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EVALUATION OF CONCRETE DURABILITY BASED ON CRACK GROWTH KINETICS DATA UNDER INFLUENCE OF ELEVATED TEMPERATURES

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Abstract
Test results of heating effect up to 800°C on cracking resistance parameters and predictions of time to failure under load were made for light-weight concrete using strength and fracture mechanics techniques.

1 Introduction

The effect of heating temperature on concrete fracture process can be established by the methods of fracture mechanics (Zaitsev and Wittmann, 1981). Based on this theory, one can determine the conditions for both crack growth and critical crack size. In this way time to failure (or durability) can be defined as the time necessary for a crack to grow from the initial size to the final critical size. Time to failure τ can be calculated for a component subjected to a constant applied stress σ_a (Ritter, 1978) according to equation:

$$\tau = B \cdot R_{btc}^{n-2} \cdot \sigma_a^{-n} \tag{1}$$

where B and n are crack propagation constants depending on environmental temperature and material composition; R_{btc} is strength of concrete when no subcritical crack growth occurs during the fracture test.

Taking into account the Weibull distribution function and the probability of failure (P), the equation (1) can be transformed to:

$$\tau = B \cdot \frac{R_{btc}}{\sigma_a} \left[\ln\left(\frac{1}{1-P}\right)\right]^{\frac{n-2}{m}} \qquad (2)$$

In this expression, m, the "Weilbull moduls", is a measure of fracture stress variability about the mean value, functionally related to the standard deviation of the distribution and related to the flaw size distribution; R_{bto} is a scale parameter or normalizing factor.

Special tests were carried out to obtain all parameters of Eq. (2) as well as the fracture energy G_f and the critical intensity factor K_{Ic}.

2 Materials and Testing Procedure

The tests were carried out on a Portland cement light-weight concrete with the mix composition 1:1.95:0.92 and w/c = 0.54. The coarse light-weigth aggregate was expanded clay and the fine aggregate was quartz sand. Samples were concrete prisms 40x40x160 mm and 50x50x320 mm. All experiments were carried out before and after heating up to 800°C with the rate of heating 50°C/h.

The first part of the experimental work was devoted to determine experimentally fundamental fracture mechanical properties of concrete: G_f, K_{Ic}, as well as dynamic Young's moduls (E) and bending tensile strength (R_{bt}). Concrete fracture energy G_f was determined according to stable load-deflection diagrams of concrete, and the "double-torsion" method was used for K_{Ic} determination.

The second part of the experimental work had the purpose to study the influence of loading rate on concrete tensile strength and to estimate the time to failure, depending on heating temperature and load level. The constants B and n in Eqs. (1,2) were evaluated by using strength measurement technique.

A special device has been developed which allows to load specimens at different velocities ranging from 10^{-7}m/s to 10^{-1} m/s. In this kind of experiments, the tensile strength in bending R_{bt} of a set of specimens was determined as a function of loading (stressing) rate, $\dot{\sigma}$. The constant n was calculated from the slope of the logarithmic plot of R_{bt} against $\dot{\sigma}$, while B was obtained from the intercept of such a plot. The value of R_{btc} was measured experimentally using rapid loading rates of specimens to minimise subcritical crack growth before failure.

3 Test Results and Discussion

The main tests results are shown on Fig. 1 and Table 1. One can see that heating temperature and rate of loading of light-weight concrete influence significantly the parameters of crack resistance (G_f, K_{Ic}) as well as the crack growth parameters. For instance, G_f decrease by 45 %, R_{bt} by 78 % and E by 88 %.

Table 1. Fracture mechanical properties of concrete

Heating temp (^oC)	R_{bt} (MN/m^2)	E (MN/m^2)	G_f (N/m)	K_{Ic} ($MN/m^{3/2}$)	B $(N/m^2)^2 \cdot$ sec	n	m
20	1.97	13000	58	0.85	576.9	27.4	12.6
300	1.38	6000	55	0.60	490.2	24.2	10.4
800	0.40	1500	32	0.23	318.8	18.4	7.2

Heating promotes material destruction that leads to its Weibull modulus m decreasing. The tensile strength coefficients of variation V_s for concrete before and after heating to 800^{o}C were equal to 9.1 and 17.2 %, respectively. Such increase of V_s after heating of the specimens also confirms flaws development in a concrete structure. Time to failure, depending on heating temperature and load level (Fig. 2) was calculated according to equations (1) and (2). Taking into account the failure probability (P =0.05-0.2) the τ-values obtained according to eq. (2) were up to 10 times less, than τ obtained according to eq. (1). The differences in τ-values, calculated according to these equations increase with the decreasing of m because of material's destruction. These data were confirmed by the experience of long-term service of furnaces made of light-weigth concrete in petrochemical industry of Low Volga Region.

