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CRACK RESISTANCE OF CONCRETE AT TRANSVERSE DISPLACEMENT

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Key words: concrete, crack resistance, stress intensity factor.

Abstract

In the case of concrete failure, destruction or strain caused by transverse displacement the formation and propagation of scratches are controlled by the stress intensity factor K_{IIC}, characterizing the state of stress at the top of the scratch. The paper presents an analysis of the results of experiments concerning the stress intensity factor K_{IIC} for lightweight (keramsite concrete) and heavy (dense) concrete exposed to high temperatures (20–800°C) in section. The methods for determining the factor K_{IIC} are also described.

Accurate determination of K_{IIC} is necessary while making analyses of reinforced concrete structures by mechanics of solid body destruction.

RYSOODPORNOŚĆ BETONU PRZY POPRZECZNYM PRZESUNIĘCIU

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Słowa kluczowe: beton, rysoodporność, współczynnik intensywności naprężeń.

Streszczenie

Przy zniszczeniu i odkształceniu betonów na skutek działania obciążenia poprzecznego formowanie się i propagacja rys są kontrolowane współczynnikiem intensywności naprężeń K_{IIC}, który charakteryzuje stan naprężeń w wierzchołku rysy.

Przedstawiono eksperymentalne badania współczynnika K_{IIC} dla lekkiego (keramzyton) i ciężkiego betonu, poddanych podwyższonym temperaturom w przedziale od 20 do 800°C. Opisano także zasadnicze metody wyznaczania współczynnika K_{IIC} i zanalizowano otrzymane wyniki.

Potrzeba dokładnego wyznaczenia wartości K_{IIC} w dzisiejszych czasach pojawiła się przy opracowaniu metod obliczania konstrukcji żelbetowych za pomocą mechaniki zniszczenia ciał stałych.

Introduction

Work reliability of reinforced concrete structures depends on the crack resistance of concrete. The criterion of crack resistance is the stress intensity factor (K_{IIC}). This factor characterizes the intensity of stress produced in the zone before the end of a scratch, where the process of destruction takes place (curve *AB* in Fig. 1). In practice it is hard to determine stress, but the value of the parameter K_C can be determined: $K_C = \lim_{s\to 0} \sigma_y \sqrt{s}$ ($\mathrm{MPa \cdot m^{1/2}}$), where $S_1,..S_2,...S_n$ – a distance between an electric resistance extensometer on the sample studied, where the stress σ_y is measured.

Similarly as e.g. the Young's modulus or the Poisson's ratio, the parameter K_C plays an important role in engineering practice, as it characterizes the crack resistance of building materials.

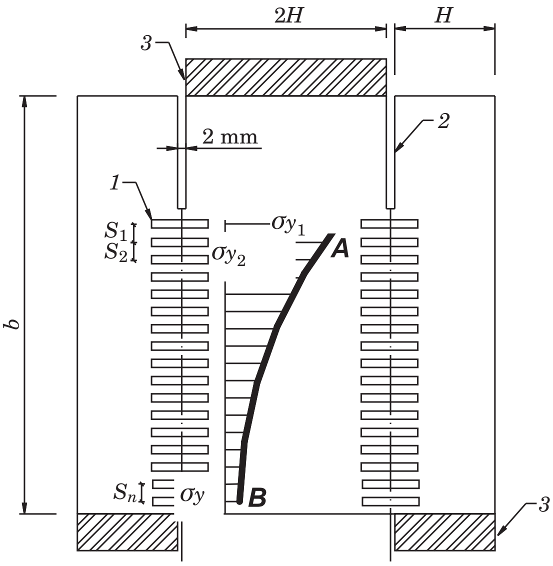

Fig. 1. Determination of the crack intensity factor K_{CP}:
1 – electric resistance extensometers, *2* – artificial crack, *3* – metal shores

The coefficient of tension intensity K_{IC} is the most widespread factor in investigations of materials for cement matrices. It is treated as a one-parameter description of spreading tension in the area of the top of the scratch and samples of different shapes and sizes are used for its determination (PROKOPSKI 1990).

The studies on scratch formation in bent elements show that in the compressed zone there appear horizontal scratches. The strains around these scratches cannot be described using the factor K_{IC} ($MPa \cdot m^{1/2}$) only, as in this case strain caused by tearing off and displacement dominates. Therefore, the factor K_{IIC} ($MPa \cdot m^{1/2}$) has to be determined experimentally, both for samples of reinforced and plain concrete.

The experimental qualification of the coefficients K_{IC} and K_{IIC} at a temperature range from 20 to 800°C was the aim of this work, followed by an analysis of the results obtained.

Materials and Methods

The complex K_{IIC} characteristics should be determined separately, as it would be very difficult to find the sample shape allowing to obtain scratch displacement in its pure form, without orientation change during destructive shearing.

