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TESTING HARDENED CONCRETE USING THE MATURITY CONCEPT

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ABSTRACT

The paper provides an overview of different methods that can be used for concrete maturity determination, outlining Romanian Concrete Code Specification (NE 012-99) in relation to using an effective and rational method in evaluating in-situ concrete strength at different ages.

Keywords: concrete durability; simulation model; maturity index; duration of curing; rate of strength development; frost resistance; strike of time of formwork.

INTRODUCTION

In-situ concrete curing is the most important factor in the concrete construction process. Poor curing practices affect the desirable properties of concrete. Proper curing is essential for the concrete to perform its intended function over the life of the structure, in the scope of obtaining maximum strength and durability. Excessive curing increases construction project cost and cause unnecessary delay in works [1].

MATURITY INDEX METHOD

The standard method of evaluating the concrete strength in monolithic concrete members is to test specimens for compressive strengths. The main disadvantage of this method is that the results are not obtained immediately and that the concrete specimens may differ from that in the actual structure because of different curing and compaction conditions while the strength properties of concrete specimens depends on their sizes and shapes [2].

An alternative to this method is to use the concrete maturity index determination, which takes into account the effects of temperature on strength development after specific curing durations. The main advantage of this method is the fact that the strength determination does not involve destructive tests [2, 3].

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The maturity index determination is used to determine the minimum required concrete strength needed for: striking of forms as the application of construction loads proceeds, assurance of minimum rate of cement hydration during winter operations, inducing precompression by prestressing force release and handling, transport and storage of precast/ prefabricated members [3, 4].

MINIMUM DURATION FOR STRENGTH ATTAINMENT

The minimum duration for concrete strength attainment is influenced primarily by the mix design, environment, exposure and curing conditions [4].

The minimum duration of curing is based on the concrete reaching a specified maturity. Once the specified value is defined, empirical relationships between time, cement type, water-cement ratio, temperature and concrete grade are used to estimate the minimum curing duration. Cementitious addition materials have slower reaction of hydration rates than Portland cement, needing longer curing periods (see table 1 and 2) [2, 5, 6, 7].

SIMULATION MODELS

Over the time, a series of models were used to calculate the maturity index by plotting the heat sifnature surve model according to time and heat capacities of the cementitious materials used [2, 5, 8], such as:

- Nurse – Saul:

$$F_m = (\theta + C)t \;\; [h^oC] \qquad (1)$$

- Dracemnot:

$$F_m = \sum_{i=1}^{n} S_n A^n \;\; [h^oC] \qquad (2)$$

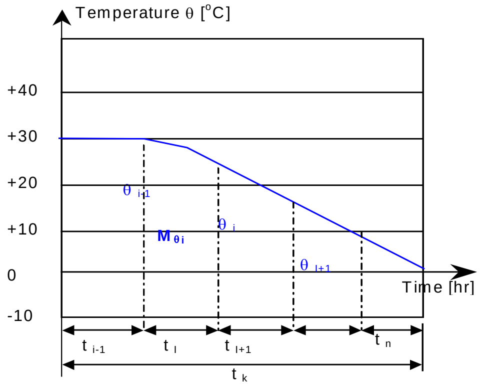
- Freiesleben-Hansen and Pederson:

$$R_\beta = R_u e^{\left(\frac{\tau}{M}\right)^\alpha} \;\; [h^oC] \qquad (3)$$

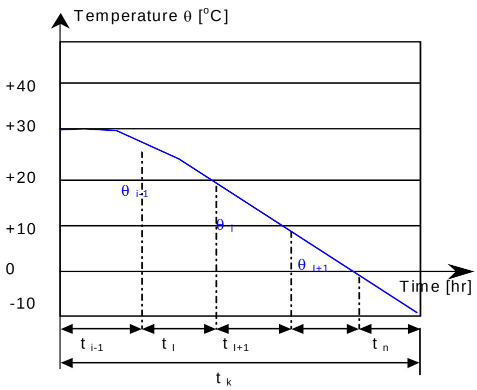
- Knudsen:

$$R_\beta = R_u \frac{\sqrt{k(M-M_o)}}{1+\sqrt{k(M-M_o)}} \;\; [h^oC] \qquad (4)$$

Figure 1 indicates the concrete thermal regime. It represents two characteristic variants, by discreet separation of the time variable in its steps, (a) in which the standard concrete temperature is varying on a straight line from the θ_{i-1} value at the beginning to the θ_i to the end and the second (b) for a concrete that has its freeze temperature artificial lowered through additives.



