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RESEARCH ON LONG-TERM STRAINS FOR BEAMS WRAPPED WITH SELF-COMPACTED CONCRETE

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ABSTRACT

Many objects built in the past do not meet the new construction standards and may be at risk from the action of special loads. Therefore, there is a need for their structural elements to be reinforced by increasing the moment of inertia, and with this, there is a need to increase the cross-sectional dimensions.

The realization of reinforcing structural elements, particularly columns and beams, can be easily achieved by increasing their dimensions using self-compacting concrete, which benefits from its excellent workability properties as fresh concrete, enabling easy filling of formworks.

In this case, the reinforced elements of reinforced concrete structures will be subjected to a new process of strains, whether elastic or more importantly, they are also subjected to strains in the long-term process such as shrinkage strains and creep strains.

For the analysis of strains in structural elements reinforced with self-compacting concrete both at the moment of load action and in the long-term process of load action, an experiment was carried out for a period of two years.

During this experiment, the mechanical and deformable characteristics of elements (laboratory samples and beams) from normal concrete and from self-compacting concrete were analysed. The research of these characteristics was carried out both at the time t0=40 days, of the load action, and in the long-term process up to the time t∞=400 days

This paper presents the results obtained for shrinkage strains and creep strains during the analysis of beams made of ordinary concrete, self-compacting concrete, as well as repaired beams, whose core is made of ordinary concrete and after hardening, at the age of 40 days they are wrapped with a layer of self-compacting concrete on three sides of the beam. Results for the modulus of elasticity, compressive strength, breaking toughness, and water permeability results obtained from laboratory sample testing will also be provided.

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KEYWORDS

Self-Compaction concrete, Conventional concrete, Creep, Shrinkage, Strains

INTRODUCTION

Self-compacting concrete (SCC) in addition to aggregate, cement, water also contains special chemical additives such as new generation plasticizers called hyper plasticizers, which greatly reduce the water/cement ratio (W/C) as well as the special content of fly ash make self-compacting concrete special in its workability properties in the phase when the concrete is fresh. The higher content of granular aggregate affects the reduction of tensile strength, in particular reduces the modulus of elasticity and in this case also increases the deformable characteristics of concrete after hardening (shrinkage strains, creep strains, settlements, etc.) both in the short-term process and especially in the long-term process of load action.

One of the ways to ensure the stability of the mixture is to increase the content of binding materials such as fly ash. Another alternative is the use of chemical additives, such as viscosity modifying agents (VMA), which help maintain the stability of the mix and are particularly suitable for self-compacting concrete [1].

The long-term performance and durability of concrete structures depend not only on the composition of the mix, but also on the curing conditions during the very early stage, which plays a key role in the formation of the microstructure of the material [1].
The formation of cracks in the early hardening of concrete is a critical factor in the deterioration of structures, as it allows the penetration of aggressive agents and accelerates the corrosion of the reinforcement. The gradual development of damage, if not controlled, significantly reduces the stability and load-bearing capacity of the structure in the long-term process of load action. Drying shrinkage strains cause a reduction in the shear capacity due to the segregation of aggregate from the cement paste[2] .

Long-term strains generated by drying shrinkage and creep in reinforced concrete (RC) beams represent a significant problem and need to be accurately determined. The four main types of shrinkage are autogenous shrinkage (caused by self-drying during hydration of concrete), plastic shrinkage (caused by moisture loss from concrete before hardening), carbonation shrinkage (caused by chemical reactions between hydrated concrete and atmospheric CO2), and drying shrinkage (as a result of long-term dehydration of concrete over a long period). Shrinkage and creep are essential for long-term serviceability [3].

Rehabilitation of structural concrete elements and their repair are important for their use not only today but also in a longer period of their use[4].

Proper repair of beams with self-compacting concrete improves some of the properties of the beams and in particular increases the stiffness and thus the rigidity of the beams, improves the appearance, limits water permeability to the maximum, closing the cracks protects the reinforcement from corrosion and will be more acceptable for environmental conditions[4].

For proper filling of the formwork of the repaired beams, we have used three-fraction self-compacting concrete since the thickness of the layer for wrapping the beams is small and the reinforcement bars and rods prevent proper distribution of the concrete throughout the length of the beam. In these cases, the self-compacting concrete must be pumped with a pressure pump or lightly spread through a rod.

