Substantiation of Reference Method For Determining Concrete's Freeze-Thaw Resistance

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Abstract. It has been analytically proved that using concrete's rate of set ε as a measure of damage, instead of decreasing of tensile strength R, increases freeze-thaw resistance's accuracy of estimation a lot under otherwise equal conditions by the time of freeze-thaw cycling. Also it has been experimentally shown that ratio of relative decreasing R to ε in direction, perpendicular to compression, is assumed to be independent on values R and ε for a given concrete and on the ways of achieving them during mechanical or freeze-thaw cycling. Taking this into account patented methods for estimation of concrete's freeze-thaw resistance as per values R and ε received after freezing and thawing cycles of some specimens and their postliminary failure by linear compression was substantiated.

1. Introduction

Freeze-thaw resistance of concrete is an ability of water-saturated concrete specimen to maintain repeated standard thermo cycles without noticeable damage. Different types of water pressure cause concrete's freeze-thaw deterioration, such as hydraulic and osmotic pressure [1], capillary pressure [2] and other types of water influence according to existing freeze-thaw resistance theory. Decreasing strenght of construction material is associated with the processes of its water freezing (for example, rock [3]). Water gets into structure of porous bodies, separates particles and breaks coupling between them [4]. Porosity of material is determinative factor for frost resistance and durability subsequently [5,6]. So, strength of concrete could be pictured as a porosity function [7]. In order to determine the concrete mix composition, it is necessary to take into account freeze-thaw resistance. Worldwide experience offers some test methods to determine durability of concrete by freeze-thaw damage, such as Slab test [8], CDF [9], CIF-Test [10] and Cube-Test [11]. But they differ in terms of their procedures and conditions and are referenced to particular conditions.

There are two different standard types of methods of determining the freeze-thaw resistance of concrete- basic [12] and reference [13] in the Russian Federation. Considerable spread of values of strength for concrete specimens (variation coefficient ρ≈17%) in constant conditions of preparing and testing determines random spread of choosing average values $\overline{R}$ in the range of $\Delta R / R = \pm 3\rho\sqrt{n}$, where n is the volume of bath of specimens. In this case for proving the significance of relative decreasing $\overline{R}$ on 0,05…0,15 it is necessary to test more that 50 specimens and support $\Delta\overline{R} / \overline{R} = 0.068\overline{R}$, when confidence figure is equal 0,95. Therefore, main disadvantages of the basic method are high labor input and small operability by virtue of the fact that duration of the basic thermo cycle is equal 4,5 at least and $F >> 50$.

One of the existing reference methods is a Dilatometric rapid method of determining the freeze-thaw resistance of concrete [13]. This method is a prototype for the method, which has been offered by me. In this method concrete's freeze-thaw resistance is determined by the maximum relative difference of volume deformations of the tested concrete and standard specimens in accordance with tables provided in standard specification [12] taking into account concrete's type, its form and the size of specimens.

However, the results from the tables provided in state standard specification are acceptable only for Portland cement concrete and slag Portland cement concrete without surface-active additives (PEAHENS), such concretes are used extremely seldom now. Now lot of new concretes are investigated, tested and used, for example, nanomodificated concrete [14], high-strength concrete [15], concrete on the basis of fine-grained dry powder mixes [16], concrete with using recycling concrete aggregates [17] etc. In order to obtain new tables long labour-consuming experiences, which imply using, basic methods are needed [18].

2. Project's objectives

The aims of this paper are to obtain the dependence between relative decreasing in strength by rate of strain and substantiate the new method for determination of concrete frost resistance. Using of measure of damage D by the time of freeze-thaw cycling is offered for removal of disadvantages. In accordance with experimental data [19, 20] dependence $D = Ac^q$ is well approximated, where: $A = D_0$ (when c=1) – value of D after first thermo cycle; c – number of thermo cycles; q – constant of material.

In accordance with this statement, evaluation of maximal measurement errors (ΔF and $\Delta F / F$) by the time of determination F is possible with help of dependence:

$$\delta R = A \cdot c^q, \tag{1}$$

where $A = \delta R_1$ (when c=1) – decreasing of strength after first thermo cycle and δR – decreasing of original strength R. The first consequence from (1) covers to constant of material q:

$$q = \{\ln(\delta R_c / \delta R_1)\} / (\ln c) \tag{2}$$

After differentiation (3):

$$q\frac{\Delta F}{F} + \{\ln(F/c)\}\Delta q = \frac{\Delta R}{R} + \frac{\Delta \delta R_c}{\delta R_c} \Rightarrow \pm\frac{\Delta F}{F} - \frac{1}{q}\left\{\left|\frac{\Delta R}{R}\right| + \left|\frac{\Delta \delta R_c}{\delta R_c}\right|\right\} + \{\ln(F/c)\}\left|\frac{\Delta q}{q}\right| = 0, \tag{3}$$

where $\Delta R / R$, $\Delta \delta R / \delta R_c$ >> $\Delta R / R$ and $\Delta q / q$ are maximal relative measurement errors of determination original value R, decreasing R after c thermo cycles or values q correspondingly. By the time of using non-destructive method [21] $\Delta R / R$ =0,03 or $\Delta R / R$=0,068, when we used bathes from 25 specimens. So, $\Delta \delta R / 2\Delta R$.

