საქართველოს მეცნიერებათა ეროვნული აკადემიის მოამბე, ტ. 16, №2, 2022
BULLETIN OF THE GEORGIAN NATIONAL ACADEMY OF SCIENCES, vol. 16, no. 2, 2022

*Materials Science*

# Dependence of Strength and Rheological Charachteristics of Concrete on the Age the Materials

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**Researches are conducted on the dependence of the strength and rheological characteristics of concretes on the materials age. Short- and long-term (creep) compression, tension and torsion tests are conducted on the traditional (concrete, fine concrete) and new composite specimens (steel fiber concrete, basalt fiber concrete, self-compacting concrete, high strength concretes). Specimens were saved and tested in a "standard" environment – air relative humidity $\varphi = 100\%$, temperature $T = 20 \pm 1°C$ . In the experiment $t_0 = 3$, 7, 14, 28, 60 and 180-day specimens creep tests were conducted. The dependence of the mechanical characteristics of the composites on deformation velocity and materials age is studied by short-term tests on universal machine „Instron Ш5". Specimens were tested at 5 qualitatively different velocities. Velocity range includes static load sphere. The examinations defined that the strength indicators increase proportionally with the materials age; Deformation velocity has minor effect on the scale of composites, strength, marginal relative deformations, elasticity and shear modulus (in researched range of deformation velocities). Creep experiments are conducted on test machines that are proven and widely known. The creep experiment duration ($t - t_0$) is 180 days. Research data defined creep nucleus of various age composites (concrete, fine concrete, steel fiber concrete, basalt fiber concrete). It is defined that creep nucleus dependence on materials age is well depicted by a power function. Analytical representation of function is elaborated and the rate of power for materials is defined. The new type of formulas is elaborated for cement-based composite compression-tension and shear creep nucleus that considers materials' age.** *© 2022 Bull. Georg. Natl. Acad. Sci.*

composite, concrete, deformation, strength, compression, tension

Short and long-term tests are conducted on specimens of cement-based composites (concrete, fiber concrete, steel fiber concrete, basalt fiber concrete, self-contracting concrete, high strength concrete) during compression, tension and torsion.

Various shape and size specimens were made for tests: Prisms 40x40x40mm for (short-term) compression tests and for (long-term) creep tests 70x70x280 mm; flat "eight" with 50mm thickness, with general length of 530mm and working part width of 70mm for tension tests; cylinders with 70mm diameters and 610mm length for torsion tests.

Short-term tests are conducted on universal machine „Instron III5" [1].

Creep tests are conducted on 36 special test machines (12 machines on each kind of tests) [1].

Specimens after manufacturing were saved and tested at "standard" terms: air relative humidity $\varphi = 100\%$, temperature $T = 20 \pm 1°C$. $t_0 = t_{ст} = 28$ day specimens are received by default.

Creep tests duration ($t - t_0$) was 180 days. Load rates of various age specimens in creep tests were 0.4 (compression) and 0.5 (tension, torsion) corresponding fracture strength.

Short-term tests defined the dependence of the composits' strength, marginal relative deformations, shears and elasticity modulus dependence on deformation velocity and materials age [1-6]. Specimens were tested at 5 qualitatively different velocities. Velocity range includes static load sphere. Dependence of concrete mechanical characteristics on materials' age and deformation velocities are given in Table 1. The analysis of Table 1 defines: strength characteristics increase in proportion with age; deformation velocity has minor effect on strength, marginal relative deformations and elasticity and shears modulus.

