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POSSIBLE RAPID METHOD FOR THE DETERMINATION OF CONCRETE'S FROST RESISTANCE

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During this research, the theoretical analysis of dependence concrete's frost resistance of sample and energy, which is emitted by a sample at destruction, was carried out. The offered method includes measurement of residual deformation of a sample after the one cycle of freezing defrosting, measurement of long strength and measurement of short-term strength. Frost resistance of a sample is as the mathematical relation of these energies, and the frost resistance of concrete is calculated as arithmetic mean on samples. The offered method doesn't demand long tests, it's high efficiency and wide scope, but special laboratory equipment is necessary.

Key words: Frost resistance, concrete, Dilatometric method, Non-destructive loading, Acoustic issue

INTRODUCTION

For determining the concrete mix composition it is necessary to take into account frost resistance. Frost resistance of concrete is ability of water-saturated concrete sample to maintain repeated standard thermo cycles without noticeable damage.

If filling concrete's pores water turn into ice, it will increase in volume and cause concrete's micro cracks. When number of cycle freezing-defrosting increases, damages of concrete are collected, and its durability decreases [24, 25]. Also different types of water pressure cause concrete's frost deterioration, such as hydraulic and osmotic pressure [37], capillary pressure [12] and other types of water influence according to existing theory of frost resistance [18]. Decreasing strenght of construction material is associated with the processes of its water freezing (for example, rock [24, 22]). Water gets into structure of porous bodies, separates particles and breaks coupling between them [11]. Porosity of material is determinative factor for frost resistance and durability subsequently [38, 39]. So, strength of concrete could be pictured as a porosity function [23].

Of course, at the present time analytical [45] or computational methods allow to simulate concrete behavior under service conditions and estimate durability of material [10], but every research need to be proven by testing nature samples [43] and good data base [44]. In worldwide experience there are some test methods to determine durability of concrete by frost damage, such as Slab test For determining the concrete mix composition it is necessary to take into account frost resistance [40], CDF [36], CIF-Test [35] and Cube-Test [10]. These test methods contain follow steps: curing and preparing the samples, pre-saturation samples and thermo cycling of them. The test liquid simulates a deicing agent and contains 3 % by weight of NaCl and 97 % by weight of (demineralized) water in case of the test of the freeze-thaw and deicing salt resistance and demineralized water to test the freeze-thaw resistance of concrete respectively. Scaling of the samples is measured after a well defined number of freeze-thaw cycles and leads to an estimate of the resistance of the tested concrete against frost damage. The test methods differ however in their procedures and conditions. So at CIF test contain determination of internal damage by measuring of the relative dynamic modulus of elasticity (to take into account ultrasonic transit time) [16]. Also there are some models of labor concrete damage due to cyclic freezing and thawing, for example interaction of load and freeze-thaw cycles with chloride exposure regime on surface scaling process of concrete and the internal cracking process [23]. There are two different standard types of methods of determination concrete's frost resistance

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- basic and rapid in Russian Federation.

Basic methods [19] include production and test of samples by series. Further, all samples have been sated by water and part of samples have been alternated repeating freezing and defrosting. After that all samples have been destroyed by compression. For comparison of average values of strength, both types of samples are taken: tested with freezing defrosting, and not. The next step is to define relative decreasing in strength of material under different number of term cycles. Concrete's frost resistance is defined by number of thermo cycles, which necessary for decreasing in strength in limits, stipulated by the standard [51-55].

During estimation of concrete's frost resistance considerable random dispersion of values of concrete strength (variation coefficient ρ = 15 … 20%) [16] under invariable conditions of production and tests of samples gives rise to a wide scatter of average values of strength and demands large volume test (quantity of test pieces 25 … 50) as proof that relative decreasing in strength of $\Delta R/R$ = 0,05 … 0,15 as a result of freezing defrosting.

Therefore, the basic methods have two main weaknesses: high labour input and small operability. Determination of frost resistance by basic methods takes big time intervals (from 1 to 6 months), so the rapid methods are necessary.