Therefore, $\Delta F / F$ depends on the measurement errors of strength $\Delta R / R + \Delta \delta R_c / \delta R_c$ with accumulation factor $1/q$ and measurement error of $\Delta q / q$ with accumulation factor $\ln(F/c)$. If $q = 1$ ($\Delta q = 0$), that we will get measurement error of calculation F by $\delta R / \delta R_{1c}$ from (3):

$$\pm\frac{\Delta F}{F} = \left|\frac{\Delta R}{R}\right| + \left|\frac{\Delta \delta R_c}{\delta R_c}\right|, \tag{4}$$

where $\Delta R / R \approx 0{,}03$; $\Delta \delta R_c = 2\Delta R \approx 0{,}06R$; $\Delta R_c \le [\delta R / R] = (0{,}05...0{,}15)R.$

After differentiation (2):

$$\frac{\Delta q}{q}=\frac{1}{\ln(\delta R_c/\delta R_1)}\left\{\frac{\Delta\delta R_c}{\delta R_c}+\frac{\Delta\delta R_1}{\delta R_1}\right\}, \qquad (5)$$

where $\Delta\delta R_c=\Delta\delta R_1=2\Delta R;\ \delta R_c=\delta R_1 c^q;\Delta\delta R_1/\delta R_1>>\Delta R/R.$ After plugging (5) in (3):

$$\frac{\Delta F}{F}\approx\frac{1}{q}\frac{\Delta\delta R_c}{\delta R_c}\left\{1+\left(\ln\frac{F}{C}\right)\left(\frac{1+c^q}{\ln c}\right)\right\}. \qquad (6)$$

Accumulation factor $\frac{1+c^q}{\ln c}$ (when $q=1$) has a minimum when $c=4$ and is numerically equal 3,6. When F = 40 and $c=4\ln(F/c)=2{,}3$ = 4; $\left(\ln\frac{F}{C}\right)\left(\frac{1+c^q}{\ln c}\right)\approx 8{,}3$, and $\frac{\Delta F}{F}\approx\frac{9{,}3}{q}\frac{\Delta\delta R_c}{\delta R_c}$. While $\Delta\delta R_c=\delta Rc$ (when c is too small), it is $\Delta F/F\approx 9{,}3/q.$ The result proved that contribution of measurement error of q in $\Delta F/F$ is more in 8 times than contribution of measurement error of R. It's the case, when measure of damage is a decreasing of strength. To decide this problem using of rate of strain $\varepsilon=\delta l/l$, where $l\approx 100mm$ – base length, $\delta l=l_c-l$ – the base deformation and l_c – base length after "c" thermo cycles, is offered. But for that it is necessary to determine dependence between decreasing in strength and rate of strain. So, this value is defined as $z=(\delta R/R)/\varepsilon$.

3. Formatting the text

To determine this dependence concrete mix was tested. Mix contained a portlandt cement (12%) of brand 400, sand (25%), granite crushed stone 5 … 20 mm (56%) and water (7%). 108 samples cubes with an edge of 150 mm were prepared. There points of intersection of diagonals of opposite sides were spaced far apart from each other (to 1,5 mm). Samples hardened 28 days in water at the room temperature, and then 60 days in damp sand at 18 … 26°C. From these 108 samples, 8 samples were cycled alternately thermally and mechanically, and 100 samples were used for a frost resistance assessment by a basic method. At realization of a basic method l distance between points of each sample was measured by means of a tool microscope before tests for frost resistance or for durability. Rate of strain was counted as. Changing of distance between points at realization of a method [22] was carried out on 20±2 °C before and after cycling by means of a bracket with variable base and a measuring head of our type (the price of division of 1 micron). Threshold loading of a water-saturated sample was determined by a way [23], registering the acoustic issue (AI) by means of the AF-15 device at cyclic loading and unloading of a sample to zero. In the first experience load of L was brought to 11 t; in the absence of acoustic issue in the course of the end of unloading value of L was increased by 5% and so until at the end of unloading there was no AE. For accepted an average of L two last cycles. The limit of long durability was found as the relation to the average area of two loaded sides. Dependence z was determined as $(L_1- L_2)/ L_1 e$, where L_1 is a maximal value L in the first loading and L_2 – in the second loading (fig. 1). Results of this experiment are given in the Table 1. Dependence z is near to linear.

