Scientific Journal of Riga Technical University
Construction Science
2011
Volume 12

Effect of Montmorillonite Nano Admixture on Long-term Deformations of Concrete

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Abstract. **The purpose of the present research is to evaluate the possibility of using montmorillonite mineral nano particles (MNP) as active additives in concrete compositions in order to improve mechanical characteristics of concrete. This paper presents the results of the experimental study carried out with the aim to evaluate basic mechanical properties and long-term creep deformations of the developed concrete composition. Concrete specimens have been tested at a constant room temperature and with a constant level of moisture and properties of the concrete have been examined. The results of the experiments demonstrating the relationship of the stress and strain have been presented. The compression strength, the modulus of elasticity, the creep and creep coefficient of the concrete specimens have been determined.**

Keywords: **creep, clay nano particles, secondary aggregates, compression strength, modulus of elasticity**

INTRODUCTION

Nowadays nano-particles of clay minerals are used in production of polymeric nanocomposites to improve their mechanical characteristics. Polymeric nanocomposites were developed by Japanese scientists in the 1970s – 80s. In Latvia, nanocomposites based on styrene-acrylate copolymer and organically modified with montmorillonite nano particles were being prepared and investigated during the recent ten years [1].

Presently, investigations on modifying concrete compositions by nano particles are carried out in different countries. It has been proved that nanosized silicium dioxide particles allow to achieve a very dense microstructure and to improve the performance characteristics of concrete [1]. In literature, there is no information about montmorillonite nano particles having been used as a concrete nano-filler. The aim of this study is to investigate the influence of synthesized montmorillonite clay mineral nano-particles (MNP) on the mechanical strength and creep behaviour of concrete.

The material used is synthesized montmorillonite clay mineral called hydrated sodium calcium aluminum silicate, the chemical formula of which is $(Na,Ca)(Al,Mg)6(Si_4O_{10})3(OH)6\text{-}nH_2O$. Montmorillonite mineral is a member of the smectite family. The montmorillonite crystal structure is 2:1, meaning that it has 2 tetrahedral layers of silicium dioxide sandwiching and a central octahedral layer of aluminium oxide. The average density of montmorillonite clay mineral is 2.35 g/cm^3, the specific surface is 750 m^2/g. The particles are plate-shaped, with the average length of 20-500 nm, the clay flakes are about 1 nm thick and, therefore, the clay may be classified as a nano-admixture.

The two main objectives in designing concrete structures are strength and serviceability. A structure must be strong enough and sufficiently ductile to resist the overloads and environmental extremes that may be imposed on it without collapsing [2]. Deformation characteristics of concrete are important in the design of sustainable structures. Concrete is an important structural material used in every country of the world. Moreover, the complexity of structures and their size continue increasing, and this has resulted in a greater importance of their deformation characteristics and more serious consequences of their behaviour [3]. One type of strain that plays a major role in successful and continuous use of the structures is creep – the deformations that appear due to long-term loading of the structural element [4]. Creep can be defined as a time-dependent part of the strain resulting from stress. The relation between stress and strain for concrete is a function of time. Therefore, designers and engineers need to know the creep properties of concrete and must take them into account in the structure analysis. Consideration of creep is a part of a rational approach to meet these criteria. Deformation characteristics of materials are an essential feature of their properties and a vital element in the knowledge of their behaviour [3].

METHODS

One of the goals of the experiment was to find out whether the new concrete composition can be competitive and whether its physical and mechanical properties are equivalent to those of an ordinary concrete. The object of this experimental study was the concrete made with an admixture of montmorillonite clay mineral nano particles (MNP). Other raw materials used for this study were: natural coarse diabase aggregate, fine aggregate quartz sand and normal portlandecement CEM I 42.5 N. Concrete mix compositions are summarized in Table 1.

