Creep Behavior of Cement Pastes Since Setting Time

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I. INTRODUCTION

For usual concrete structure built in several phases, concrete deformations are restrained during the hardening process. When shrinkage is restrained, tensile stresses are induced and a cracking risk occurs. The thesis deals with experimental and numerical study of the early age properties of cement-based materials and more specifically the development of the autogenous deformation. The new approach was defined on an ordinary concrete and the next ended to the study of the following parameters: the water-cement ratio, the restrained effect of aggregate on the cement paste in the development of concrete properties at early age.

Properties of early age concrete

Concrete has the particularity to be a complex material for which its properties continuously change.It evolves from a nearly liquid state to a visco-plastic material within a few hours, followed by the setting of the concrete. Then the mechanical properties start to develop and the material exhibits a viscoelastic behavior. During the first days after mixing, the evolution of the concrete properties is very intense. This period is called the early age. Finally, the concrete properties continue to evolve on a period counted in years.

During the hardening of cement-based materials, volume changes occur due to the hydration of cement. If the displacement of the concrete is restrained, stresses are induced in the concrete. When this displacement corresponds to a contraction of the material, concrete is in tension and per consequent a cracking risk exists.

HARDENING PROCSS

The life-cycle of concrete can be separated in three states:

- The fresh state
- The hardening state
- The hardened state

It is generally accepted that, just after the casting of a concrete, a first period exists during which the material can be transported and cast into mould where it can be vibrated and where it can flow to fill the mould (period of workability). This period corresponds to the fresh state of the material. Just after casting, the aggregates can move slowly under the effect of the gravity and, eventually, a bleeding can appear. Cracking is then possible under the effects of these movements, especially when reinforcement bars are present. A second period, or period of the setting, commonly defined after the results of penetration tests on cement pastes or mortars, corresponds to a progressive coalescence of a continuous path of hydrates. At the beginning of this period, the concrete stiffness is almost inexistent while, at the end of this period (t_0), the concrete starts to stiffen [1]. In a third period, after t_0, stiffness, thermal and autogenous deformations evolve rapidly so that risks of cracking become critical, especially when deformations are restrained. It is then considered that the material behaves like a solid. Therefore the hardening state of the material starts at the setting. For the sake of predictions of structural behaviour, measurements of these parameters at early age are of a great interest [2,3]. However one question remains on how to determine t_0?

<u>BASIC CREEP</u>

This work is limited to the study of concrete in sealed conditions. Each time that the creep is mentioned, it is referred to the basic creep. The drying creep is not studied in this work. Creep and relaxation have not been thoroughly investigated at early age especially in tension. The knowledge of these properties is essential for assessing the long term performance but also the early age performance. Several authors tried to explain the physical mechanism of the creep and the relaxation. No theories of the basic creep are commonly accepted by the scientific community. But some experimental facts are accepted. A synthesis of these similarities is given in [74,75]:

- **A high sensitivity to the age of concrete at loading**. The creep amplitude decreases with the age of concrete at loading (during and after the hydration process).
- **The influence of the W/C ratio**. The creep amplitude increases when the W/C ration increases.
- **The fundamental role played by the water in the basic creep mechanism**,[76–80].
- **The influence of the type of cement and the mineral addition**[81].
- **The localization of the creep strain in the C-S-Hof the cement paste** [82,83].

- **The creep recovery is only partially reversible** [84]**. The increase of temperature leads to higher creep deformations** [85]**.**

Another commonly accepted point of the basic creep is the non-linear behaviour of basic creep for which the creep strain depnds on the level of loading. According to the level of loading, the creep strain can be divided in three parts (Figure 5):

- The primary phase (level of loading < 30-50 % of the compressive strength) during which the creep strain is proportional to the stress.
- The secondary phase, the relationship becomes nonlinear between creep strainand stress.
- The tertiary phase, during which if the stress level exceeds 85%ofthe strength the failure can occur in a very short period. Before failure a high increase of cracking occurs.