The action of some dynamic loads leads to defects and then the appearance of cracks, subjecting concrete structures to a possible failure [5]. Self-compacting concrete fills the spaces where the old concrete meets the new and leaves no gaps inside the cut, therefore it is one of the most suitable materials for increasing the performance of beams in the case of repair [6].
The creep strains are very similar for the same maintenance conditions of beams made of self-compacting concrete and beams made of ordinary concrete[7].

In Kosovo, since 2008, the rehabilitation of structural elements with self-compacting concrete has begun. The reinforcement of the bridge piers in the Han i Elezit-Kaqanik segment was made with self-compacting concrete.

Self-compacting concrete has been used both in the renovation of some existing business buildings and in new buildings for the construction of basements where it has played the role of waterproof concrete in order to eliminate the use of special insulation.
In this paper, we aim to provide experimental results for some of the characteristics of concrete elements that have been made with self-compacting concrete, and which results have been compared with those made with ordinary concrete.

But the main goal is to provide an overview of the behaviour of reinforced concrete elements repaired with self-compacting concrete to short-term and long-term loads. It is important to understand the impact of the cooperation between the two types of concrete (SCC and OC) both in shrinkage strains and in creep strains.

The results presented in this paper will help civil engineering professionals, both in the design and construction phases, to apply new methods for the rehabilitation of damaged structural elements.

MATERIALS AND METHODS

Experimental program

Preparation of equipment - To carry out the experiment, it was necessary to prepare equipment in advance to carry out the load with which the beams that were investigated for

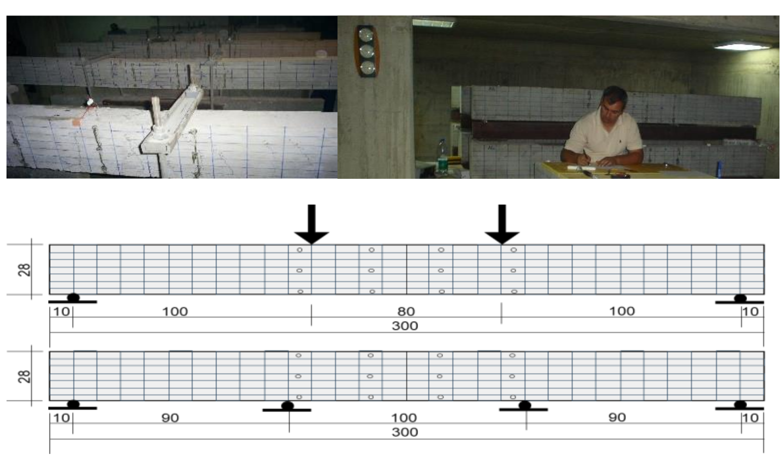

Fig. 1- Real appearance and schematic representation of beams treated in creep and shrinkage [11]

determining the creep strains were loaded. Supports with metal profiles and rods were made which were then loaded with concrete sides. This metal support was hung at two points on the beams where in this way the beam was loaded with two concentric gravitational forces. The beams were placed on concrete pillars with dimensions of 40x40cm. The beams that were used to carry out the research on shrinkage strains were placed on metal beams supported on four points with unhindered possibility for small displacements in the longitudinal direction. During the entire time, the temperature and relative humidity of the air were measured.

For the research of the creep coefficient, a device was prepared to realize the load which must be constant throughout the research process [1], [8], [9].