TABLE 1
Concrete Mix Compositions

Mix designation:	**HSC**	**HSC MNP**
Portlandcement CEM I 42.5 N	800	800
Diabaze 0/5 mm	640	320
Sand 0/2.5	640	320
Silicafume	120	120
MNP		8
Water	200	200
Superplasticizer	15	15
Water/Cement ratio	0.25	0.25

Fig. 1. Specimens containing small clay particles

Raw components were weighed and mixed for five minutes in a laboratory mixer. Standard sample cubes of 100x100x100 mm and prisms of 40x40x160 mm were made to investigate the mechanical characteristics of the material (see Fig. 1). Concrete mixtures were cast into oiled steel moulds and compacted on the vibrating table. In two days the moulds were removed. Standard hardening conditions (temperature +20 ± 1ºC, RH > 95%) were provided during 44 days. After the hardening period, the specimens were measured and tested in standard conditions. Their compression strength was determined in conformity with LVS EN 12390-3:2009.

Creep experiments were carried out on prismatic specimens of 40x40x160 mm which were weighed both before and after the test.

The tests were conducted in two extreme conditions. In one case, no moisture exchange with the environment was permitted, which was ensured by protecting the specimens against desiccation, and in the other case, drying was permitted under conventional conditions, by protecting the specimens against moisture. In order to prevent humidity exchange between the specimen and the environment, the surface of the specimens was coated with two protective aqua stop layers (see Fig. 2).

Fig.2. Specimens coated with protective layer

Before this sealing, four aluminium plates had been centrally and symmetrically glued onto two sides of the test prism in order to provide a basis for the strain gauges (see Fig. 3). The distance between the centres of the two plates was 50 mm.

Fig.3 Specimens with aluminium plates

The creep (time-dependent strain) was measured for hardened concrete specimens subjected to a uniform compressive load which was kept constant over a long period of time [4]. The constant compressive load was equal to 30% of the maximum strength of the concrete, which had been determined during destructive tests carried out on the cubic specimens. The load was applied gradually in four steps and as fast as possible.

The instantaneous strain that occurs immediately upon application of stress may be considered to be elastic at low stress levels, and therefore:

$$\varepsilon_{e(t)} = \sigma_{c0} / E_{c(\tau 0)} \, , \tag{1}$$

where $E_{c(\tau 0)}$ is the elastic modulus at time τ_0
$\varepsilon_{e(t)}$ is the instantaneous strain
σ_{c0} is the compressive stress

The capacity of concrete to creep is usually measured in terms of creep coefficient, $\phi_{(t,\tau)}$. In a concrete specimen subjected to a constant sustained compressive stress, $\sigma_{c(\tau)}$, first applied at age τ , the creep coefficient at time t is the ratio of the creep strain to the instantaneous strain and is given by:

$$\phi_{(t,\tau)} = \varepsilon_{cr(t,\tau)} / \varepsilon_{e(\tau)} \, , \tag{2}$$

where $\phi_{(t,\tau)}$ is the creep coefficient
$\varepsilon_{cr(t,\tau)}$ is the creep strain
$\varepsilon_{e(\tau)}$ is the instantaneous strain [2].

At the beginning of the test, the specimens were 51 and 63 days old and they were kept under a constant load for 80 days. Two +/– 0.01 mm precision strain gauges were symmetrically connected to each specimen and then the specimens were put into a creep lever test stand and loaded (see Fig. 4).

Fig.4. Creep lever test stand

They were kept in a dry atmosphere of controlled relative humidity in standard conditions: temperature 23 ± 1ºC and relative humidity 25 ± 3%.

RESULTS

The tests for determining creep, the creep coefficient, the modulus of elasticity, density and compression strength have been done on the concrete specimens where montmorillonite nano particles (MNP) have been used as admixture. The experimental work made it possible to compare the strength of the reference concrete specimens and the ones containing MNP.

Cubes' strength tests were carried out after 7, 37 and 93 days (see Fig. 5) of hardening in standard conditions. Various compression strengths of concrete specimens of different ages, containing MNP as an aggregate, were then compared to those of reference concrete specimens. The MNP containing concrete showed 5% lower strength in the first 7 days, but on the 37^{th} day the strength increased and was by about 4.8% larger than that of the reference concrete, and on the 93^{rd} day the strength of concrete with small clay particles was by about 3.5% larger. Some of the results of the experiments are presented in Table 2.

