TI-B 103 (94)
Test Method
Activation Energy for the Maturity Method

Danish Technological Institute
Building Technology

Test Method
Activation Energy for the Maturity Method

Descriptors:

Concrete, Properties, Maturity, Activation Energy

PRELIMINARY

Version: 1
Date: March 1996
No. of pages: 5
Approved by: SOO

Test Method Activation Energy for the Maturity Method

0. Foreword

This TI-B method determines Activation Energy, E(θ), for the relative rate function H(θ) in a hardening concrete according to the formula:

$$H(\theta) = \exp\left[\frac{E(\theta)}{R}\left(\frac{1}{293} - \frac{1}{273+\theta}\right)\right]$$

The rate of reaction is calculated relative to the rate of the reaction at 20°C or 293°K. For use in practice the Activation Energy, E(θ), is determined as a function of the temperature during the curing process. This temperature dependence is especially distinct at temperatures below 20°C.

1. Background and Scope

This TI-B method specifies a procedure for the determination of the Activation Energy in the Maturity Function for determination of the temperature dependence of the development of concrete property.

The rate of reaction of the curing process, k, as a function of temperature is found from the formula:

$$k = A \cdot \exp\left[\frac{E}{RT}\right]$$

In a diagram with 1/T as X-axis and the natural logarithm to k, ln k, as Y-axis, the ratio E/R will be the slope of a straight line cutting ln A at the Y-axis.

The relative rate of reaction with T_0 as a reference is $H = k_1/k_0$ resulting in the formula:

$$E = (\ln k_1 - \ln k_0) \cdot \frac{R}{\left(\frac{1}{T_0} - \frac{1}{T_1}\right)}$$

Furthermore, the Activation Energy, E, is in itself temperature dependent, E = E(θ). Therefore, it is necessary to measure the development of the property at several temperature levels.

At temperatures higher than 20°C E is a constant, while E is a variable at temperatures lower than 20°C. Generally Activation Energy is expressed as:

$E(\theta) = B$	for $\theta \geq 20°C$
$E(\theta) = B + C(20 - \theta)$	for $\theta < 20°C$

To determine the temperature dependence of the Activation Energy, the development of the relevant property is measured at test specimens cured at 6 different temperature levels: 5, 10, 15, 20, 30 and 40°C.

2. References

ASTM: C 1074 - 87" Standard Practice for Estimating Concrete Strength by the Maturity Method".

3. Definitions

H	=	Relative reaction rate relative to the rate at 20°C
exp	=	Exponential function, e^x
E(θ)	=	Activation Energy, as a function of temperature [J/mol]
θ	=	Actual temperature [°C]
R	=	The gas constant R = 8.314 [J/mol]
k	=	Rate of reaction
k_1, k_0	=	Rate of reaction at the absolute temperatures T_1 and T_0
T, T_0, T_1	=	Absolute temperature [°K]
A	=	Constant
B, C	=	Constants [J/mol]

4. Test Method

This test method determines the Activation Energy for the development of a selected concrete property as a function of temperature.

It is a condition of the method that the curing takes place under conditions that ensure the reaction between cement and water. Curing under water or encapsulation of the test specimens will comply with such requirements.

The test is performed at relatively low temperatures in order to minimize the reducing effect on the final level of the properties caused by curing at high temperatures.

In a semi-logarithmic diagram the concrete properties will develop along an S-shaped curve, with the time at a logarithmic X-axis and the property at a linear Y-axis. The rate characterizing the rate of the development of the property is seen from the straight line, which is the deflection tangent to the S-shaped curve.

In practice the straight line is determined by means of at least 3 measurements of the property made so early in the process that it is possible to determine the line. When deciding on the time intervals for different concrete mix designs, it is necessary both to consider the time of setting and to take into account the rate of reaction at the chosen curing temperatures. The development of the property is measured at 6 temperature levels.

For ordinary hardening concrete the following table may be used as a guide:

Tempe-rature θ [°C]	Rela-tive rate, H	Time of setting Hours	Time intervals Hours			
20	1.0	5 - 8	12	24	36	48
5	0.3	17 - 27	40	80	120	160
10	0.5	10 - 16	24	48	72	96
15	0.75	7 - 11	16	32	48	64
30	1.6	3 - 5	8	15	23	30
40	2.4	2 - 3	5	10	15	20

5. Procedure

The concrete specimens to be used are cast and tested in accordance with the relevant standard, e.g. DS 423.21, 23, 25 and 34.

Three test specimens are used at each time interval.

Immediately after casting the test specimens are stored under water at the chosen temperatures.

The setting time of the concrete is tested at the reference temperature according to DS 423.17.

At the first test interval the forms are removed, and the specimens are marked and placed in water bath until the test is carried out.

The curing temperature is controlled with an accuracy of ± 1°C.

When the properties are tested on specimens which have been cured at different temperatures, the development of the properties will follow parallel lines in the diagram mentioned, as shown in figure 1.

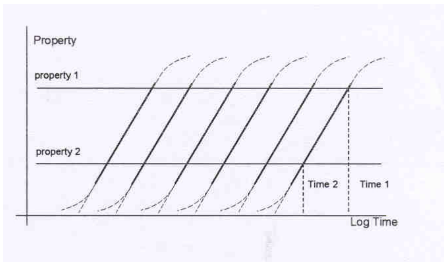

Figure 1
Property as a function of time

In the rectilinear area the rate of reaction is determined for each property as:

$$k_\theta = \frac{(\text{property } 1 - \text{property } 2)}{(\text{time } 1 - \text{time } 2)}$$

For each temperature level the Activation Energy is calculated from the formula:

$$E(\theta) = (\ln k_\theta - \ln k_{20}) \cdot \frac{R}{\left(\frac{1}{T_{20}} - \frac{1}{T_\theta}\right)}$$

6. Test Result

For temperatures higher than or equal to 20°C the constant activation energy is calculated as the average of the three values:

$$E(\geq 20) = (E(20) + E(30) + E(40))/3$$

For temperatures lower than 20°C, C_θ is calculated at each temperature level as:

$$C_\theta = \frac{E(\theta) - E(\geq 20)}{20 - \theta}$$

The constant C is then determined as the average:

$$C = (C_5 + C_{10} + C_{15}) / 3$$

The results are stated as:

$E(\theta) = E(\geq 20)$ for $\theta \geq 20°C$
$E(\theta) = E(\geq 20) + C(20-\theta)$ for $\theta < 20°C$

where both $E(\geq 20)$ and C are stated without decimals.

7. Test Report

A test report shall include at least the following information:

a) Name and address of testing laboratory
b) Date and identification of the report
c) Name and address of client
d) Test method (No. and title)
e) Deviation from the method, if any
f) Identification of the concrete, including mix design
g) Date of test period
h) All related results from test of properties and periods of testing arranged by the level of curing temperature
i) Table showing the calculated rates of reaction and the corresponding calculated values of the activation energies.
j) Test result, refer section 6.
k) Further information of significance for the evaluation of the results
l) Evaluation of the results, if included in the assignment
m) Signature.