**Table 1. Composite's mechanical characteristics dependence on materials' age and deformation velocities**

| Specimen age $t_o$-Day | Deformation velocities 1/sec | Strength ($\sigma_{11}$; $\sigma_{12}$) mpa | Deformation ($\varepsilon_{11}$; $\varepsilon_{12}$)$\cdot 10^{-6}$ | Modulus of elasticity shear $E\cdot 10^4$ mpa modulus $G\cdot 10^4$ mpa |
|---|---|---|---|---|
| Concrete, compression | | | | |
| 28 | $4.2\cdot 10^{-7}\div 4.2\cdot 10^{-3}$ | 38.10÷46.50 | 1270÷1200 | 3.02÷3.88 |
| Fine concrete, compression | | | | |
| 28 | $4.2\cdot 10^{-7}\div 4.2\cdot 10^{-3}$ | 31.20÷37.00 | 1440÷1390 | 2.48÷2.92 |
| Steel fiber concrete, compression | | | | |
| 28 | $4.2\cdot 10^{-7}\div 4.2\cdot 10^{-3}$ | 42.50 ÷50.60 | 1660 ÷1630 | 2.72÷3.24 |
| Concrete, tension | | | | |
| 28<br>60 | $2.13\cdot 10^{-7}\div 2.13\cdot 10^{-3}$<br>$2.13\cdot 10^{-7}\div 2.13\cdot 10^{-3}$ | 3,50÷4.1<br>3.20÷4.30 | 130÷123<br>130÷110 | 3.20÷3.81<br>3.51÷4.15 |
| Fine concrete, tension | | | | |
| 28 | $2.13\cdot 10^{-7}\div 2.13\cdot 10^{-3}$ | 2.80÷3.55 | 124÷120 | 2.45÷2.98 |
| Steel fiber concrete, tension | | | | |
| 28<br>60 | $2.13\cdot 10^{-7}\div 2.13\cdot 10^{-3}$<br>$2.13\cdot 10^{-7}\div 2.13\cdot 10^{-3}$ | 6.50÷8.24<br>6.40÷8.30 | 252÷246<br>250÷230 | 2.70÷3.26<br>2.76÷3.3 |
| Fine concrete, torsion | | | | |
| 28 | $0.56\cdot 10^{-7}\cdot 0.56\cdot 10^{-3}$ | 3.86÷4.55 | 390÷373 | 1.03÷1.22 |
| Steel fiber concrete, torsion | | | | |
| 28 | $0.56\cdot 10^{-7}\cdot 0.56\cdot 10^{-3}$ | 9.50÷11.6 | 890÷860 | 1.13÷1.35 |
| Self-compressing concrete, tension | | | | |
| 28 | $2.13\cdot 10^{-7}\div 2.13\cdot 10^{-3}$ | 7.40÷8.8 | 220÷215 | 3.2÷3.62 |
| Compression, high strength concrete/basalt fiber concrete | | | | |
| 7 | $4.2\cdot 10^{-5}$ | 43.8 / 58.65 | - | - |
| 28 | „ | 73.2 / 78.0 | - | - |
| 60 | „ | 78.2 / 85.0 | - | - |
| 90 | „ | 86.5 / 92.0 | - | - |
| 120 | „ | 92.5 / 103.1 | - | - |
| 180 | „ | 101.2 /110.3 | - | - |

Creep experiment include compression, tension and torsion tests [1, 7-9] on specimens of fine concrete, steel fiber concrete and basalt fiber concrete.

Materials creep nucleus will be defined for each $t_0$ age, from composites creep deformations experimental data. Creep nucleus calculated values are given in Table 2.