TABLE 2
Physical and Mechanical Properties of Concrete Specimens

Specimen	Age	Density, kg/m^3	Compression strength, MPa
HSC Reference	7	2391	84.6
HSC Reference	37	2407	104.2
HSC Reference	93	2387	113.2
HSC MNP	7	2402	80.4
HSC MNP	37	2406	109.1
HSC MNP	93	2386	117.2

The concrete mix containing montmorillonite nano particles shows good strength development during long-term hardening. Specimens with MNP admixture showed a 45.8% increase of compression strength, while the reference specimens showed a 33.8% increase of compression strength during the same period.

The modulus of elasticity (see Fig. 6) was determined by measuring deformations on the sides of the specimens according to Hooke's law. For the reference concrete at the age of 51 days, the difference between the specimens hardened in moist and dry conditions is approximately 1.9%, but at the age of 63 days the difference is 16%. For specimens containing MNP admixture, this difference is approximately 17.4% and 11% respectively. The comparison of the modulus of elasticity of the 51 days old reference concrete specimens and the specimens containing MNP shows that the modulus of elasticity for the specimens with clay particles is larger. For the specimens hardened in moist conditions, this difference is 34.5%, while for the specimens hardened in dry conditions it is 9%. However, the comparison of the modulus of elasticity of the 63 days old reference concrete specimens and those containing MNP shows the contrary results – the modulus of elasticity for the reference specimens is larger.

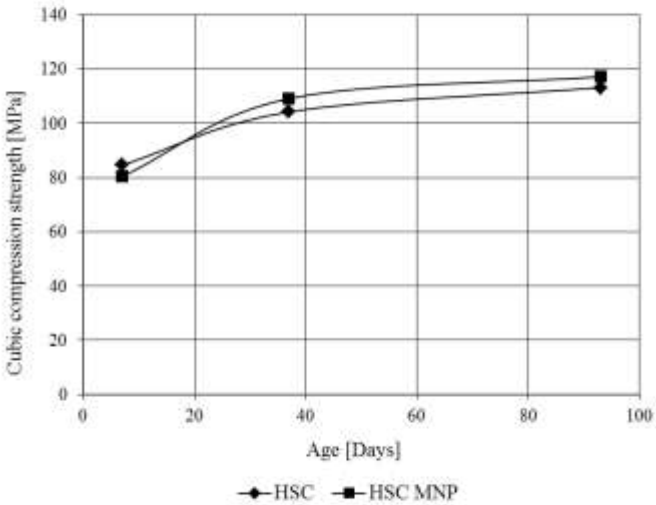

Fig.5. Compression strength in 7, 37 and 93 days [MPa]

For the specimens hardened in moist conditions, this difference is 43.5%, while for the specimens hardened in dry conditions it is 6.2%. The same tendency can also be seen from the stress-strain relation (see Fig. 7). The stresses are almost proportional to the strain, and therefore the stresses do not reach the point of microcracking.

When concrete is subjected to a sustained stress, creep strain develops gradually in time, as shown in Fig. 8. Creep increases with time at a decreasing rate. During the period immediately following the initial loading, creep develops rapidly, but with time the rate of increase slows down considerably.

In a loaded specimen, that is in hygral equilibrium with the ambient medium (i.e. no drying), the time-dependent deformation caused by stress is known as *basic creep* [5].