The samples used in the present experiments, aimed at determining the crack resistance of concrete at transverse displacement, were slabs with two parallel artificial scratches. Shearing tests were performed using a support made of steel washers (Fig. 2).

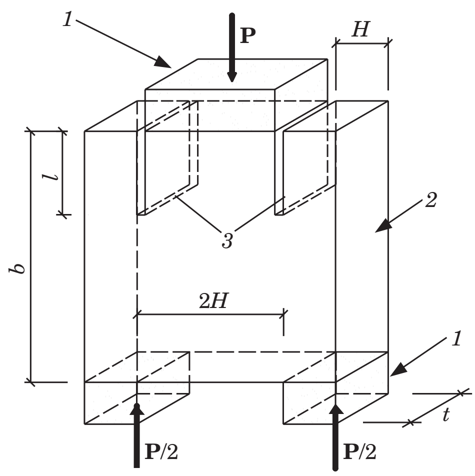

Fig. 2. Sample used in transverse displacement tests:
l, t, H, b – dimensions of sample, *1* – metal shores, *2* – studied sample, *3* – artificial cracks

The parameter K_{IIC} can be calculated from the formula:

$$K_{IIC} = \frac{P}{2tH}\sqrt{lY(l,b)} \quad (\mathrm{MPa \cdot m^{1/2}}),$$

where:

P – destructive force,

$Y(l,b)$ – correction factor depending on the l/b ratio and the value t (Table 1),

l,t,H,b – dimensions of sample (Fig. 2).

Table 1

Value of the function $Y(l,b)$ (Guzeev et al. 1999)

1/b	Y(l,b) by H (m)		
	0.037	0.025	0.012
0.10	1.20	1.10	1.97
0.20	1.26	0.99	0.90
0.30	1.30	0.95	0.76
0.40	1.32	0.95	0.65

The solution of the function $Y(l,b)$ was based on the finite element method – the procedure is given in (Dixon, Strannigan 1972). The test results show (Piradov et al. 1985) that the optimum sample dimensions are as follows: b = 0.15 m, l = 0.05 m, t = 0.05 m, H = 0.04 m.

The specimens were tested on a stand (Fig. 3), which allowed to impose a load at both normal and increased temperatures.

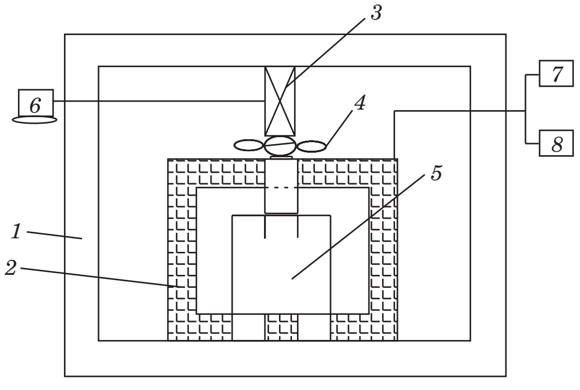

Fig. 3. The layout of the setup for testing samples for crack resistance during normal shearing and transverse shift depending on temperature: *1* – a force frame, *2* – a heating furnace, *3* – a lifting jack, *4* – a dynamometer, *5* – a sample, *6* – a pumping station, *7* – a temperature regulator, *8* – an automatic recorder

Results and Discussion

Samples of heavy concrete and keramsite concrete in a temperature range from 20 to 800°C (Table 2) were tested and the results obtained were analyzed applying the mechanics of solid body destruction.

Table 2

Values of the stress intensity factors KI_C and K_{IIC} ($MPa \cdot m^{1/2}$)
and their dependence on temperature

°C	K_{IC}	K_{IIC}	$\frac{K_{IC}}{K_{IIC}}$	$K'_{IIC}=$ 11.5 K_{IC}	$\frac{K'_{IIC}}{K_{IIC}}$	± %	K_{IC}	K_{IIC}	$\frac{K_{IC}}{K_{IIC}}$	$K'_{IIC}=$ 11.5 K_{IC}	$\frac{K'_{IIC}}{K_{IIC}}$	± %
	heavy concrete						keramsite concrete					
20	0.40	4.50	12.30	4.60	1.02	2	0.32	3.57	11.20	3.68	1.03	3
100	0.25	3,70	14.80	2.88	0.78	–22	0.14	1.98	14.10	1.61	0.81	–19
200	0.14	1,98	14.10	1.61	0.81	–19	0.15	2.06	13.70	1.73	0.84	–16
300	0.20	2,88	14.10	2.30	0.80	–20	0.13	1.76	13.50	1.50	0.85	–15
400	0.18	2,38	13.20	2.07	0.87	–13	0.12	1.50	12.50	1.38	0.92	–8
500	0.17	2,29	13.50	1.96	0.85	–15	0.11	1.40	12.70	1.27	0.90	–10
600	0.16	2,30	14.40	1.84	0.80	–20	0.10	1.37	13.70	1.15	0.84	–16
700	0.14	2,17	15.50	1.61	0.74	–26	0.09	1.21	13.40	1.09	0.86	–14
800	0.13	2,08	16.00	1.50	0.72	–28	0.08	1.10	13.80	0.92	0.84	–16