**Table 2. Creep nucleus of different age concrete in time**

| Age, $t_0$ Day | $(\Pi, \Pi_p) \cdot 10^6$ MPA, In Time, $t-t_0$ Day | | | | | | |
|---|---|---|---|---|---|---|---|
| | 2 | 10 | 20 | 30 | 60 | 120 | 180 |
| Compression, fine concrete/steel fiber concrete | | | | | | | |
| 3 | 82,1/57,0 | 120,0/77.0 | 136.0/86,0 | 144.0/91.5 | 158.0/105.0 | 172.0/109.0 | 180.0/114.0 |
| 7 | 62.0/47.0 | 86.0/61.0 | 93.0/68.0 | 105.0/71.7 | 115.0/78.5 | 127.0/85.2 | 133.0/89.5 |
| 14 | 50.0/42.0 | 71.0/54.2 | 81.0/60.5 | 87.0/64.1 | 96.0/70.5 | 106.0/75.1 | 111.0/80.0 |
| 28 | 45.3/37.3 | 64.0/49.5 | 72.0/54.5 | 78.0/57.5 | 86.0/63.0 | 95.0/68.0 | 100.0/71.5 |
| 60 | 38.0/35.3 | 57.0/44.0 | 64.0/49.0 | 68.0/52.0 | 75.0/57.0 | 82.0/62.0 | 86.0/65.0 |
| 180 | 36.0/31.0 | 47.0/37.0 | 53.0/41.5 | 57.0/43.5 | 63.0/48.0 | 68.0/52.2 | 72.0/54/7 |
| Tension, fine concrete/steel fiber concrete | | | | | | | |
| 3 | 95.6/63.9 | 125.0/83.0 | 144.0/92.5 | 154.0/98.0 | 169.0/108.0 | 183.0/115.0 | 198.0/121.0 |
| 7 | 65.0/49.1 | 96.0/63/5 | 108.0/70.5 | 115.0/74.5 | 128.0/81.0 | 141.0/87.6 | 149.0/91.5 |
| 14 | 56.7/45.1 | 78.0/58.5 | 88.0/64.5 | 92.0/67.5 | 105.0/73.0 | 117/0/79.0 | 122.0/82.5 |
| 28 | 44/9/37.1 | 66.0/52.0 | 75.0/57.0 | 82.0/60.0 | 90.0/69.0 | 98.0/71.5 | 104.0/74.0 |
| 60 | 42.0/36.9 | 58.0/46.0 | 65.0/50.0 | 69.0/52.5 | 77.0/57.0 | 84.0/61.5 | 87.5/64.0 |
| 180 | 36.8/32.1 | 46.0/38.5 | 540.0/42.5 | 56.0/45.0 | 63.0/49.0 | 70.0/53.5 | 72.0/56.0 |
| Torsion, fine concrete/steel fiber concrete | | | | | | | |
| 3 | 104.1/68.0 | 146.0/93.5 | 161.0/104.5 | 172.0/109.0 | 189.0/121.0 | 207.0/131.5 | 218.0/138.1 |
| 7 | 74.0/54.0 | 108.0/72.0 | 120.0/79.8 | 128.0/84.5 | 140.0/92.0 | 152.0/100.5 | 159.0/105.0 |
| 14 | 66.0/48.5 | 93.0/61.1 | 105.0/71.0 | 110.0/75.3 | 120.0/82.0 | 131.0/89.2 | 138.0/93.8 |
| 28 | 56.8/42.3 | 80.1/57.0 | 90.0/64.7 | 94.9/67.8 | 105.0/75.0 | 115.0/81.5 | 120.0/85.0 |
| 60 | 48.0/39.0 | 68.0/51.0 | 75.0/56.5 | 80.0/60.5 | 98.0/66.0 | 96.0/71.9 | 101.0/75.8 |
| 180 | 44.1/36.0 | 57.0/44.5 | 63.0/49.1 | 67.0/52.6 | 74.0/56.9 | 80.0/62.1 | 84/0/65.0 |
| Torsion, concrete/basalt fiber concrete | | | | | | | |
| 3 | 102.0/70.0 | 143.0/96.3 | 158.0/107/5 | 168.5/112.9 | 185.0/124.6 | 203.0/135.1 | 213/5/142.2 |
| 7 | 71,5/55.5 | 105.5/74.2 | 117.5/82.2 | 125.0/87.0 | 137.0/94.7 | 149.0/103.5 | 155.5/108/2 |
| 14 | 64.0/49.9 | 91.0/66.2 | 103.0/71.1 | 108.0/77.6 | 118.0/84.5 | 128.5/91.9 | 133.0/98.8 |
| 28 | 55.5/43.6 | 78.0/58.7 | 88.0/66.6 | 92.0/69.8 | 102.5/77.3 | 113.0/85.0 | 117.5/87.5 |
| 60 | 47.0/40.0 | 66.5/52.5 | 73.0/58.2 | 79.0/62.3 | 86.0/68.0 | 95.0/74.1 | 99.1/78.1 |
| 180 | 43.0/39.1 | 55.0/45/8 | 60.0/49.1 | 65.5/54.2 | 72.5/58.6 | 78.5/64.0 | 82.0/66.9 |

The analysis of Table 2 data defines that during constant moisture content ($W = \text{const}$) and temperature ($T = \text{const}$) creep nucleus are precisely reflected in formulas [1, 7-9]; given the whole range $\left(3 \le t_0 \le 180\right)$ of materials age:

$$\Pi(t,t_0) = A(t,t_0) + B(t,t_0) \cdot \lg \frac{t-t_0}{t_1}, \tag{1}$$

$$\Pi_p(t,t_0) = A_p(t,t_0) + B_p(t,t_0) \cdot \lg \frac{t-t_0}{t_1}, \tag{2}$$

where $\Pi_p$ is the compression-tension creep nucleus; $\Pi$ is the shear creep nucleus; $t-t_0$ is the test duration; $t_0$ is the specimen age at the beginning of test $t_1 = t - t_0 = 2$ days.

$\Pi(t,t_0)$ and $\Pi_p(t,t_0)$ – comparisons during different $t_0$ age shows that they are identical for the whole $t-t_0$ period except period $t-t_0 \le 2...4$ days. Therefore in creep nucleus figures arises distinctive time feature $t_1$ and necessity in formulas (1) and (2) logarithmic terms to be considered equal to zero, when $t-t_0 \le t_1$, in our case $t_1 = 2$.

