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Materials Science

Influence of Moisture Conductivity on the Creep of Cement-Based Composites during Torsion

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The processes of materials moisture conductivity with the environment (drying, moistening) and their influence on the creep of cement-based composites are investigated. Long-term torsion tests are conducted on specimens of concrete and steel-fiber concrete. The experiment's goal is to determine the effect of moisture conductivity in the environment on creep deformations. During the creep test, the specimens (cylinders with a diameter of 70 mm and length of 610 mm) experienced a process of drying and moistening with different intensities. "Standard" specimens were tested. $t_0 = 28$- Day specimens were received "standardly", which, during manufacturing and before testing, were saved at "standard" conditions: air relative humidity $\varphi = 100\%$, temperature $T = 20 \pm 1^0 C$. At the beginning of testing specimens moisture content was $W_0 = 4.7\%$ (according to mass). Part of specimens was dried up to moisture content of $W_0 = 1.0\%$ (according to mass). Creep test duration was 240 days. Specimens were tested in chambers with relative humidities of 100, 70, 50, and 20%. Experiments reveal that creep deformations are intensifying at torsion during specimen drying and moistening processes. Ongoing creep and relaxation processes that are complex and simultaneous and take place in cylinders during moisture conductivity between specimens and the environment are defined. This is due to a humidity gradient, during which moisture content in the specimen's lateral section changes over time, and therefore stresses according to the radius will be different. Variable moisture in given humidity terms, variable moisture is a function of radius and time. Variable moisture in the specimen's lateral section is determined by test outcome and theoretical processing. Equations according to time and radius to be usable in variable moisture cylindrical specimen torsion tasks are created and are based on the concrete shear creep nucleus universal expression established by us. Dividing the cross-section of a cylinder with circles of N quantity according to the radius, we have Volterra's second-kind integral equation for every circle. Known variables in the equation are creep deformations (determined from experiments); shear creep nucleus and variable moisture values (determined by theoretical processing of experimental data). Stresses remain unknown, and the main task of the experiment is to define them. The stress values in each circle are determined by solving the equation with the numeric method. Stress determining method is established. *© 2023 Bull. Georg. Natl. Acad. Sci.*

composite, concrete, steel fiber concrete, torsion, shear creep nucleus, moisture content, deformation, formula

Experiments are conducted, and the dependence of steel fiber concrete creep deformations on moisture conductivity with the environment (drying, moistening) is determined.

“Standard” specimens were tested [1, 2]. Cylinders are received “standardly” with diameter 70mm and length 610 mm, age $t_0 = 28$, , moisture content $W_0 = 4.7\%$, , according to mass [1,2].

Short-term tests [1] defined: concrete strength of – 4.55 mpa, steel fiber concrete of – 11.6 mpa, shear modulus for materials was G=1.22 mpa and G=1.35 mpa respectively. Long-term creep tests are conducted on 12 special testing machines that are known and approved [1, 3].

During materials drying process in creep tests specimens were tested in the environment of 100, 70, 50, and 20% relative humidity. In experiments during moistening process of materials, specimens were dried up to ($W_0 = 1.0\%$ according to mass) and tested in the environment of 20 and 100% relative humidity. Duration of all experiments was 240 days. Specimens in torsion tests were tested by “Standard” specimens rupture strength value of 0.5.

Parallel to creep tests, the equilibrium moisture content of materials (cylinders with diameters of 70mm and lengths of 70 mm with isolated ribs) was determined using a weighing method in the intended relative humidity environment. During the drying process in a 100, 70, 50, and 20% relative humidity environment, the equilibrium moisture content in both composites were identical and equaled W=4.7; 3.1; 2.0; and 1.0% according to mass respectively. During moistening in 20 and 100% relative humidity environments, the equilibrium moisture content in specimens was 1.0 and 3.8% according to mass (Table).

