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Prediction of compressive strength at early age of concrete – Application of maturity

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ABSTRACT

While respecting the requirements of concrete strength in a structure, the maturity technique is part of a rapid and safe achievement of construction operations (formwork, prestressing, etc.). This technique transforms, in real time, the temperature history of on-site concrete into a strength. The objectives of this study are (1) to study the temperature evolution of four types of concrete such as self compacting concrete, high performance concrete and high performance synthetic or metallic fiber-reinforced concrete; and (2) to study the mechanical strength evolution depending on the age hardening and the cure temperature. Based on the mechanical strength reference curve at 20 °C of these four types of concrete studied, the final objective is to characterize the on-site strength as a function of the equivalent age of 5 h after casting of concrete.

1. Introduction

The term “non-destructive” is given to every test that does not damage or affect the structural behavior of the elements and leaves the structure in an acceptable condition. Malhotra [1] presented a comprehensive study of non-destructive methods used for the assessment of concrete structures.

Currently, the determinatMarocion of early age concrete strength is essential in construction field. Indeed, stripping of the forms in record time while respecting the specifications, constitute critical operations for building and civil engineering companies. The evolution of this property depends on several factors, but for a given formulation, the temperature at early age constitute the more factor influencing the cement hydration and therefore the mechanical strength of concrete [2].

At early age, the determination of progress rate of hydration reactions, corresponding to the hardening of concrete, represents “the maturity technique”. The latter requires a good knowledge of the regularity of concrete manufacturing and of its constituents. This concept allows to reflect the curing of concrete condition, that is to say its hardening level. It incorporates the coupled effects of temperature and time on the kinetic of concrete maturing [3]. The maturity technique is based on the general law of chemical reactions acceleration depending on the temperature proposed by Arrhenius [2]. This approach has the advantage of being very efficient but requires knowledge of another parameter: “the activation energy of concrete” [4]. In this case, it is preferable to refer to the apparent activation energy, because various anhydrous constituents of cement hydration produce several chemical reactions, each of which have their own activation energy [5,6].

In addition, the evolution of the compressive strength of concrete at short-term by the maturity relies primarily on special concept. This latter involves the transforming of the history of concrete temperature in an equivalent age of maturing at 20 °C. This means that for a given concrete, age after casting, compressive strength and history of temperature, we try to determine the time it would have taken to get the same compressive strength, but for a constant temperature equal to 20 °C, of the end of mixing until the measurement. The fundamental aspect in the maturity technique is the knowledge of the concrete reference curve. It presents the evolution of concrete compressive strength according to an age equivalent to 20 °C. For each composition, this reference curve is performed from the breakage of specimens stored at 20 °C. The principle of the maturity is schematized as follows (Fig. 1):

The application of maturity method (Fig. 1) allows to process the evaluation of compressive strength at early age by defining the critical points of a structure. The information is near-instantaneous and does not require transporting specimens, fixing and organizing the crushing deadlines. It is also more interesting than a simple result of crushing since we can easily predict the necessary time to

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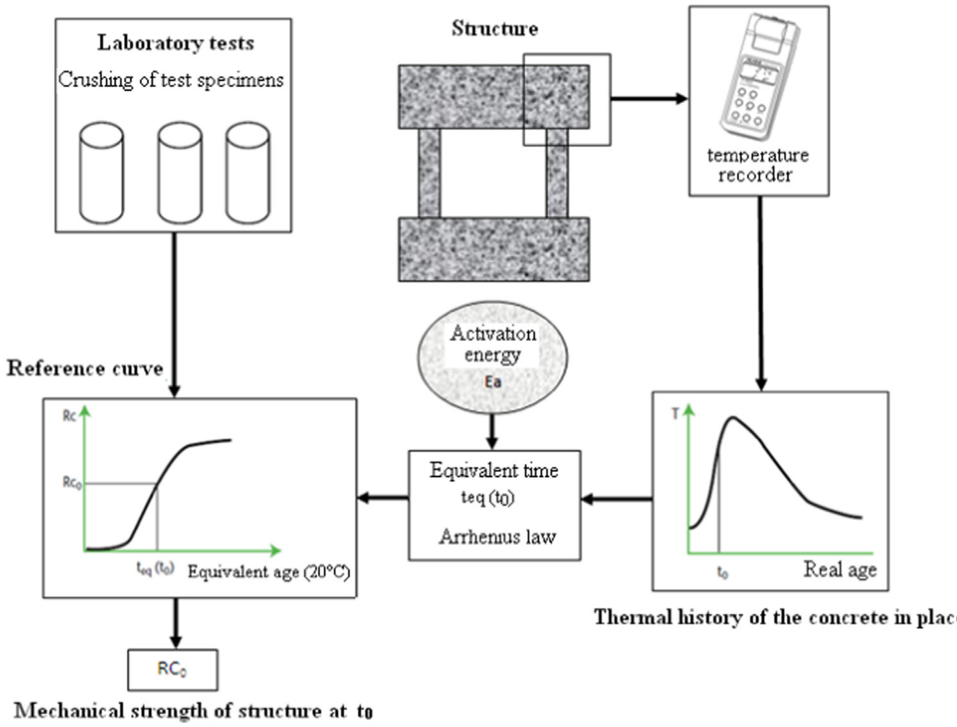