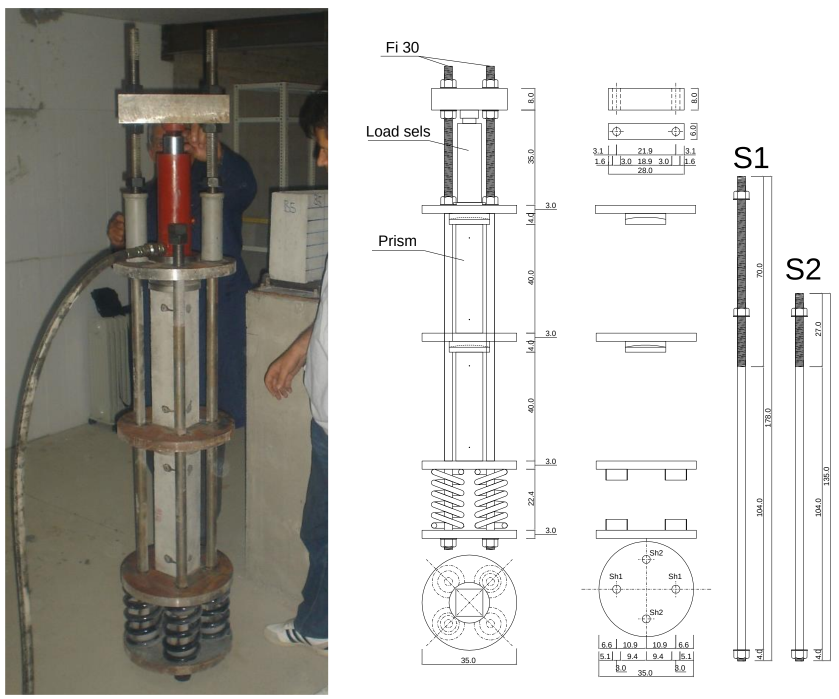

Fig. 2 - Equipment for the research of the creep coefficient [11]

The measurement of strains in the long-term process was carried out with a mechanical deform meter, while in the process of testing the beams at break in the short-term process, measuring tapes and a data logger were also used for direct reading of strains using the Watson bridge. The force was carried out with a hydraulic pump where the force was read in the data logger for reading the force.

The measurement of the size of cracks with a special microscope was carried out both in the long-term process and during the process of breaking the beams, and verification of new cracks and their distribution under the influence of increasing forces was also carried out.

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Fig. 3 - Measurement and verification of cracks [11]

Measurement of the settlements with mechanical settlement gauge during testing in the short-time process and in the long-time process are shown in the figure 4.

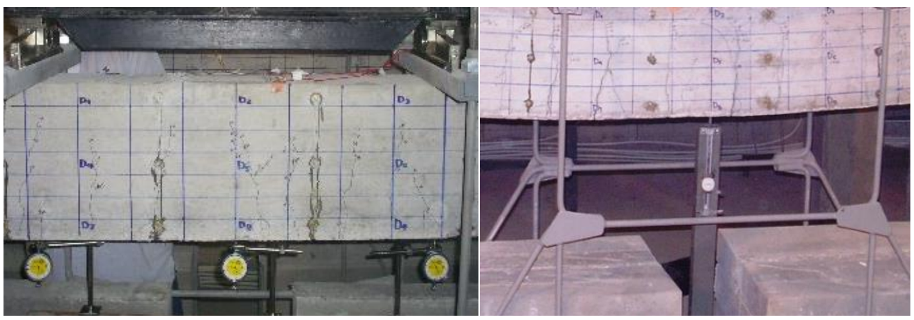

Fig. 4 - Measuring deflections [11]

Preparation of the room for the experiment

Considering the fact that the research of strains in the long-term process requires constant hydrometric conditions and temperature conditions, we were forced to prepare a space where the temperature throughout the experiment was constant (20+-20C) and the air humidity was also approximately constant (60-70%). The surface area of the room for the long-term research was S=150m^2.

But previously, for the preparation of the beams, a space of 500m^2 and a considerable number of people were used, both for the preparation of the samples and for the realization of the breaking tests [10].The process of concrete work and filling the samples - The concrete was worked in the experimental space where the mixing was carried out with a mixer with a capacity of 1m^3.

Two concrete mixtures were carried out, initially the ordinary concrete mixture was carried out, while after forty days the self-compacting concrete mixture was carried out. This was done so that the cores of the beams repaired from ordinary concrete would go through the hardening phase and then be covered with self-compacting concrete.

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The used materials

Considering that self-compacted concrete has specific characteristics, the choice of materials is also of particular importance. The use of stone fly ash to homogenize the concrete mix as well as the application of special chemical admixtures to enable easy processing and placing of the concrete without vibration make the difference between ordinary concrete and self-compacting concrete [8].

The beams are made of concrete class C 30/37, to produce concrete, crouched aggregate divided into three fractions produced from limestone rocks is used. Maximum aggregate grain 16 mm, PC 45 15p USJE cement is used to produce ordinary concrete and self-compacting concrete, while to produce self-compacting concrete, a hyper plasticizer chemical additive (superfluid 21) is applied and stone fly ash from the same aggregate is used as powder. The beams are reinforced with steel reinforcement of B500B quality [12][13].

The concrete mix design for ordinary concrete and for self-compacting concrete are shown in Table 1.