Table 1. Results of experimental determination dependence between R and ϵ after 20, 42, 84 and 105 cycles (thermocycles and mechanical cycles)

№ of specimen		1	2	3	4	5	6	7	8	Average
Origin value R_0, [MPa]		9,45	16,8	22,7	23,4	24,3	24,3	25,0	30,1	22,0
After 20 cycles	R_0, [MPa]	9,18	16,2	22,2	22,7	23,5	23,9	24,1	29,4	
	$\delta R/R \cdot 10^5$	2857	3571	2203	2991	3292	1646	3600	2326	2811
	$\varepsilon \cdot 10^3$	216	210	204	206	204	200	202	190	204
	z	13,23	17,00	10,80	14,92	16,14	8,23	17,82	12,24	13,8
After 42 cycles	R_0, [MPa]	9,03	16,15	21,9	22,3	23,4	22,9	23,9	20,4	
	$\delta R/R \cdot 10^5$	4482	3869	3524	4701	3704	561	4440	3222	4213
	$\varepsilon \cdot 10^3$	406	452	404	408	394	396	410	394	408
	z	11,04	8,56	8,72	11,52	9,40	14,55	10,73	8,18	10,32
After 84 cycles	R_0, [MPa]	8,10	14,7	19,1	21,2	21,0	23,0	22,6	26,7	
	$\delta R/R \cdot 10^5$	1429	893	1586	940	1244	1230	1253	1130	1213
	$\varepsilon \cdot 10^3$	1206	1217	1188	1196	1201	1207	1196	991	1175
	z	11,85	5,31	13,35	7,86	10,36	9,31	7,36	11,04	9,55
After 105 cycles	R_0, [MPa]	7,75	14,2	18,6	20,1	21,1	20,9	21,4	26,4	18,8
	$\delta R/R \cdot 10^5$	1799	1547	1806	1410	1317	1399	1440	1229	1488
	$\varepsilon \cdot 10^3$	1582	1440	1435	1534	1561	1459	1297	1196	1439
	z	11,37	10,74	12,59	9,19	8,43	9,59	11,10	10,28	10,40
$\bar{z}$ for specimen		11,40	10,76	11,04	10,73	10,21	10,30	11,05	10,34	$\bar{\bar{z}}$ =10,73
R- average value of the long-term strength in conditions of compression, δR decreasing R after specimen cycling, ε - rate of strain in the direction, perpendicular compression; $z = (\delta R / R) / \varepsilon$;								S^2	S	ρ
								1,94	1,394	0,134
z_k-value z after 105 cycles; $\bar{z}$ - average value z for specimen; $\bar{\bar{z}}$ - average value for $\bar{z}$; S^2 –sampling variance; S-mean square deviation; ρ- variation coefficient								0,183	0,428	0,04

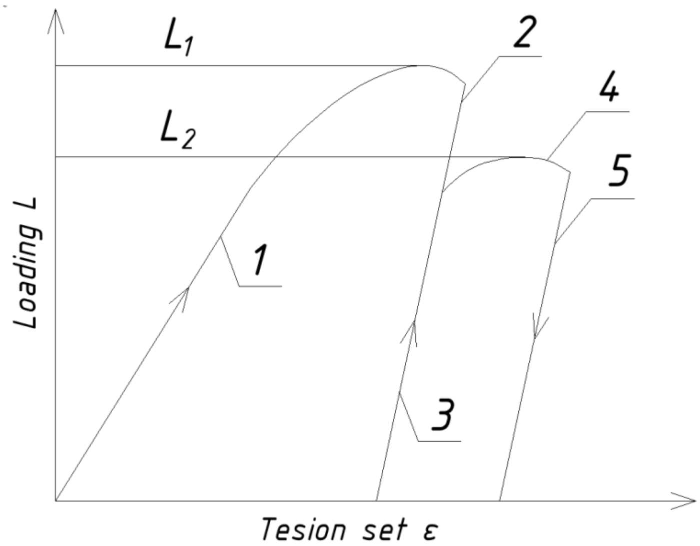

Figure 1. This is a shedule of specimen loading in conditions of monoaxial compression after thermocycles: 1 – line of first loading; 2 – line of first unloading; 3 – line of second loadind; 4 - line of second loading; 5 - line of second unloading; ε – relative longitudinal tension set; L_1 – extreme loading of the first loading; L_2 – extreme loading of the second loading.

Also results by non-destructive method were compared with results by standard method (Table 2)

Table 2. Comparison results by non-destructive method and standard method.

Average value of:	Non-destructive method	Basic method
δR/R	0,1488	0,161
ε	0,01439	0,01448
z	10,4	11,1

Results

Results by non-destructive method differ 6,3% from results by basic method. Also this dependence is not delicate to changing some thermo cycles to mechanical cycles. So, value of z is constant and dependence of relative decreasing in strength is linear. After mathematical manipuleations it becomes clear, that using ε as a measure of damage is more accurate than using δR, in approximately in 35 times.

After taking into account theese results new method for determination of concrete frost resistance was offered by application for a patent [24].

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