Fig. 1. Maturity method.

obtain the compressive strength required (by extrapolation on the temperature curve) [3].

The steps of this work are the following: (1) determination of the concrete temperature history during three days; (2) measurement of the development of compressive strength as a function of age (1, 3 and 7 days) and of four curing temperatures (20, 30, 35 and 40 °C); (3) determination of the activation energy and the equivalent age by applying the concept of maturity; and (4) determination of the strength of concrete at any age based on the equivalent age and the reference curve.

The aim of this study is to characterize the temperature evolution and the maturing of four types of concrete such as self compacting concrete (SCC), high performance concrete (HPC), high performance synthetic fiber-reinforced concrete (HPSFRC) and high performance metallic fiber-reinforced concrete (HPMFRC) in order to estimate the strength a few hours after the concrete casting phase in building site.

2. Experimental investigation

The application of maturity method (Fig. 1) allows to process the evaluation of compressive strength at early age by defining the critical points of a structure. The information is near-instantaneous and does not require transporting specimens, fixing and organizing the crushing deadlines. It is also more interesting than a simple result of crushing since we can easily predict the necessary time to obtain the compressive strength required (by extrapolation on the temperature curve) [3].

The work is done in the following way: firstly, the determination of the concrete temperature history, the measurement of the development of compressive strength and the determination of the activation energy and the equivalent age by applying the concept of maturity; and finally, the determination of the strength of concrete at any age.

2.1. Materials

Concretes adopted in this study have been previously developed to Polytech'Marseille, Aix-Marseille University [7]. In these mixtures, ordinary Portland cement CEM I 52.5 R (manufactured by Ciments Calcia – Italcementi Group) according to European Standard EN 197-1 was used as binder. Two types of supplementary cementitious materials were used: limestone filler (LF) and silica fume (SF) provided by Carmeuse and Sika France companies, respectively. The used superplasticizer (SP) is SIKA VISCOCRETE KRONO 20, according to European Standard NF EN 934-2 and manufactured by Sika France. The chemical composition and physical properties of Portland cement, mineral admixtures and superplasticizer are given in Table 1. Two types of fibers, manufactured by Sika France companies and according to European Standard NF EN 14889-1 were used. Their characteristics are presented in Table 2.

In this study, local crushed aggregates, natural limestone, are

Table 1
Chemical and physical proprieties of the used materials.

	CEM I	LF	SF	SP
C_3S (%)	67	–	–	–
C_2S (%)	12	–	–	–
C_4AF (%)	9	–	–	–
C_3A (%)	9	–	–	–
SiO_2 (%)	20.5	–	85	–
Fe_2O_3 (%)	2.6	0.04	–	–
Al_2O_3 (%)	5.0	<0.4	–	–
CaO (%)	65.0	–	1.0	–
MgO (%)	1.1	–	–	–
SO_3 (%)	3.6	–	2.0	–
NaO_2 eq. (%)	0.43	–	1.0	<1
Cl^-	0.01	–	<0.1	<0.1
Density	3.15	2.70	2.24	1.085
Blaine (cm^2/g)	4750	5550	2200	–
pH	–	–	–	4.5
Dry extract (%)	–	–	–	41