Tab. 1 - Concrete mix design for ordinary concrete and for self-compacting concrete

	Ordinary concrete kg/m3	Self-compacting concrete kg/m3
Fraction (0-4)	710	750
Fraction (4-8)	430	470
Fraction (8-16)	735	473
Cement	325	320
Water	210	200
Stone powder	x	104
Admixture(hyperplasticizer)	x	3

Preparation of elements and testing methods

For determining the quality of concrete, a significant number of cylindrical, cubic and prismatic samples were prepared, through which the following were determined: compressive strength EN 12930-3[14], Flexural Strength EN 12930-5 [15], Tensile Splitting Strength 12930-6 [16], modulus of elasticity ASTM 469[17], waterproofing EN 12930-8[18] , sound conductivity, pore content, shrinkage EN 12930-16[19] and creep coefficient [20].

This paper also provides a comparison of the results of mechanical characteristics between regular concrete and self-compacting concrete [21].

Fig. 6 - Laboratory testing process of samples [11]

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Compressive strength EN 12930-3

The compressive strength was determined on cubic samples with dimensions of 15x15x15cm. A digital hydraulic press was used for testing, where the speed of the load was 500 Kpa, and the sensitivity during testing of the sample was 5Mpa.

Tensile Splitting Strength 12930-6

Cubic samples were also used to determine the tensile Splitting Strength. For testing, a metal mechanism was used to transmit the linear force from the press to the sample and a hydraulic press, where in this case the speed of the load was 50Kpa, while the sensitivity for the tear strength was 0.5Mpa.

The secant modulus of elasticity was determined using cylindrical samples with a diameter of 150mm and a height of 300mm.

A metal mechanism was used to measure strains at three points and a deform meter with an accuracy of 0.001mm, where the sample was subjected to the loading-unloading process until two consecutive equal results were achieved.

A sample was previously tested to determine the compressive strength and a value of 40% of this result was used to load the samples during the elastic modulus testing for OC and SCC.

Water permeability EN 12930-8

To carry out the water permeability testing, cubic samples from OC and SCC with dimensions of 15x150x150mm were used, which were previously processed by removing the thin layer of cement past in the place where water will act at a pressure of 5bar for a period of 72 hours.

The determination of the depth of water penetration is determined after the sample is removed from the device for carrying out the action of water under pressure, is inserted into the press and divided into two parts by splitting the sample, where then with a metal ruler the distance from the end of the sample to the knee where the water has penetrated is measured.

Creep coefficient

Eurocode EN 1992-1-1 and ACI 209 provide methods for calculating and understanding the creep coefficient- To determine the coefficient of creep, prismatic samples of OC and SCC with dimensions 100x100x400mm and the special frame, which is presented in Figure 2, a deform meter with a measuring step of 300mm and an accuracy of 0.001mm was also used. References for measuring strains on the four sides of the prismatic samples were placed on the prism.

The creep coefficient testing process consists of two types of deformation measurements at the same time:

In the device where we have placed two prisms under the action of the load, the creep and shrinkage strains were measured together (creep & shrinkage), in order to know the result only from creep, we used three samples from the same concrete where we measured the shrinkage strains which we have subtracted from the previous result (creep & shrinkage-shrinkage) and thus we have only extracted the results from creep.

For testing self-compacted concrete in the fresh phase, the following methods were used: J ring, V funnel and U box with the test results [22]: J ring, h=7.4cm, d=59cm; V funnel, t1=8.2s, t2 =9.5 s; U box, h=37 mm. The j-ring and V-funnel testing is shown in Figure 11.

Fig. 3 - J-ring and V-funnel test [22]

To analyse the impact of short-term and long-term loads on concrete beams, eighteen concrete beams with a cross-section of (15x28) cm and a length of 3m were made. Three series of beams are made with two types of concrete, with ordinary concrete and with self-compacting concrete. The beams are reinforced with B 500B reinforcement, placed two Φ12 bars in the lower and two bars Φ 8 on the top of the cross-section, Figure 7.

The cooperation of normal concrete with self-compacting concrete is a very important characteristic for the rehabilitation of concrete elements. To investigate this cooperation, beams with ordinary concrete cores with cross-section dimensions of (7x20) cm were made, the same after reinforcement were wrapped with self-compacting concrete[13][20].