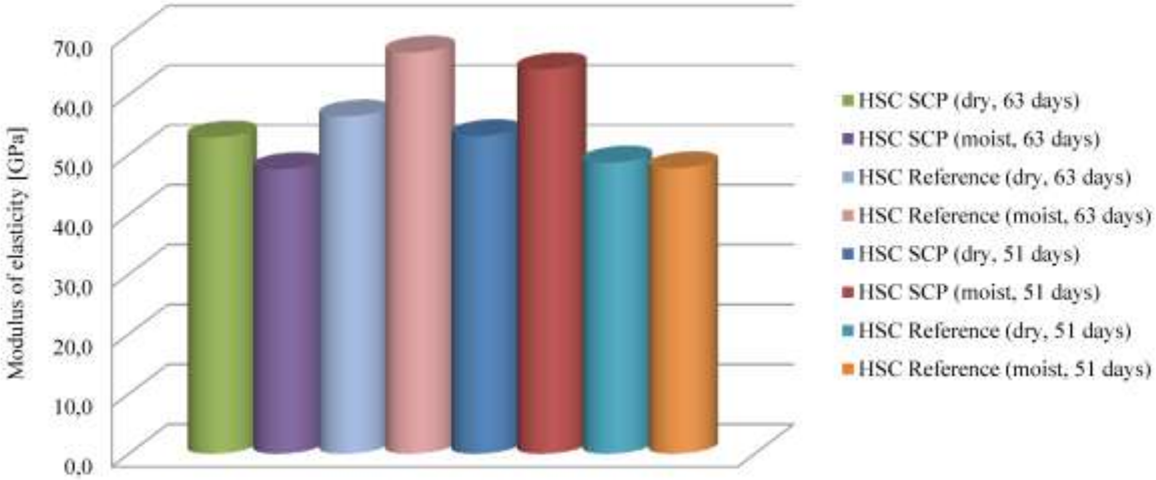

Fig.6. Modulus of elasticity of different concretes

The graph in Figure 8 shows elastic strain, plus linear basic creep and shrinkage, as time dependent. It is evident from the gathered data that creep developed in the reference concrete specimens hardened in moist conditions at the age of 51 days. The smallest deformation was exhibited by the concrete specimens containing MNP. Among the same age specimens hardened in dry conditions, the smallest deformation was exhibited by the concrete specimens with MNP.

The average difference between the reference concrete specimens hardened for 51 days in moist and in dry conditions is approximately 22%, but for the reference concrete specimens at the age of 63 days hardened in moist and in dry conditions the amount of deformations is contrary – the creep is larger in dry-hardened specimens, and the average difference is approximately 20%. For the 51 days old MNP specimens this difference is approximately 86%, and for the 63 days old specimens it is 34.4%. At both ages, the larger deformation was exhibited by the dry-hardened specimens. If we compare the average difference between the reference concrete specimens at 51 days and the MNP ones of the same age, we can see that for the specimens hardened in moist conditions this difference is 20.6%, and for the specimens hardened in dry conditions it is 89.8%. It is interesting that in moist conditions the larger deformation is exhibited by the reference concrete specimens, but in dry conditions it is contrary – the larger deformation is exhibited by the MNP specimens. In comparison with the 63 days old specimens, the difference is 3.9% and 15% respectively. In both conditions, the larger deformation is shown by the concrete specimens containing MNP.

