

Discussion of articles published in the

Magazine of Concrete Research

Heat of hydration in concrete*

by Erik Rastrup, M.Eng.F.

Contribution by M. G. Hancock

Some recent tests carried out at King's College, University of London, are relevant to Mr Rastrup's paper. In these tests, neat cement pastes of a water/cement ratio of 0.45 were stored at temperatures of 18°C, 50°C and 100°C, and the heat evolution was determined by the heat of solution method. The results have been examined on the basis of Saul's maturity function, i.e. the time-temperature integral, using a base of 0°C. The relationship is shown in Figure 1. There is some experimental scatter, but the points are seen to conform to a fairly clearly defined relationship. Figure 2 shows the same results when plotted against the time-temperature

function $2\theta/10t$ used by Rastrup. Here it will be seen that for temperatures of 18°C and 50°C there is good conformity, but that for 100°C the relationship breaks down completely.

The fact that the results for moderate temperatures can be handled with equal success by both functions is in agreement with both the theoretical and the experimental data in Rastrup's paper. However, in the light of the present results it would seem that Saul's simple time-temperature function is the more general in its application since it can be used to include tests up to 100°C.

Reply by the author

Mr Hancock's contribution is most interesting, as he points out that his results are in good conformity with the time-temperature relationship given in my paper at temperatures of 18°C and 50°C. At 100°C Mr Hancock finds that Saul's maturity function is more suitable and thus has a more general application.

It should be pointed out that the author's tests only

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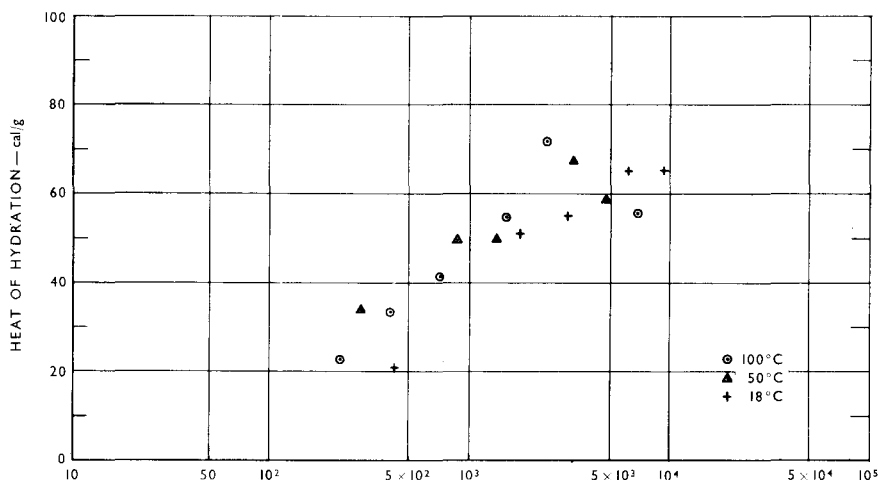


Figure 1: Heat of hydration plotted against θt .

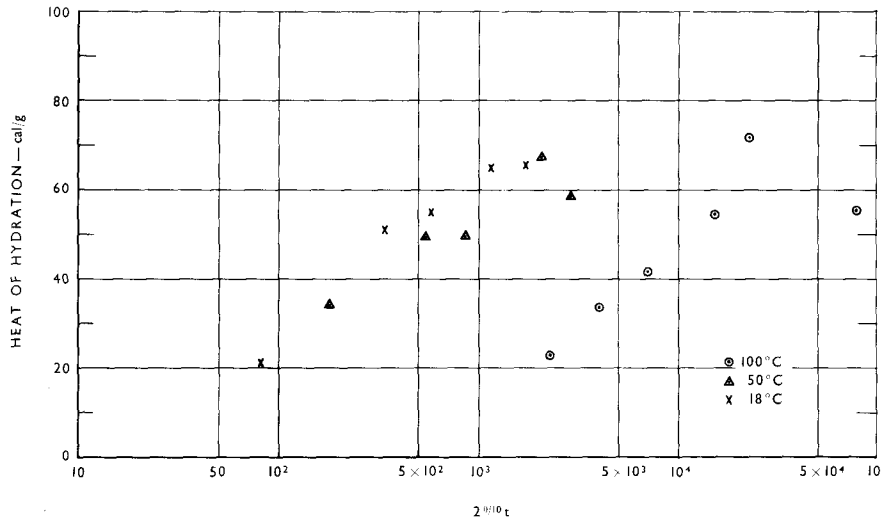


Figure 2: Heat of hydration plotted against $2^{(\theta-100)/10} t$.

comprise the temperature interval between 2°C and 45°C, and the author has stressed that it is not justified to extrapolate beyond this range.

The author has used Mr Handcock's test results for further computation as given below.

The time-temperature function mentioned in the paper

$$\tau_a = \int_0^t 2^{(\theta - \theta_a)/10} dt \dots \dots \dots (1)$$

where θ = temperature of the concrete,
 θ_a = temperature of reference of the process studied, and
 t = curing time,
 is a special case of the general formula

$$\tau_a = \int_a^t f_a dt \dots \dots \dots (2)$$

where f_a may be called the temperature function. Application of Saul's formula gives

$$f_a = \frac{\theta}{\theta_a} \dots \dots \dots (3)$$

and the author's function expressed in the same way gives

$$f_a = 2^{(\theta - \theta_a)/10} \dots \dots \dots (4)$$

It should be noted that f_a is without dimensions, and $f_a = 1$ when $\theta = \theta_a$.