(a)



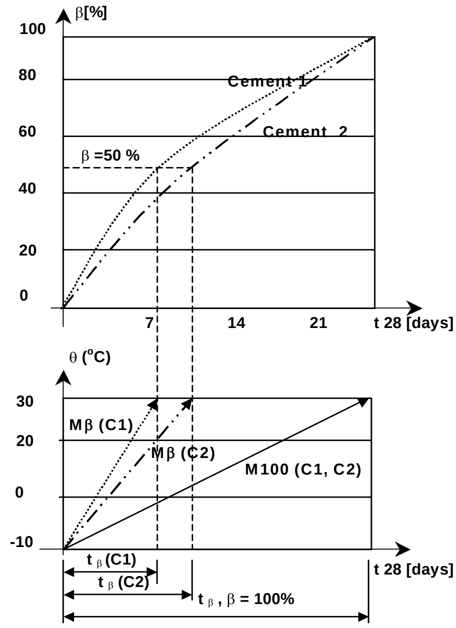
(b)

Figure 1. Temperature variation of concrete for different ages and freezing temperatures

For both graphs, the lower datum temperature was considered as –10°C and the upper datum temperature as +30°C. [9]

The hardening velocity modification is defined by the deviation form the value θ_{ij}, during the t_β duration, which corresponds to a rate of hardening β, that is given by the percentage ratio of the effective compressive strength R_β and the mean conventional strength R_u:

$$\beta = \frac{R_\beta}{R_u}100 \;\; [\%] \qquad (5)$$



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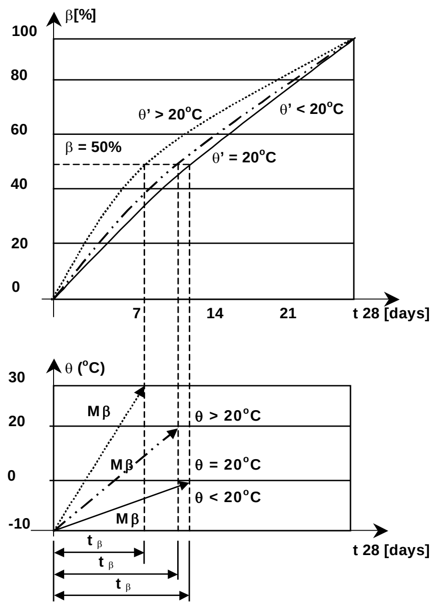

(b)

Figure 2. Variations in the rate of hardening due to the use of different cementitious materials. The rate of hardening–maturity index correlations: (a). β-M_β for different cement types at the normal temperature (θ_N); (b). β-M_β for the same cement types but with different levels of temperature; C1, C2 – different cement types.

CRITICAL CONCRETE HARDENING LEVEL

The deviation from the "normal step of temperature", is defined by two limits. The minimum temperature $\theta_{b\ min}$ = +1 °C (that represents positive values) and the maximum temperature $\theta_{b\ max}$ = +30 °C (that is obtained according to the cement composition) [3], [5].

Beyond these limits, a series of physical and chemical phenomena appear. These phenomena have disadvantageous effects on the concrete structure and implicit on the final strengths that will remain inferiors to those obtained in normal environmental conditions.

If a minimum concrete strength is developed between these limits known as critical hardening level (β_k), in cold weather, the concrete will not be damaged. This strength is defined as the critical maturity index M_k.

The attainment of the critical rate of hardening (β_k), depends on the concrete mix design, type of cement and especially on its voids volume, which is influenced by the water quantity respectively by the entrapped air by compaction.

RATE OF CONCRETE HARDENING IN ACCORDANCE WITH THE THERMAL HISTORY

The concept of maturity establishes correlations between the rate of hardening (β) and the maturity index (M_β) at normal temperature θ_{ij}, but especially for different cement types used in the concrete mix.

The maturity index M_β [hr°C], is defined by the content area between the concrete temperature variation curve and the –10 °C ordinate (datum temperature - theoretical adopted value for which the chemical reactions stop), on the t_β duration (see Figure 1).

The t_β duration can be inferred form the relationship:

$$t_\beta = \frac{M_\beta}{(\theta_{ij} + 10)} \text{ [hr]} \quad (6)$$

The method accuracy regarding the correlation of determination, β - M_β for the usual cements, highlight the fact that the method accuracy decreases if the concrete temperature has great variations in comparison with the environmental temperature θ_N. However, the accuracy is improved by the application of k_θ method [5], [8].