Table. The dependence of composite’s creep deformations on the intensity of moisture conductivity with environment

Testing environment relative humidity φ, %	Specimen moisture content at the end of test W, %	Deformations $2\varepsilon_{12} \cdot 10^{-6}$ In time, $t - t_0$, day $t - t_0$								
		0	2	5	10	30	60	120	180	240
1	2	3	4	5	6	7	8	9	10	11
Drying, concrete, beginning $W_0 = 4.7\%$										
100	4.7	187	257	330	370	439	484	531	541	550
70	3.1	191	380	418	480	624	744	784	805	810
50	2.0	187	431	469	573	770	926	978	1007	1017
20	1.0	182	478	541	636	807	1053	1115	1150	1160
Drying, steel fiber concrete, beginning $W_0 = 4.7\%$										
100	4.7	441	491	570	661	786	870	958	986	1020
70	3.1	435	630	680	745	893	1015	1060	1090	1102
50	2.0	452	735	801	905	1118	1302	1363	1385	1395
20	1.0	441	795	882	1010	1274	1510	1576	1630	1635
Moistening, concrete, beginning $W_0 = 1.0\%$										
20	1.0	173	196	209	218	234	243	255	263	266
100	3.8	174	233	248	269	314	354	366	374	378
Moistening, steel fiber concrete, beginning $W_0 = 1.0\%$										
20	1.0	429	464	487	510	534	545	568	580	585
100	3.8	429	464	560	592	671	740	789	806	812

Data from the Table show that long-term deformations of both composites are increasing intensively in both (drying and moistening) cases. During the moisture conductivity with the environment, creep and relaxation processes that are complex and simultaneous take place in specimens. These processes are due to a humidity gradient, during which the moisture content of material according to the specimen’s lateral section is different over time and therefore stresses according to the lateral section will vary. To solve material creep issues in terms of the free moisture conductivity process with the environment, it is necessary to know the regularity of moisture content change in specimens. This type of issue is solved for cylindrical specimen specimens variable moisture content in given humidity terms is a function of (for a cylinder) R radius and t time.

The universal expression of the shear creep nucleus we created for various t_0 age and W moisture content of concrete after some modifications to be used in specimens torsion tasks that have variable moisture content according to time and radius will be expressed as follows:

$$\Pi(t,\xi,W)=\left(\frac{t_{CT}}{\xi}\right)^{\alpha}\left[\pi_0\text{-}\pi_1(\upsilon\text{-}\upsilon_0)\times\ln\frac{t\text{-}\xi}{t_c^1}\right] \tag{1}$$

[1, 2] and in (1): t time will count from the specimen manufacturing moment $(t=0)$; ξ – any moment in interval $0 \le \xi \le t$; $\xi = t_0$ – the start of load (specimen age), in (1) $\Pi(t,\xi,w)$ nucleus is obtained from [1,2] by substitution of t_0, with ξ; t_{CT} - “Standard” specimen age $t_{CT} = t_0 = 28$ day; α- quality indicator; for concrete $\alpha = 0.2$ for steel fiber concrete $\alpha = 0.15$ [1].

$$\pi_0 = \gamma \cdot A\ ;\ \pi_1 = \frac{\gamma \cdot W_c}{\upsilon_0 \cdot W_m}\ ;\ t_c^1 = \frac{t_1}{t_c^{II}} \tag{2}$$

$$\upsilon = \frac{W - W_c}{W_0 - W_c}\ ;\ \upsilon_0 = \frac{W_c}{W_c - W_0}\ , \tag{3}$$

where: W_0 is specimen moisture content at the beginning of test; W_C – moisture content at the end of test; W – moisture content during test; $0 \le W \le W_0$; W_m – maximum moisture content 100% in relative humidity environment, in our case $W_m = 4.7\%$ – according to mass; $t - \xi = t - t_0 \le t_1 = 2$, $t_1 = 2$ [1]. A, γ, , t_c^{II} is determined from the ratios:

$$A=\frac{A(t_{CT},0)}{\gamma};\ \gamma = B(t_{CT},W_m)\cdot \lg e;\ \lg t_c^{II} = \frac{A(t_{CT},W_m) - A(t_{CT},0)}{B(t_{CT},W_m)}. \tag{4}$$

$A(t_{CT},W_m)$; $A(t_{CT},0)$; $B(t_{CT},W_m)$ coefficient values are calculated from the data of the Table with corresponding formulas [1,2].

From theory [4] υ is defined by the formula:

$$\upsilon(r,t) \equiv \upsilon(\rho,\tau) = \sum_{n=1}^{N} A_n \cdot I_o(\rho,\mu_n)\cdot e^{-\mu_n \cdot \tau}\ . \tag{5}$$

In (5) coefficient values and there defining methods are given in [4]. According to radius during the variable moisture cylinder torsion $M(t)$ twisting momentum is expressed by inner stresses with σ_{12}:

$$M(t) = 2\pi \cdot R^3 \int_0^1 \sigma_{12}(\rho,t)\cdot \rho^2 \cdot d\rho, \tag{6}$$

where R radius of cylinder; $0 \le r \le R$; $\rho = \frac{r}{R}$; $0 \le \rho \le 1$.