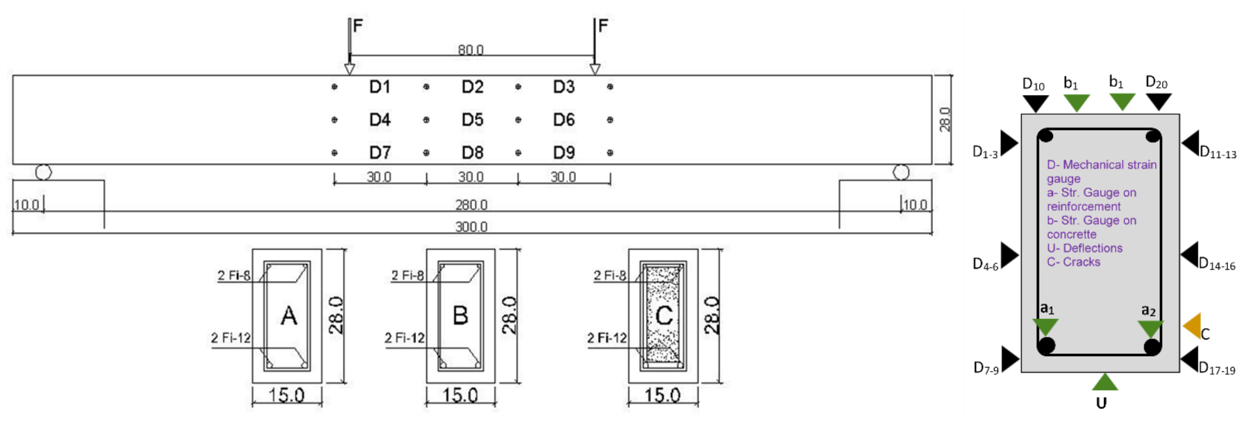

Fig. 7 - Beam, beam cross-sections and positioning of measuring points [11]

Applying strain gauge to concrete and reinforcement as well as measuring strains with a mechanical strain gauge and measuring of porosity are presented in Figure 8.

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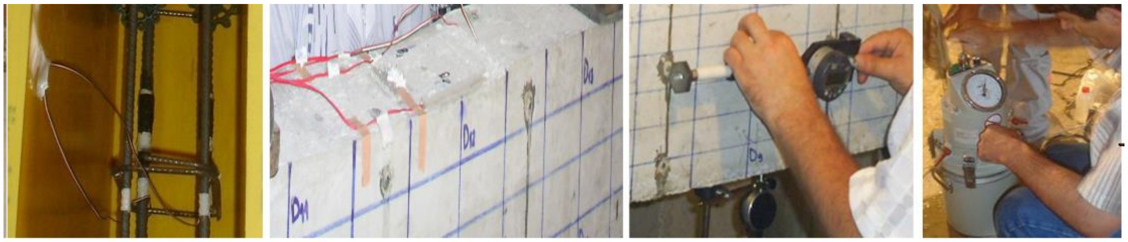

Fig. 8 - Application of measuring tapes, mechanical deformation and porosity measurement [11]

RESULTS

The test results for compressive strength, fracture toughness and modulus of elasticity are presented through the diagrams shown in Figure 9. These results were obtained from testing samples from OC and SCC under completely identical conditions.