Assuming that the heat of hydration can be expressed by a mathematical function, as for instance that developed by the author,

$$Q = q + Ee^{-\alpha\tau_a - n} \dots \dots \dots (5)$$

single values of f_a may be computed.

Assuming $q = 4$ cal/g, $\tau_a = f_a t$ and $n = \frac{1}{2}$, equation (5) gives

$$Q = 4 + Ee^{-\alpha/\sqrt{f_a} t} \dots \dots \dots (6)$$

TABLE 1: Heat of hydration as function of time and temperature of curing (Handcock).

$\theta = 18^\circ\text{C}$		$\theta = 50^\circ\text{C}$		$\theta = 100^\circ\text{C}$	
Time (h)	Q (cal/g)	Time (h)	Q (cal/g)	Time (h)	Q (cal/g)
23.4	21	5.7	34	2.25	23
98	51	17	49	4.0	33.5
169	55	27	49	7.0	41
339	65	65	67	15.0	55
510	65	94	59	24	71.5
				68	55.5

TABLE 2: Determination of the temperature function f_a .

$\theta (^\circ\text{C})$	$\log f_a$	f_a
18	0	1
50	0.80 ± 0.07	$6.3 \begin{cases} + 1.1 \\ - 0.9 \end{cases}$
100	1.01 ± 0.17	$10.2 \begin{cases} + 4.8 \\ - 3.3 \end{cases}$

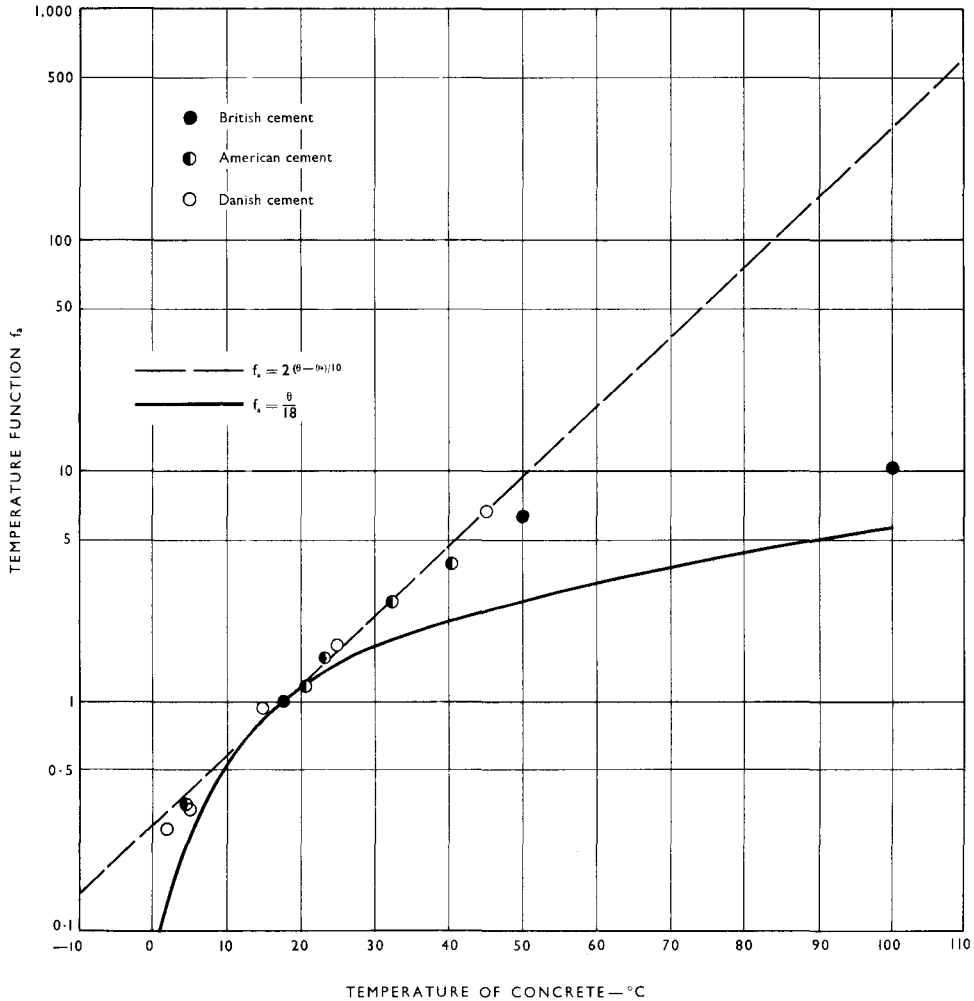


Figure 3: The temperature function f_a plotted against the temperature.

In this equation f_a may be determined from the test results.

Table 1 gives the heat of hydration as a function of time and temperature of curing according to the test results obtained by Handcock as read from Figures 1 and 2.

Table 2 gives the average value and standard deviation for the temperature function f_a obtained by inserting values from Table 1 in equation (6).

A similar computation has been carried out for the two cements mentioned in the original paper, and Figure

3 shows f_a plotted against the temperature of concrete. The scale for f_a is logarithmic.

The curve corresponding to equation (3) (Saul) is shown in full line and to equation (4) in dotted line.

It will be seen—as already pointed out by Mr Handcock—that the author's function $f_a = 2^{(\theta - \theta_a)/10}$ is suitable for temperatures below 45–50°C. Above this limit the function cannot be applied. As the test results are limited it is not yet possible to determine the exact form of the curve.