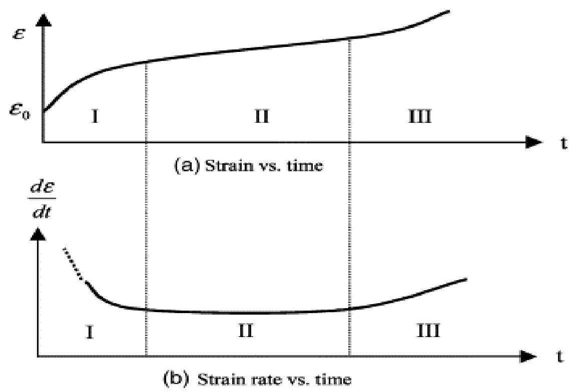

Figure5-Developmentofthecompletecreep strains [86]

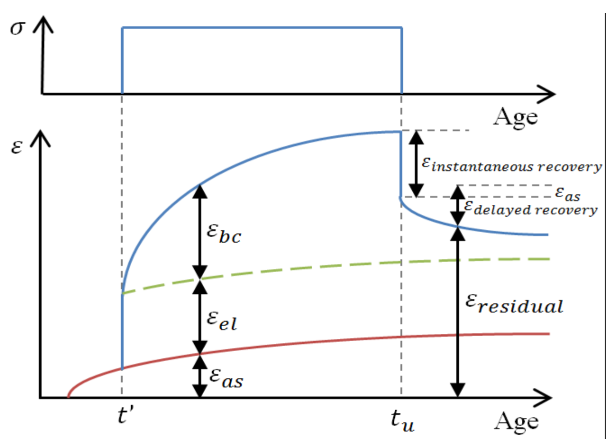

Figure6–Decompositionofthestrainin auto genous condition during loading[87]

Among many previous studies like those reported in [62,88–95], several theories were developed to clarify mechanisms related to creep behaviour. However each theory alone does not allow explaining all experimental observations. Globally each theory can be linked to two mechanisms: direct mechanisms linked to the cement paste and responsible of the highest part of the creep amplitude and indirect mechanisms linked to the heterogeneity of the concrete. Direct mechanisms are related to the water mobility and to the solidification of the material and can be separated in short and long terms phenomena [80,96–98]. The short term phenomenon is reversible with a small characteristic time of about 10 days, is linked to a stress-induced water movement towards the largest diameter pores and to the solidification [98,99] of the material, and occurs under increasing volume for uniaxial compression. The long term phenomenon is irreversible with a high characteristic time and related to viscous flow in the hydrates and occurs under almost constant volume. The creep rate of this long term phenomenon evolves as a power function t^n[100–102] with an exponent $n$between -1 and -0.9 according to[103],between-0.72and -0.69accordingto results of[104] on concrete and an exponent n between -0.86 and -0.6 on cement paste according to results of [94]. Nano indentation tests were carriedout on C-S-HbyVandamme, *etal*[105].It was shown that C-S H exhibits alogarithm iccreep which is in agreement with results obtained on concrete. Vandamme [106] compared also this logarithmic behaviour with other heterogeneous and porous materials with porosity including several orders of magnitude (soils and wood). For these non-ageing materials, a logarithmic long-term creep was also observed. It can then be assumed that this long term creep is not linked to a hydration process or any chemical specificity of the C-S-H.

The indirect mechanisms are due to micro-cracks which occur progressively in the cement paste andat the interface between cement paste and inclusions. Their presence can cause a redistribution of the stresses in the material. Rossi, *et al* [107–109] proposed an approach of the creep mechanisms by means of a micro-cracking process which occurs during loading and which is confirmed by acoustic emission. Over the time, an increase of the density of micro-cracks occurs. These micro-cracks are distributed through the volume of the specimen and allow water transfers inducing some additional self-desiccation shrinkage (but there is no experimental evidence of this additional self-desiccation).

The principal load-bearings function of concrete in structures is to carry compressive stresses. Reinforcement and prestressing tendons carry tensile stresses. For this purpose, most investigations were carried out for the determination of the mechanical properties of concrete in compression. Similarly, most explanations about mechanical properties concerned the compressive case. The creep phenomenon was also mostly studied in compression for technical reasons. The study of tensile creep is more elaborated and complex than test in compression. It is yet more uncommon to have experimental results for the relaxation phenomenon. Indeed, the study of the relaxation is very complicated for a specific technological reason. The relaxation test needs to take into account in real time the subtraction between the total deformation and the free deformation. This subtraction has to be constant during the entire test, so that the jack of the machine must be controlled by this value. It is possible to avoid this technological problem thanks to the existing relation between the creep function and the relaxation function according to the superposition principle. Inversely it is also possible to find the creep function with the relaxation function. However, the direct use of the superposition principle implies making the assumption that creep is totally reversible.

Tanks and containments are not always prestressed. Tensile stresses occur in the structure and no cracking has to be ensured. To improve the prediction of the behaviour of the concrete structures and for economic reasons, designers need more information about tensile properties. In concrete structures, internal restraint causes a build up of tensile stresses within the material due to shrinkage whereas tensile creep counteracts the shrinkage as a stress relaxation mechanism. Importance of tensile creep isto be considered for the onset and the prediction of cracking propagation. The study of tensile creep has direct relevance for the design of concrete structures. Time that concrete takes to crack depends on the tensile strength and also the tensile creep. However, the current data about tensile creep at early age are very scarce. Data about restrained conditions are even less common.