The k_θ method is based on correlations established between the concrete hardening level at different temperature steps (Figure 2 b) and the maturity index M (see table 3).

$$M_\theta = M_\beta^\theta k_\theta \quad (7)$$

The maturity index of concrete, for the interval of time t_i will be calculated as follows:

$$M = (\theta_i' + 10) k_\theta t_i \text{ [hr°C]} \quad (8)$$

Because of the straight-line variation between θ_{i-1} and θ_i temperatures the parameter (θ'_i) used for computing will be considered, as:

$$\theta_i' = \frac{\theta_{i-1} + \theta_i}{2} \text{ [°C]} \quad (9)$$

The maturity index is estimated using the relationships:

$$M = \sum_{i=1}^{n} M_{\theta i}' k_{\theta i} = \sum_{i=1}^{n} (\theta_i' + 10) t_i k_\theta \geq M_\beta^N \text{ [hr°C]} \quad (10)$$

$$M = \sum_{i=1}^{n} M_{\theta i}' k_{\theta i} = \sum_{i=1}^{n} (\theta_i' + 10) t_i k_\theta \geq M_k^N \text{ [hr°C]} \quad (11)$$

Example: The concrete maturity achieved in normal conditions (+20 °C, 28 days) is:

$$M_{28} = (20 + 10) * 28 * 24 * 1{,}00 = 2016 \text{ [hr°C]}$$

CONCLUDING REMARKS

This paper has reviewed the basic concepts related to curing of concrete with emphases on Romanian standard practice. The Nurse-Saul approach is a complex one in which many factors effect the duration of curing, ensuring at the same time that it will develop a sufficient level of its potential properties to perform as intended.

This type of approach needs to be run in tandem with more traditional methods of ensuring concrete curing to asses the practical problems that might arise in applying the tests on site. Since testing specimens for compressive strengths is expensive, the number of tests performed can be reduced, significant savings in labor, storage space, and materials quantities can be achieved. It is not expected that maturity modeling would eliminate testing, but it could substantially reduce the number and duration of tests needed.

LIST OF TABLES

Table 1. Recommended critical cold weather maturity level for concrete (M_K)

Critical maturity index for concrete (M_K) [h °C], (at +20 °C), for different W/C ratio				
Water/Cement ratio	0,4	0,5	0,6	0,7
Cement type II A - S 32.5	850	1 100	1 400	1 620
Cement type I 32.5	750	1 000	1 270	1 500

Where: II A - S 32.5 - Low heat air entrained slag Portland cement
I 32.5 - Ordinary Portland cement

Table 2. Recommended striking off maturity level for concrete (M_β)

Striking off maturity level of concrete (M_β) [h°C], (at +20 °C), for β= [%]									
Hardening level β (%)	10	20	30	40	50	60	70	80	90
Cement Type II A-S 32,5	600	880	1290	1880	2760	4050	5930	8700	12700
Cement type I 32.5	520	740	1150	1690	2510	3720	5520	8200	12100

Where: β - Rate of hardening percentage value according to the concrete grade

Table 3. Values of coefficient $K_{\theta i}$ of equivalency for the maturity level assessed at θ'i temperature and that assessed at the standard temperature of +20 °C

θ'i	$K_{\theta i}$	θ'i	$K_{\theta i}$	θ'i	$K_{\theta i}$
1	0,270	11	0,912	21	1,020
2	0,420	12	0,924	22	1,040
3	0,560	13	0,936	23	1,060
4	0,660	14	0,948	24	1,080
5	0,760	15	0,960	25	1,100
6	0,800	16	0,968	26	1,136
7	0,840	17	0,976	27	1,172
8	0,868	18	0,984	28	1,208
9	0,884	19	0,992	29	1,244
10	0,900	20	1,000	30	1,280

LIST OF SYMBOLS

M maturity index, assessed for the face of the member most exposed to cooling, during the duration t_i [hr °C]
M_{Ki} critical maturity index necessary for obtaining a quality concrete before its complete freezing [hr °C]
M_β maturity index necessary for striking off formwork [hr °C]
M_o the offset maturity index when strength development begins;
t age of concrete [hr];
θ temperature [°C] for duration ti;
$K_{\theta i}$ rate constant involving the maturity index assessed at θ'i and that assessed at the standard laboratory temperature of +20 °C;
β rate of hardening [%];
R_β compressive strength at maturity index M;
R_u ultimate maturity achievable value of strength (MPa);
F_m maturity factor;
C coefficient that depends on the type of cement;
τ time constant;
α shape parameter.

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