For $\sigma_{12}(\rho,t)$ stresses integral equations are accepted, that express there shear $\varepsilon_{12}(t)$ during the intended moisture content on the outer surface of cylinder $W(\rho,t)$ of infinite order according to - ρ and - t or moisture relative difference at body point on frontier (ρ,t). Integral equation is:

$$\int_{t_0}^{t}\Pi\left[t,\xi,\upsilon(\rho,\xi)\right]d\sigma_{12}(\rho,\xi)=\Pi\left[t_1,t_{0,}\upsilon(\rho,t)\cdot\sigma_{12}(t)\right]-\int_{t_0}^{t}\cdot\sigma_{12}(\rho,\xi)\cdot d\Pi(t,\xi)=\varphi_{12}(\rho,t). \qquad (7)$$

At the same time $\varphi_{12}=\rho\cdot\varepsilon_{12}(t)=\frac{1}{2}\rho\cdot R\frac{\varphi(t)}{\ell}$, where φ is specimens torsion angle, ℓ is specimens calculating length during creep torsion $M(t)=0$, when $t<t_0$; $M(t)=M_0=\text{Const}$, when $t\geq t_0$, otherwise $M(\xi)=M_0 h(\xi-t_0)$, where h is Heaviside step function.

Solving equation (7):

$$\sigma_{12}(t)=0;\ t<t_0;\ \sigma_{12}(t)\neq 0;\ ;\ t\geq t_0$$

$$\sigma_{12}(r,\xi)=f(r,\xi)\cdot h(\xi-t_0),$$

respectively $\varepsilon_{12}(\xi)=\varepsilon_{12}(\xi)\cdot h(\xi-t_0)$

$$\sigma_{12}(r,\xi)=\frac{\partial f(\rho,\xi)}{\partial\xi}\cdot h(\xi-t_0)d\xi+f(\rho,\xi)\cdot\delta(\xi-t_0)\cdot d\xi,$$

where δ is Dirac function.

$d\sigma_{12}(r,\xi)$ including expression in (7) formula is expressed as follows:

$$\int_{0}^{t}\Pi\left[t,\xi,\upsilon(\rho,\xi)\right]\cdot df(\rho,\xi)=\rho\left[\varepsilon_{12}(t)-\varepsilon_{12}(t_0)\frac{\Pi(t,t_0)}{\Pi(t_0,t_0)}\right]\equiv\rho\cdot\Delta\varepsilon_{12}, \qquad (8)$$

$$\Delta\varepsilon_{12}=\frac{1}{2}\rho\cdot R\left[\frac{\varphi(t)}{\ell}-\frac{\varphi(t_0)}{\ell}\cdot\frac{\Pi(t,t_0)}{\Pi(t_0,t_0)}\right].$$

$\Pi(t,t_0)=\Pi(t,t_0,\upsilon=0)$ creep nucleus during infinite moisture $\upsilon=0$.

$\Pi(t_0,t_0)=\Pi(t_0,t_0,\upsilon=0)$ creep nucleus during instant load and infinite moisture $\upsilon=0$.

Intended $M_0=M_0\cdot h(t-t_0)$ During test (Table data) will define $\varepsilon_{12}(t)$ and $\varepsilon_{12}(t_0)$.

Equation (8) is solved for continuous function $f(\rho,\xi)$, $t_0\leq\xi\leq t$ in (8) $\frac{\Pi(t,t_0)}{\Pi(t_0,t_0)}=\pi_0+\pi_1\cdot\upsilon_0\ln\frac{t-t_0}{t_c^1}+\frac{\pi_1}{\pi_0}\cdot\upsilon_0\cdot\ln\frac{t-t_0}{t_c^1}$.

Conclusion

Separating $\rho=0;0.1;...\rho_i;...0.9;1$ $(i=1,2,3......N)$ from formula (8) for each – ρ_i we have Volterra's second kind integral equation:

$$\int_{0}^{t}\Pi\left[t,\xi,\upsilon(\rho_i,\xi)\right]df_i(\xi)=\rho_i\Delta\varepsilon_{12}(t,t_0), \qquad (9)$$

where $f_i(\xi)=f(\rho_i,\xi)$.