One of the existing rapid methods is a "Dilatometric rapid method for the determination of frost resistance" [19]. This method is a prototype for method, which has been offered by me. Dilatometric rapid method for the determination of frost resistance includes production of concrete samples, measurement of samples, determination of initial volume, saturation of samples by water, simultaneous freezing of each sample sated with water and a standard sample in the dilatometer up to the standard temperature and measurement thus differences of values of volume deformations of the concrete and standard samples (relative changing of volume). Concrete's frost resistance is established by the maximum relative difference of volume deformations of the concrete and standard samples in accordance with tables provided in standard specification [19] taking into account a type of concrete, a form and the size of samples [03-08].

However, the results from tables provided in state standard specification are acceptable only for concrete on a Portland cement and slag Portland cement without surface-active additives (PEAHENS), such concretes are used extremely seldom now. Now lot of new concretes are investigated [47], tested and used, for example, nanomodificated concete [21, 44], high-strength concrete [22,33], concrete on the basis of fine-grained dry powder mixes [17], silica particles [48], concrete with using recycling concrete aggregates [17] etc. For obtaining of new tables long labour-consuming experiences with using basic methods are needed [13,14,15].

Task of project is expansion of methods for rapid definition of concrete's frost resistance, decreasing labour input and increasing operability. Also cost of testing is one of the most important problems in our day [46], but it's not purpose of existing manuscript.

OFFERED METHOD FOR DETERMINATION OF CONCRETE'S FROST RESISTANCE

Suppositive solution belongs to test methods of porous water-saturated bodies and is intended for definition of brand of concrete on frost resistance. That is number of standard cycles of freezing defrosting (for example, from +20 to -18±2˚C for 4 hours), necessary for decreasing in strength of samples sated with water, at a size stipulated by the standard specification, in particular, for 5 or 15%, i.e. relative decreasing in strength of $\Delta R/R$ = 0,05 … 0,15.

Sample's long-time strength in the conditions of stretching correspond irreversible development of cracks in a concrete sample. Definition of relative tension set and long-time strength of a sample of a sample allows estimating the energy disseminated on processes destructions per unit of volume of material in the course of freezing-defrosting as per formula:

$$W_{tc}=\theta_{rel} R_{lt} \quad (1)$$

where:

W_{tc} – the energy per unit of sample's volume disseminated in the course of freezing-defrosting;

Θ_{rel} - relative tension set of a sample;

R_{lt} - sample's long-time strength in the conditions of stretching;

R_{lt} is calculated by corresponding to it greatest nondestructive loading in the conditions of stretching L_0, which is determined by experiment. Longevity of concrete takes infinite value without outreaching L_0.

In our time concept of greatest nondestructive loading L_0 is usefully employed for express-monitoring different kinds of long resistance, such as durability (mechanical and exegetical), remaining life of product, longevity [29], frost resistance [02, 03, 35], cracking resistance, erosion behaviour [30], corrosion [07] and time-dependent deformation [08].

In time of freezing development of concrete's damages is explained of subcritical cracks growth. In the brittle solids cracks begin to take off by shearing action [29], also speed of them development is no more than 10-4 m/s [33, 34]. Therefore in conditions of freezing water filled crack in concrete capture of the nearby closed pores. It stabilize pressure in the water filled crack about the value causing in a material stretching tension, equal to long-time strength of a sample in the conditions of stretching.

If temperature body change since 78 K to 1493 K and loading is like describing earlier, value L_0 shifts inside of deviation determination of it, i.e. 1÷3% [30]. This fact permit to use value L_0 received at a low temperature, when energy per unit of sample's volume disseminated in the course of freezing-defrosting is established.

Sample's loading in the conditions of monoaxial compression to extreme loading, registration these values of axial loading and axial strain, corresponding to loads, allows to calculate energy per unit of sample's volume disseminated in the course of its compression to extreme loading by numerical integration of dependence of axial loading from axial strain.. Value of the energy disseminated in unit of volume of a sample in the course of its compression to extreme loading, in proportion to a square of short-term strength [01]:

$$W_{com}=\alpha R \qquad (2)$$

where:

W_{com} – the energy per unit of sample's volume disseminated in the course of its compression to extreme loading;

R – short-term strength;

α – proportionality coefficient.