*A*, $A_p$, *B*, $B_p$ constants and their dependence on $t_0$ are defined using the least square method based on table 2 data with formulas (1), (2). Constructing data on a double logarithmic scale $\lg A \sim \lg t_0, \ldots$ given the defined constants, we will be convinced that dependences $\lg A \sim \lg t_0, \ldots$ with good precision are linear. *A*, $A_p$, *B*, $B_p$ constants relevant power dependence on $t_0$ are calculated in figures:

$$A(t_0) = A(t_{\text{ст}}) \left[ \frac{t_{\text{ст}}}{t_0} \right]^{\alpha_1} ; \quad B(t_0) = B(t_{\text{ст}}) \left[ \frac{t_{\text{ст}}}{t_0} \right]^{\alpha_2} , \tag{3}$$

$$A_p(t_0) = A_p(t_{\text{ст}}) \left[ \frac{t_{\text{ст}}}{t_0} \right]^{\alpha_1} ; \quad B_p(t_0) = B(t_{\text{ст}}) \left[ \frac{t_{\text{ст}}}{t_0} \right]^{\alpha_2} . \tag{4}$$

In formulas (3), (4) $\alpha_1$ and $\alpha_2$ are power indicators and are found by using the least square method. In our case, for concretes $\alpha_1 = \alpha_2 = 0,2$ , fiber concretes $\alpha_1 = \alpha_2 = 0{,}15$. By putting (3), (4) in (1) and (2) we will get new type figures of cement based composites creep nucleus that considers the materials' age [8, 9].

## Conclusion

**Research defined** that cement based composites' strength characteristics during compression, tension and torsion show that strength characteristics increase proportionally with age; deformation velocity has minor influence on the scales of strength, marginal relative deformations and elasticity modulus in the researched range of deformation velocities.

**The composite creep tests prove** that dependence of creep nucleus on materials age is well reflected by a power function. Function figure is given and power indicators for materials are defined.

New type of compression-tension and shear creep nucleus figures are elaborated for cement-based composites that consider the materials' age:

$$\Pi(t, t_0) = \left[ \frac{t_{\text{ст}}}{t_0} \right]^{\alpha_1} \cdot A(t_{\text{ст}}) + \left[ \frac{t_{\text{ст}}}{t_0} \right]^{\alpha_2} \cdot B_p(t_{\text{ст}}) \cdot \lg \frac{t - t_0}{t_1} , \tag{5}$$

$$\Pi_p(t, t_0) = \left[ \frac{t_{\text{ст}}}{t_0} \right]^{\alpha_1} \cdot A_p(t_{\text{ст}}) + \left[ \frac{t_{\text{ст}}}{t_0} \right]^{\alpha_2} \cdot B_p(t_{\text{ст}}) \cdot \lg \frac{t - t_0}{t_1} . \tag{6}$$

*მასალათმცოდნეობა*

# ბეტონების სიმტკიცისა და რეოლოგიური მახასიათებლების დამოკიდებულება მასალათა ასაკზე

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გამოკვლეულია ბეტონების სიმტკიცისა და რეოლოგიური მახასიათებლების დამოკიდებულება მასალათა ასაკზე. ჩატარებულია ტრადიციული (ბეტონი, წვრილმარცვლოვანი ბეტონი) და ახალი (ფოლადფიბრობეტონი, ბაზალტფიბრობეტონი, თვითშემჭიდროებადი ბეტონი, მაღალი სიმტკიცის ბეტონი) კომპოზიტების ნიმუშების ხანმოკლე და ხანგრძლივი (ცოცვადობა) გამოცდები კუმშვაზე, გაჭიმვასა და გრეხაზე. ხანმოკლე გამოცდებით მანქანაზე „Instron III5" შესწავლილია კომპოზიტების მექანიკური მახასიათებლების დამოკიდებულება დეფორმაციების სიჩქარესა და მასალათა ასაკზე. ნიმუშები იცდებოდა 5 ერთმანეთისგან ხარისხით განსხვავებული დეფორმაციის სიჩქარის დროს. სიჩქარეთა დიაპაზონი მოიცავს სტატიკური დატვირთვების სფეროს. დადგენილია, რომ სიმტკიცის მაჩვენებლები იზრდება მასალების ასაკის პროპორციულად: კომპოზიტების სიმტკიცის, ზღვრული ფარდობითი დეფორმაციების, დრეკადობის და ძვრის მოდულების სიდიდეზე დეფორმაციის სიჩქარე სუსტ გავლენას ახდენს. ცოცვადობაზე ექსპერიმენტების ხანგრძლივობა იყო 180 დღე. გამოიცდებოდა ბეტონის, წვრილმარცვლოვანი ბეტონის, ფოლადფიბრობეტონის და ბაზალტფიბრობეტონის ნიმუშები. გამოკვლევით დადგენილია: მასალების ცოცვადობის ბირთვები და მათი ასაკზე დამოკიდებულების ამსახველი ხარისხობრივი ფუნქციები; შემუშავებულია კომპოზიტების კუმშვა-გაჭიმვის და ძვრის ცოცვადობის ბირთვების ახალი სახის გამოსახულებები, რომლებიც ითვალისწინებს მასალების ასაკს.

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*Received May, 2022*