In (9) $\Delta\varepsilon_{12}$ it is known from the Table data, Π and υ are defined from Table data (1), (5), [1,2] solving the tasks with respective formulas and therefore its known. In equation (9) stresses remain unknown $f_i(\xi)$. Solving the equation with numeric method $f_i(\xi)$ stresses for each *i* – circle is found. $f_1(\xi);f_2(\xi);....f_n(\xi)$ After that from (6) we find:

$$\tilde{M}(\xi)=2\pi\cdot R^3\sum_{i=1}^{N}f_i(\xi)\cdot\rho_{icp}(\rho_{i+1}-\rho_i), \qquad (10)$$

$$\tilde{M}(t) = \tilde{M}(\xi)\big|\xi = t; \;\; \rho_{icp} = \frac{\rho_{i+1} + \rho_i}{2}.$$

Comparing – $\tilde{M}(t)$ to – $M(t) = M_0 \cdot h(t - t_0)$ if $\left|\frac{\tilde{M} - M_0}{M_0}\right| \ll 1$ theory is reflecting creep well during the variable moisture.

მასალათმცოდნეობა

გარემოსთან ტენგაცვლის გავლენა ცემენტის ფუძიანი კომპოზიტების ცოცვადობაზე გრეხისას

ა. საყვარელიძე

**საქართველოს ტექნიკური უნივერსიტეტი, სამშენებლო ფაკულტეტი, თბილისი, საქართველო*

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გამოკვლეულია ცემენტის ფუძიანი კომპოზიტების ცოცვადობაზე გარემოსთან ტენგაცვლის (გამოშრობა, დატენიანება) გავლენის საკითხები. ჩატარებულია ბეტონის და ფოლადფიბრობეტონის ნიმუშების ხანგრძლივი გამოცდები გრეხაზე. ცოცვადობაზე გამოცდების დროს ნიმუშები (ცილინდრები დიამეტრით 70 და სიგრძით 610 მმ) განიცდიდა გამოშრობას და დატენიანებას სხვადასხვა ინტენსივობით. იცდებოდა „სტანდარტული“ ნიმუშები, რომელთა ასაკი t_0=28 დღეა, ტენშემცველობა W=4.7% - მასის მიხედვით. გამოცდების წინ ნიმუშების ნაწილი შრებოდა ტენშემცველობამდე W=1% - მასის მიხედვით. ცოცვადობაზე გამოცდების ხანგრძლივობა იყო 240 დღე. ნიმუშები იცდებოდა კამერებში ფარდობითი ტენიანობით 100, 70, 50, და 20%. ექსპერიმენტმა გვიჩვენა, რომ გრეხისას ცოცვადობის დეფორმაციები ინტენსიურად იზრდება როგორც ნიმუშების გამოშრობის, ისე დატენიანების დროს. დადგენილია: ნიმუშებსა და გარემოს შორის ტენგაცვლის დროს ცილინდრებში მიმდინარეობს ცოცვადობის და რელაქსაციის რთული ერთდროული პროცესები. ეს განპირობებულია ტენიანობის გრადიენტით, რომლის მოქმედების დროს ტენშემცველობა ნიმუშების განივ კვეთში იცვლება დროში და ძაბვები რადიუსის მიხედვით იქნება სხვადასხვა. ცვალებადი ტენიანობა მოცემულ ტენიან პირობებში არის რადიუსის და დროის ფუნქცია. ცვალებადი ტენიანობა ცილინდრებში დადგენილია ჩატარებული ცდებით და შედეგების თეორიული დამუშავებით. ჩვენ მიერ შექმნილი ბეტონების ძვრის ცოცვადობის ბირთვების უნივერსალური გამოსახულების საფუძველზე შემუშავებულია განტოლება დროისა და რადიუსის მიხედვით ცვალებადი ტენიანობის ცილინდრული ნიმუშების გრეხის ამოცანებში გამოსაყენებლად. ცილინდ-

რის განივკვეთის რადიუსის მიხედვით დაყოფით N რაოდენობის რგოლად, გვაქვს თითოეული რგოლისთვის ვოლტერას მეორე რიგის ინტეგრალური განტოლება. განტოლებაში ცნობილია: ცოცვადობის დეფორმაციები ექსპერიმენტებიდან; ძვრის ცოცვადობის ბირთვების და ცვალებადი ტენიანობის განსაზღვრული სიდიდეები. უცნობი რჩება ძაბვები, რომელთა დადგენა გამოკვლევის ძირითადი ამოცანაა. თითოეულ რგოლში ძაბვების დადგენა ხდება განტოლების რიცხვითი ამოხსნის მეთოდით. შემუშავებულია ძაბვების განსაზღვრის მეთოდიკა.

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