The logarithmation of expression (2) and the subsequent differentiation introduce the dependence between relative decreasing in the energy disseminated per unit of volume of a sample in the course of its compression to extreme loading and relative decreasing in short-term strength:

$$\Delta W/W_{com} = 2\,\Delta R/R \qquad (3)$$

where:

ΔW – absolutely changing of energy disseminated in unit of volume of a sample in the course of its compression;

ΔR – absolutely changing of short-term strength;

The formula (3) allows to pass from relative decreasing in short-term strength allowed by the standard for concrete to admissible for a studied sample to relative decreasing in the energy [ΔW] disseminated per unit of volume of a sample:

$$\Delta W=2W_{com}\,[\Delta R/R] \qquad (4)$$

where:

[ΔW] - standard absolutely changing of energy per unit of sample's volume disseminated in the course of its compression to extreme loading.

Thus, frost resistance as number of freezing defrosting will defined by the relation between admissible absolute changing of the energy per unit of volume of a sample disseminated in the course of compression and energy per unit of sample 's volume disseminated in the course of freezing defrosting, i.e. as per formula:

$$F_{sam}= [\Delta W]/W_{tc} \qquad (5)$$

where:

F_{sam} – concrete sample's frost resistance;

REALIZATION OF OFFERED METHOD

This way is realized as follows. First of all is making samples in the form of cylinders or cubes with an edge of 10 sm. from concrete mix of demanded structure. After curing samples are sated with water, measured. Further greatest non-destructive loading of L0 is defined for each sample by a nondestructive testing, for example a method of acoustic emission [30, 31]. Without outreaching L_0 a sample's crack doesn't develop yet in the conditions of stretching. Expedient stretching tension in cylinders or cubes is created compression of them on lines of contact of cylinders with the plane (splitting). If L0 is determined, it is possible to calculate a limit of long durability for the tested sample:

$$R_{lt}=2L_0/\pi S \qquad (6)$$

where:

S–area of section of a sample, perpendicular compression planes;

L_0–the greatest nondestructive loading of a sample in the conditions of stretching.

After sample's freezing-defrosting up to the standard temperatures and definition of relative tension set of a sample it's possible to calculate the energy per unit of sample's volume disseminated in the course of its freezing defrosting as per formula (1).

Further, a sample is squeezed in the conditions of monoaxial compression to extreme loading, and the current values of axial loading and relative tension set of a sample corresponding to them are registered. Numerical integration of dependence of axial loading from absolute relative tension set of a sample and distribution of its result on the volume of a sample allows calculating the energy per unit of volume of a material disseminated before achievement of extreme loading. Frost resistance for a concrete sample Fsam is calculated by the received results as per formula:

$$F_{sam}=2[\Delta R/R]\cdot W_{com}/W_{tc} \qquad (7)$$

where:

Concrete's frost resistance is found as an average of values of frost resistance for samples. Confidential interval of concrete's frost resistance is counted on dispersion of values of frost resistance for a series of samples.

In particular, this way was realized on 10 samples cubes, an edge of 10 cm at the age of 88 days made of a concrete mix of such structure: Brand 400-1 portlandtsement weight part, sand – 2 weight parts, granite rubble 5 … 20 mm – 4,5 weight parts, waters – 0,6 weight parts. It is experimentally established in two different ways for this concrete at the age of 88 days that after 105 freezing-defrosting corresponding to brand of this concrete on frost resistance, average relative decreasing in strength makes 0,142 on a way [30] and 0,16 on the basic way [19], that is both values lie within an error of the used ways. On the average relative decreasing in strength makes 15%.

Samples have been sated with water according to item state standard specification, measured and registered volume. For each sated with water cube splitting according to item value of the greatest nondestructive loading (without which excess of a crack in a sample don't develop yet is irreversible) were defined. After each test the plane of compression of a sample was changed for the perpendicular plane to previous compression. Definition of the greatest nondestructive loading carried out by means of an acoustic issue way, using the AF-15 AE-complex of Kishenevskiy manufacture. Acoustic sensors with a frequency of 20-200 kHz established on the verge of a sample, parallel to plane of compression. For creation of axial loading a hydraulic press was used. By received value of the greatest nondestructive loading, corresponding to it value of a sample's long-time strength in the conditions of stretching was counted. Then average value of a long-time strength was counted too. Results of calculating are given in the table.