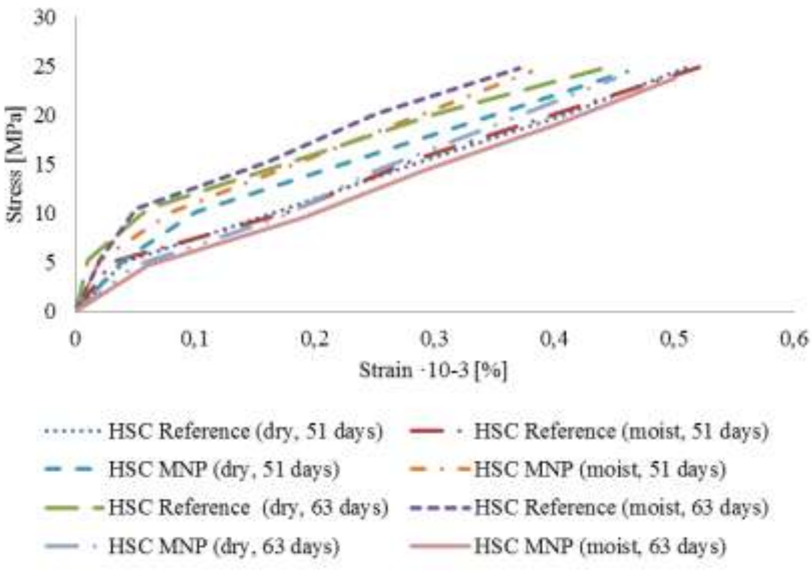

Fig.7. Relation between stress and strain

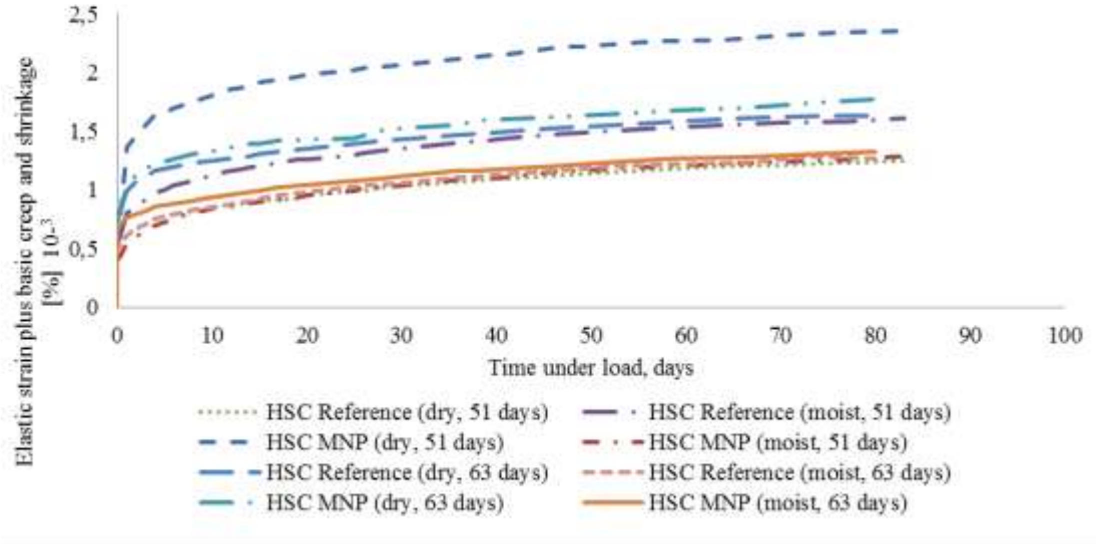

Fig.8. Elastic strain and long-term deformations of high strength concrete specimens

Under constant mechanical loading, the strain of reference concrete at the ages of 51 and 63 days increases significantly with the loading duration, the increase reaching 2.4 to 3.3 times the value of the instantaneous strain. At both ages, the strain increase of the concrete specimens containing MNP reaches 2.5 to 5 times the value of the instantaneous strain.

The creep coefficient increases with time at an ever-decreasing rate. The final creep coefficient is a useful measure of the creeping capacity of concrete.

The comparison of the creep coefficients of the reference concrete specimens and the MNP specimens at the age of 51 days shows that the creep coefficient for the specimens with clay particles is larger, but at the age of 63 days the creep coefficients of the dry-hardened specimens are similar, while the creep coefficient of the concrete specimens containing MNP is larger in specimens hardened in moist conditions. The average difference between the reference concrete specimens at the age of 51 days hardened in moist and in dry conditions is approximately 20.7%, but for the reference concrete specimens at the age of 63 days hardened in moist and in dry conditions the coefficient is larger for dry specimens. The difference is approximately 0.9%. For the 51 days old MNP specimens this difference is approximately 53.3%, and for the specimens at the age of 63 days it is 47.7%. At both ages the larger coefficient is exhibited by the dry-hardened specimens. If we compare the average difference between the 51 days old reference concrete specimens and the ones containing MNP, we can see that for specimens hardened in moist conditions this difference is 8.9%, and for specimens hardened in dry conditions it is 110%. In comparison with the 63 days old specimens, the difference is 23% and 12.5% respectively. What is interesting, in moist conditions the larger coefficient is exhibited by the reference concrete specimens, but in dry conditions the larger coefficient is shown by the specimens containing MNP.

CONCLUSIONS

This experimental study proves that montmorillonite nano particles in small dosage (8 kg in m^3) have no negative influence on mechanical and deformation characteristics of concrete. Some positive effects are established. The long-term deformation testing was carried out and the modulus of elasticity, the density and the compression strength of ordinary concrete and of concrete containing montmorillonite nano particles have been determined.