A comparison between tensile and compressive creep were performed in [110]. The ratio between basic compressive creep strains and tensile ones according to several authors are plotted in Figure 7 and a very large dispersion can be observed. Much more investigations are thus required tounderstand the causes of this difference between tensile and compressive creep.

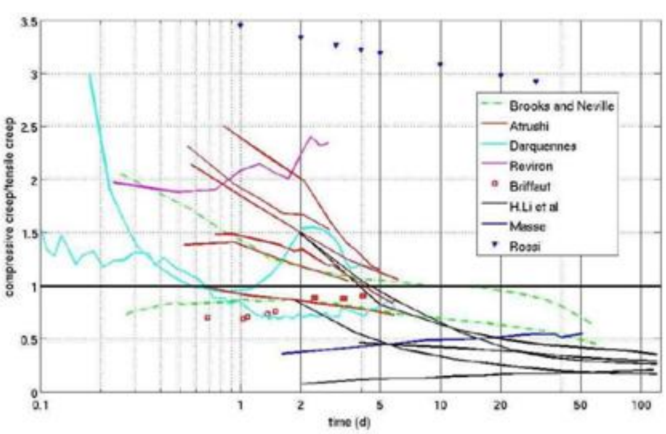

Figure7–ratioofcompressivecreeptotensilecreep [110]

Tensile creep can be measured with different devices as uniaxial tensile test, ring test, restrained shrinkage test and bending test. Uniaxial tensile tests and bending tests are the most used for the study of the tensile creep. Differences from both tests were compared [107,111]. Carpinteri *et al.* [111] found that load level affect more the time of failure in bending tests than in tensile tests. Rossi *et al.* [107]with results of [112], highlight that during bending creep tests on notched sample, it exists at the notch tip very high tensile stresses and so a high *stress/tensile strength* ratio. However thecompressivepartisveryweaklyloadedandthe*stress/compressivestrength*ratioisverylowintheupper part of the beam. Consequently, several phenomena occur simultaneously during a creep bending test. The first point is the stress level. The stress level is far higher in tension than in compression and nonlinear creep can occur in tension. The second point comes from the dissymmetry of the creep behaviour in tension and in compression. Both points occur at the same time so that an important scale effect relating to creep in tension has to be considered.

On hardened high performance concrete, Ranaivomanana, *et al.* [84] compared tensile, compressive and flexural basic creep of specimens subjected to three different sustained stress levels (30, 40 and50 % of the tensile or compressive strength), assumed to fall within the linear creep behaviour. Results of specific creep in compression, in tension and in flexure are presented in Figure 8. An increase in magnitude during the early days for each type of loading is observed, but differences in behaviour appear after about five days. During direct compression loading (Figure 8a), strains are increasing (very fast at the beginning and then slower). During direct tension loading (Figure 8b), strains are first increasing, but then are decreasing after about five days. During bending loading (Figure 8c), flexure-induce compression evolves similarly to direct compression, while flexure- induced tension are not decreasing as direct tension. The effect of the stress level is different for the different loading:

- For direct compression loading, Non-linearity occurs between 30 and 50%. Compressive specific creep is higher for higher stress level;
- Fordirecttensileloading,theresultsarequitescatteredandnoconclusion can be drawn about the stress level;
- For bending loading, a symmetrical trend is observed between flexure-induced compression and tension at 40 and 50%of the strength, but not at 30%. While specific creep for 30%isthe lowest in tension, it is the highest in compression.

Results of specific recovery in compression, in tension and in flexure are plotted on Figure 9. Results are roughly similar for each type of loading. As creep recovery corresponds to the reversible part of creep, discrepancies should be due to the irreversible part of creep in which damage appears.

The investigation of the physical mechanisms at the origin of the development of the properties of cement based materials since the earliest age is not an easy task. However, for the sake of predictions of structural behaviour, measurement of these parameters at early age is of great interest [1,2]. That is why several devices allow already monitoring properties of cement based materials since setting or even before. Such methods are generally non-destructive and are needed for the study of an evolving material as concrete. From the experimental data, the concrete behavior is defined. These data can also be used to validate numerical models. For a good understanding of the physical mechanisms occurring at early age, several compositions are tested and are presented in the first section of this chapter. The existing method which has been developed in the past for the characterization of cement based materials and which has been used in this work are presented in the second section of this chapter. Finally the main principles of the experimental program are stated in the third section

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