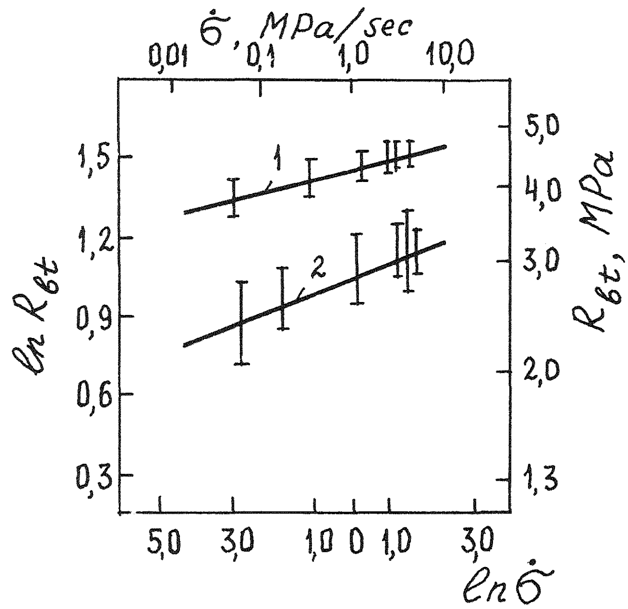

Fig. 1. Concrete tensile strength at bending as a function of stressing (loading) rate $\dot{\sigma}$; 1 - before heating and 2 - after heating up to 800°C.

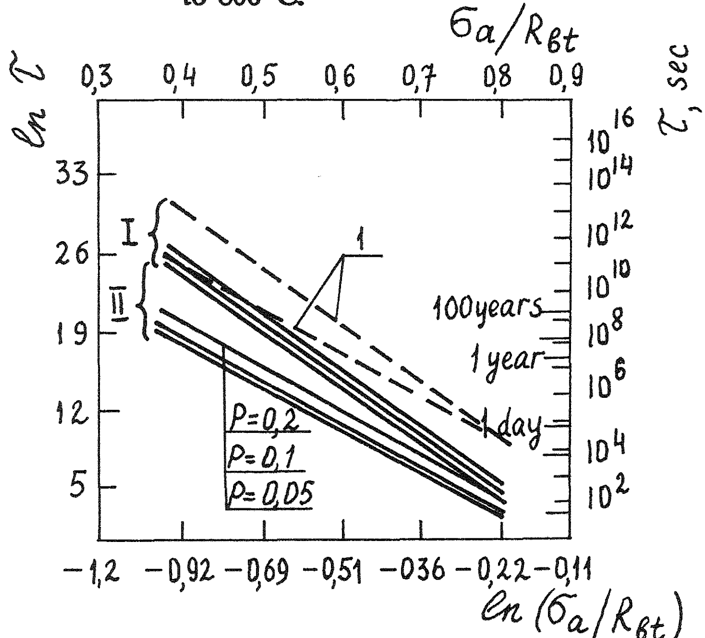

Fig. 2. Time to failure of concrete (τ) depending on heating temperatures and stress applied; I - before heating; II - after heating at 800°C; 1 - τ, calculated according to equation (1).

4 Conclusions

1. Heating of concrete up to 800°C results in decrease of concrete fracture energy G_f by 45 %, bending tensile strength R_{bt} by 78 % and modulus of elastisity E by 88 %.
2. Concrete tensile strength depends both on heating temperature and loading rate of tested specimens. The increase in strength with increasing in loading rate is clearly associated with the phenomenon of subcritical crack growth.
3. Increase of heating temperature up to 800°C leads to decrease of concrete crack propagation parameters B and n (1.45 and 1.33 times respectively).
4. The quantitative estimation of time to failure τ taking into account the failure probability (Eq. 2) for tested concrete is less (up to 10 times) than τ calculated according to Eq. (1). That means that the τ determination must be done taking into account the failure probability.

5 References

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