The concrete mix containing montmorillonite nano particles shows the long-term hardening effect. The compression strength of the 93 days old concrete specimens containing MNP is larger than that of the reference concrete specimens.

The modulus of elasticity at the age of 51 days is larger for the specimens containing MNP, but at the age of 63 days it has larger values in the reference concrete.

The MNP concrete specimens hardened in dry conditions have shown larger increase of basic creep deformations than the reference concrete specimens, but for the specimens hardened in moist conditions the values of basic creep deformation are similar.

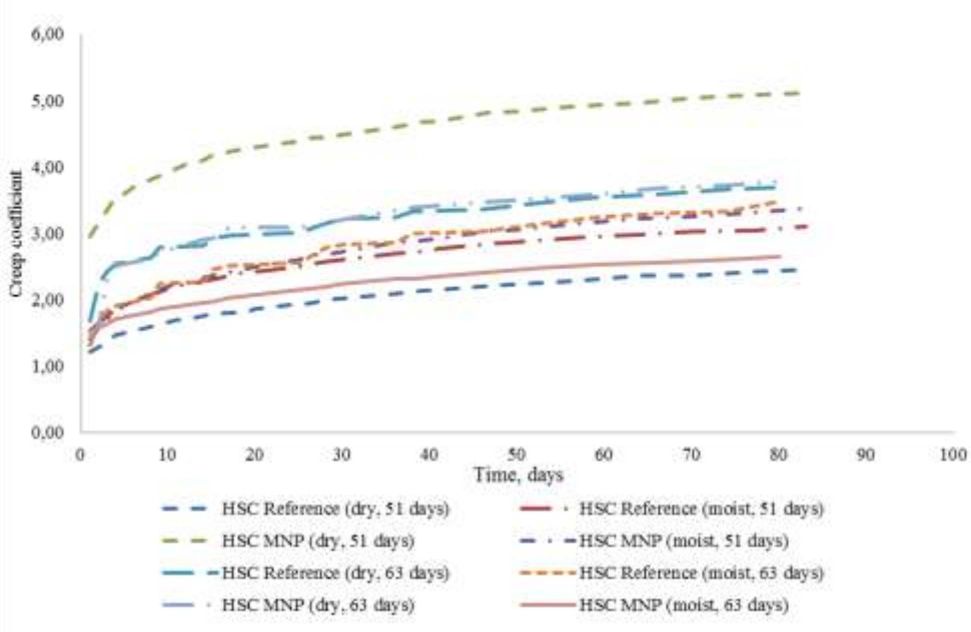

Fig.9. Creep coefficient of high strength concrete specimens

Under constant mechanical loading, the strain of concrete increases significantly with the loading duration, the increase often reaching 2.4 to 3.3 times the value of the instantaneous strain for the reference concrete specimens and 2.5 to 5 times for the specimens containing montmorillonite nano particles.

The creep coefficient increases with time at an ever-decreasing rate. The final creep coefficient is a useful measure of the creep capacity of concrete. On the 80th day of testing, the value of the basic creep coefficient reaches 2.42 to 3.36 for the reference concrete specimens and 2.56 to 5.09 for the concrete specimens containing MNP. The results of this experiment can be used to predict creep deformations.

In the future, the physical and mechanical properties of new high-strength concrete containing montmorillonite nano particles as an alternative admixture should be investigated in a more detailed way. Possibilities to increase the efficiency of montmorillonite nano particles must be considered. Additional chemical treatment or thermal activation of particles may be used in future research.

The obtained results indicate a quite high dispersion of the experimental data. In order to decrease the dispersion of the results, the number of specimens and tests should be increased.

ACKNOWLEDGEMENT

This work has been supported by the European Social Fund within the scope of the project "Support for the Implementation of Doctoral Studies at Riga Technical University".