The water-saturated samples were placed in the measuring camera of the differential volume dilatometer DOD-100-K, and in its second camera a standard aluminum sample was placed. Both cameras were filled with kerosene and pressurized. The dilatometer with samples was installed in the freezer and after 30 min. endurance freezing with a speed 0,3˚C/mines before achievement of temperature (-18±2) ˚C was began. According to the dependency diagrams of differences, relative volume tension set of a concrete and aluminum sample was calculated. Energy per unit of sample's volume disseminated in the course of its freezing-defrosting as per formula (1) for each sample.

Further average value of sample's long-time strength in the conditions of stretching was defined as arithmetic average Rlt values long-time strength in the conditions of stretching.

Axial compression of samples by splitting [52] with a speed of 400 kg/sec. carried out on the hydraulic press equipped with the graph plotter of dependence of axial loading from axial strain. Values on a dynamometer are determined by the location of the conducted and conducting arrows being part of the closed electronic chain with a control bulb. Removal of sample's loading was begun on a signal of the control bulb, which is switched off by electro contacts on a conducted and conducting arrow of a dynamometer. The conducted arrow of a dynamometer press registered value of the maximum loading. By the dependence received on the graph plotter the area under it was determined, i.e. received the energy disseminated per volume of a sample in the course of its compression to extreme loading. The energy per unit of sample's volume disseminated in the course of its compression to extreme loading, was received as per formula (8):

$$W_{com}=W/V \quad (8)$$

where:

W-energy disseminated of sample in the course of its compression to extreme loading;

V-sample's volume.

Then for each sample brand of a concrete sample on frost resistance was counted (Table 1) as number of freezing defrosting necessary for decrease in its strength for 15% on as per formula (7).

Further, an average for values of the F15i, and an average square deviation of results of experience were calculated:

$$S=\frac{\sqrt{(F_{15i}-\overline{F_{15}})}}{3} \quad (9)$$

where:

S – an average square deviation of results of experience;

F_{15i}- the value concrete i-sample on frost resistance at decreasing sample's short-term strength in the conditions of compression for 15%, received by the offered way; where i is changed since 1 to 10;

(F_{15}) – concrete's frost resistance, equal to arithmetic-mean value of frost resistance for series of concrete samples at decreasing theirs short-term strength in the conditions of compression for 15%.

The average square deviation of F_{15i} values was equal 16. Taking into account it, a divergence of average value of frost resistance of concrete is take on 99,7 and the earlier experimentally found number of cycles 105 (F_{15} brand) necessary for decreasing R for 15%, it is possible to consider casual, and the offered way is correct.

SUMMARY

The offered way expands a list of technical means for the rapid definition of concrete's frost resistance. Duration of determination of frost resistance is caused by the time of sample's water saturation (4 days according to standard specification [19]). In our time, there is existing pending patent application for offered way. Detailed researches and pilot studies are necessary to get more data that are experimental and create new method of determination of frost resistance in future.

Table 1: Definition type concrete's frost resistance as per offered method

№	R_{lt} MPa	Θten•10^4	W_{tc}•10^4 MPa	W_{com} •10, MPa	[ΔW] •10^2 , MPa	F_{15i}
1	1,5	2,7	4,05	0,9990	2,997	74
2	1,7	3,1	5,27	1,7215	5,165	98
3	1,8	1,8	3,24	1,2312	3,694	114
4	1,9	2,6	4,90	1,6796	5,039	102
5	2,0	2,5	5,00	1,4333	4,300	86
6	2,1	1,9	4,00	1,4364	4,309	108
7	2,2	2,6	5,72	2,2308	6,692	117
8	2,3	2,1	4,83	1,3846	4,154	86
9	2,9	1,8	5,22	1,6008	4,802	92
10	3,1	1,5	4,65	1,8600	0,558	120
Average	2,15	2,1	4,69	1,5577	-	99,7

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