanical loads compared to tests results.

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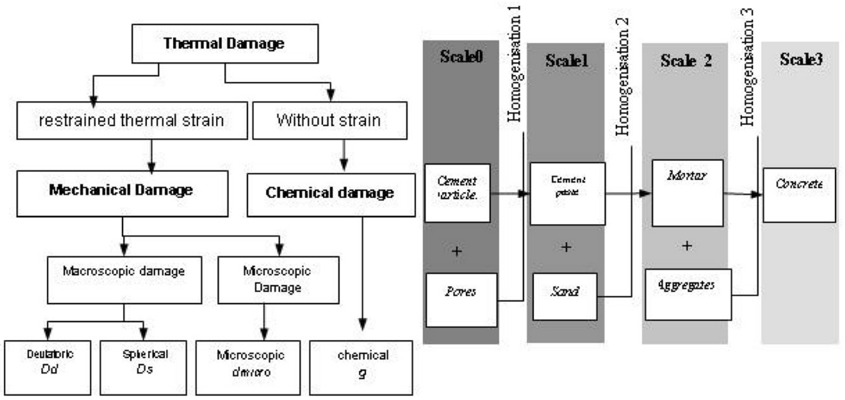

(a) (b)

Fig. 2. Thermal damage approach and multi-scale homogenization.

the mortar behavior. This process is repeated for concrete homogenization by introducing in the DC model, the characteristics of the homogenized mortar, obtained in the previous step, and the characteristics of aggregates. This step enables us to obtain the thermo-mechanical behavior of concrete.

The local DC model considers a random approach to generate the internal structure of a heterogeneous material as concrete, mortar or cement paste on a smaller scale. The proposed approach considers a multiphase material with successions of *n* phases spatially distributed in a random manner. In the present simulations, to represent concrete, the following phases are taken into account: 1st phase: solid skeleton of the matrix cement P_1; 2nd phase: a random distribution of aggregates with the possibility of analyzing this phase in n sub-phases to represent different sizes and natures of aggregates P_{21}, P_{22} … P_{2n}.

In the proposed approach, we have decomposed into two main categories the basic mechanisms leading to the thermal damage of concrete [6,7]:

Purely thermal damage without strains due to the different chemical transformations, which occurs mainly in cement paste: dehydration, important mass loss beyond 120°C, and other chemical transformations. This damage has been identified from experimental tests performed on cement samples [7].

Mechanical damage of thermal origin accompanied with strains and due to the restrained thermal strains on a macroscopic and mesoscopic scale: the mechanical damage can be the temperature gradient or the boundary conditions, or even the geometric shape on a macroscopic scale, and the differential expansion between the cement paste and the aggregates on a mesoscopic scale. The mechanical thermal damage of concrete is modeled with the deviatoric damage model MODEV. This model introduces 2 scalar damage variables representing respectively local sliding and crack opening [5].

3. Numerical simulation

The experimental tests carried out by Holst [1] have been simulated. Cylindrical specimens (68 × 132mm^2), have been subjected to several constant compressive loads and heated up to 800°C with a heating rate of 4.98°C/min.

The tests are modeled in 2D, with an axisymetrical model. A constant compressive load is applied at the top of the specimen at the beginning of the heating stage and is maintained constant during the test. The load represents 0%, 20%, 40% or 60% of the compressive strength of the high-strength concrete (HSC) (108 MPa). Figure 3 shows the geometry, the mesh and the boundary conditions adopted for the computations. The thermo-mechanical characteristics of the HSC are given by Holst [1]. To perform the computations with the digital-concrete model, it is also necessary to know the properties of cement paste and aggregates separately

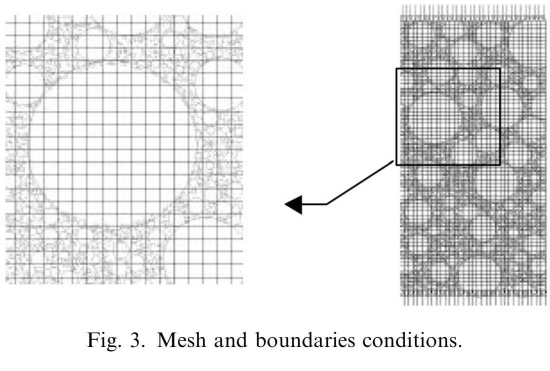

Fig. 3. Mesh and boundaries conditions.

Table 1
Materials parameters defined for the cement paste and for concrete aggregates

	E (MPa)	ν	f_t (MPa)	G (MPa)	G_f (N/mm)	α	B_c
Cement Paste	20000	0.2	4	15	0.1	0.3	80
Aggregates	80000	0.28	10	20	0.15	0.3	70

Table 2
Thermal expansion coefficient of cement paste and aggregates

Cement paste		aggregates	
T (°C)	α_{th} ($°\mathrm{C}^{-1}$)	T (°C)	α_{th} ($°\mathrm{C}^{-1}$)
20	10 e-6	20	3 e-6
120	15 e-6	200	9 e-6
400	−5 e-6	500	21 e-6
1200	−25 e-6	800	57 e-6

(tensile and compressive strengths, thermal expansion coefficient, fracture energy, Young modulus ...), this information is presented in Tables 1 and 2, where E is the Young modulus, f_t the tensile strength, G_f the fracture energy and ν the Poisson's ratio. B_c and α are two parameters of the damage model MODEV.

The damage computed, at the constituent's scale, using micromechanical approach is mainly due to the strong difference between the coefficients of thermal expansion of cement paste and aggregates; a uniform temperature variation generates strain gradients in the material which is now analyzed as a structure. These strain gradients are responsible for the induced damage zones at the mesoscopic level. Figure 1 presents for simulations and experiments, the evolution of the total strain versus the temperature for the 4 loading levels (0, 20, 40, and 60%). These results show that the evolution of the total strain can be obtained with no additional strain component such as transient or creep strain. It is obtained basically by introducing the thermal degradation of concrete stiffness at high temperature.

4. Conclusion

In order to understand the mechanisms leading to the deterioration of concrete under the effect of combined compressive and thermal loading, numerical micromechanical simulations of the experimental tests carried out by Holst have been performed. These simulations show that the experimental 'transient strain of concrete' does not reflect an intrinsic material behavior, but should be considered as structural behavior due to both restrained boundary conditions and microscopic thermal damage. So, no additional strain component, such as transient or creep strain, is needed to obtain the evolution of the total strain versus temperature.

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