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Andīna Sprince, Leonīds Pakrastiņš, Aleksandrs Korjakins, Genādijs Šahmenko. Montmorilonīta nanopiedevu ietekme uz betona ilgstošām deformācijām

Turpina pieaugt betona konstrukciju sarežģītība, un līdz ar to palielinās arī stiprības un deformāciju raksturlielumu nozīme. Šļūdes ievērošana ir daļa no racionālās pieejas, lai apmierinātu deformāciju kritērijus. Mūsdienās arvien vairāk tiek veidoti jauni, progresīvi betonu sastāvi, kas ir daudz ekoloģiskāki, stiprāki, izturīgāki, bet šie materiāli nav pietiekami izzināti. Pētījuma mērķis ir novērtēt iespēju izmantot minerāla montmorilonīta nano daļiņas (MNP) kā aktīvu piedevu betona maisījumam ar mērķi uzlabot fiziskos, mehāniskos un deformāciju rādītājus. Tika izprojektēti dažādi betona maisījumi un izgatavoti paraugi, izmantojot iepriekš minēto, netradicionālo aktīvo piedevu. Tā kā betona ilgspējības svarīgs rādītājs ir deformācijas, kas attīstās ilgākā laika periodā, tad tika veikti eksperimentāli pētījumi ar mērķi noskaidrot šāda jaunizveidota betona sastāva šļūdes parametrus. Pēc betona sacietēšanas paraugi tika slogoti ilgstošu laika periodu ar nemainīgu, vienmērīgu spiedes slodzi pie nemainīga gaisa mitruma un temperatūras. Eksperimentos tika noteiktas jauno betona sastāvu paraugu šļūdes deformācijas pie divām dažādām mitruma koncentrācijām – piesātinātā mitrā stāvoklī un gaissausā stāvoklī, šļūdes deformācijas tika salīdzinātas ar kontrolparaugu deformācijām. Paraugi tika aizsargāti no mitruma apmaiņas ar apkārtējo vidi. Eksperimentu rezultātā tika iegūtas likumsakarības starp spriegumiem un deformācijām 80 dienu periodā. Izgatavotiem betona paraugiem tika noteikta spiedes stiprība, elastības moduļi, šļūde un šļūdes koeficienti. Pētījuma dati dod iespēju prognozēt betona ilgstošas deformācijas. Rezultātā var izdarīt secinājumus par to, cik konkurētspējīgs ir jaunizveidotais betona sastāvs ar montmorilonīta nano daļiņām .

Андина Спринце, Леонид Пакрастиньш, Александр Корякин, Геннадий Шахменко. Эффект влияния нано добавок монтмориллонита на длительные деформации бетона

Вместе с возрастающей сложностью бетонных конструкций одновременно возрастают требования к прочностным и деформативным свойствам. Учет ползучести является частью рационального подхода для удовлетворения требований по деформациям. В настоящее время разрабатываются новые прогрессивные составы бетонов, которые более экологичны, прочны и выносливы, но малоисследованы. В данной работе исследуется возможность использования нано частиц минерала монтмориллонита, как активного заполнителя в составе бетонной смеси с целью улучшить физико-механические и деформативные свойства бетона. Были запроектированы составы бетона, используя вышеупомянутую нетрадиционную добавку. Поскольку анализ длительных деформаций в бетоне является важным фактором при проектировании долговечных конструкций, в данной работе представлены результаты экспериментального исследования параметров ползучести разработанных составов бетона. Были изготовлены экспериментальные образцы нескольких видов, которые после твердения нагружались равномерной сжимающей силой постоянного значения в течение длительного периода. Нагружение и тестирование бетонных образцов проводилось при постоянной комнатной температуре и уровне влажности. Исследование проводилось при двух крайних условиях: первый вариант с максимальной влажностью образцов защищенных от высыхания и второй вариант для высушенных образцов, защищенных от увлажнения. Представлены результаты тестов, демонстрирующие взаимозависимости напряжений и деформаций в течение 80 дней. В результате определены прочность на сжатие, модуль упругости, ползучесть и коэффициент ползучести для изготовленных бетонных образцов. Результаты исследования дают возможность прогнозировать долговременные деформации ползучести и позволяют сделать вывод о конкурентоспособности новых видов бетона с использованием нано частиц минерала монтмориллонита.