The results obtained show that an increase in temperature resulted in a decrease in the stress intensity factor in all cases. This indicates a tendency of concretes to brittle failure while drying. A comparison between the results for keramsite concrete specimens and heavy concrete specimens shows that for the former the factor K_{IIC} decreases rapidly, which confirms much lower crack resistance of light concrete while heating.

An analysis of Figures (Fig. 4a, b) demonstrates that the dependencies between the coefficients K_{IC} and K_{IIC} and temperature are critical in a range from 100 to 200°C. A significant decrease of these coefficients in the first segment of the curves is explained by destructive processes connected with water transition from the liquid state to vapor. During this process the pressure in capillaries and pores of concrete increases rapidly, and thermal deformation results in their expansion. In consequence, the existing micro-scratches become deeper and new ones appear. Tensile stress relaxation can be observed in the second segment of the curves. The vapor pressure decreases and thermal deformation takes place at 200–250°C; the pressure stabilizes with further heating. Above a temperature of 250°C the decrease in the values of the coefficients K_{IC} and K_{IIC} is less significant with regard to tensile and stress shearing relaxation(vapor pressure decreasing).

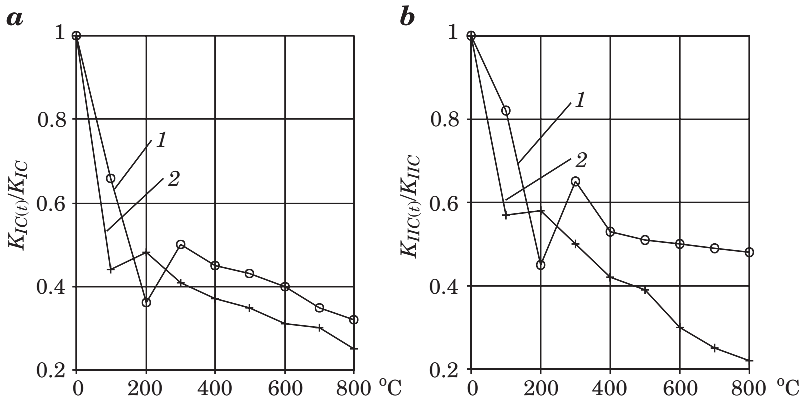

Fig. 4. Dependence of the scratch resistance of concrete on temperature: *1* – heavy concrete, *2* – keramsite concrete

A comparison between the values of factors K_{IC} and K_{IIC} (Fig. 5) shows that concrete resistance at transverse displacement is higher than at normal shearing.

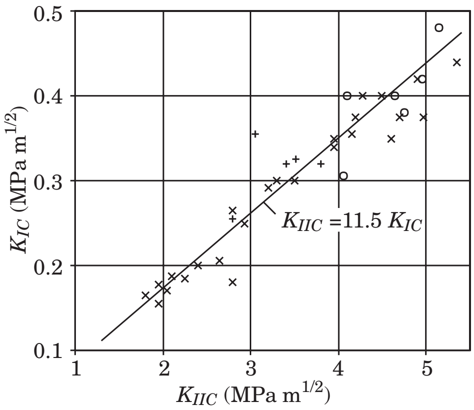

Fig. 5. Dependence of the stress intensity factors K_{IC} on the stress intensity factor K_{IIC} at a temperature of 20°C : o – heavy concrete, + – keramsite concrete, *x* – data (GUZEEV et al. 1999)

If the least square method is applied, the correlation between K_{IC} and K_{IIC} at 20°C assumes the form: K_{IIC} = 11.5 K_{IC}. This allows to determine the value of K_{IIC} with 85% accuracy, which is consistent with the data reported by (GUZEEV et al. 1999). At higher temperatures the factor K_{IIC} changes, which requires its additional correction.

Conclusions

Intensive heating of concrete at high temperatures results in: further development of the existing micro-scratches and the appearance of new ones, reduction in the elastic strain energy accumulated in concrete until the moment of its expansion, lower crack resistance and strength, a decrease in the modulus of elasticity, and an increase in porosity In analyses of reinforced concrete structures the correlation between K_{IC} and K_{IIC} allows to determine the factor K_{IIC}, use the factor K_{IC} and provide the basis for applying the numerical crack resistance parameter in the form:

$$K_C = \sqrt{\left(K_{IC}^2 + K_{IIC}^2\right)} \ (\text{MPa} \cdot \text{m}^{1/2}).$$

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