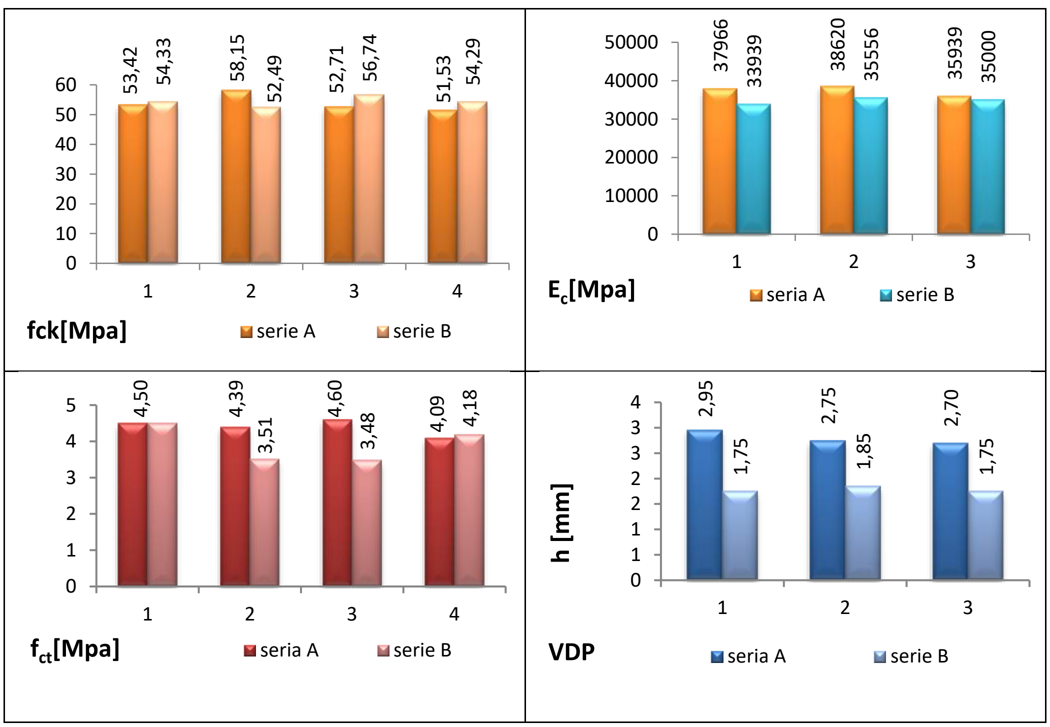

Fig. 9 - Comparison of the: Compressive strength(fck), Modulus of elasticity(E), Tensile Splitting Strength and Flexural Strength (fct), waterproofing (VDP)

The results for the creep coefficient for the OC samples, for the SCC samples and the calculated results according to Eurocode 2 (EC-2) are presented graphically in Figure 10.

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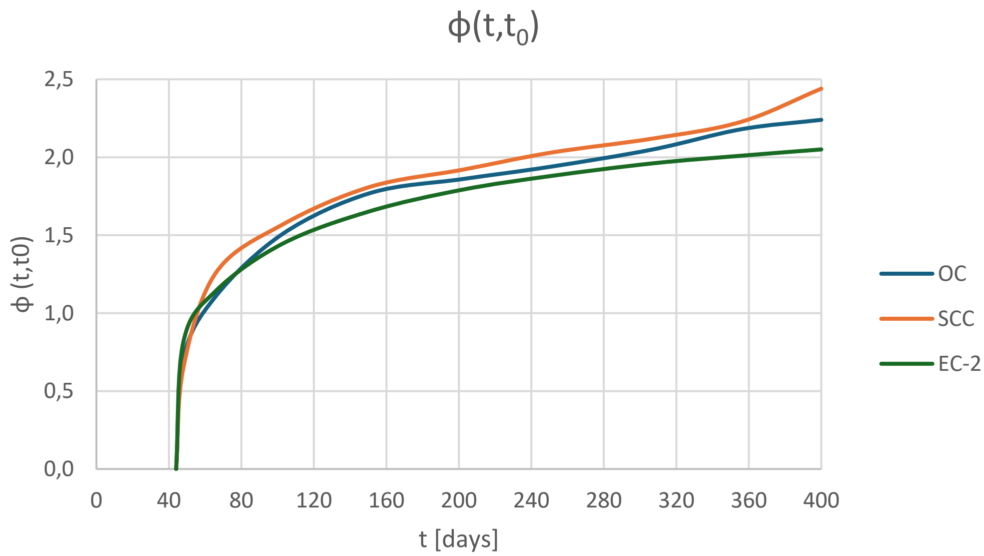


Fig. 10 - Creep coefficient results (OC, SCC, EC-2)

All the results for strains in the long-term process (shrinkage strains and creep strains) will be presented in graphically form for beams of series A, B and C.

During the experiment, measurements for shrinkage strains and creep strains were measured at twenty points, but we will present the diagrams of concrete strains in the compressed zone and in the tensile zone between the beams [23].

To analyse the shrinkage strains for ordinary concrete beams, AI-2 and AII-2 beams were analysed, for self-compacting concrete beams, B-3 and B-4 beams were analysed, while for beams covered with self-compacting concrete, there were treated beams C-3 and C-4.

Shrinkage strains result for ordinary concrete beams (A-series beams), shrinkage strains results for self-compacting concrete beams (B-series beams) and shrinkage strains results for self-compacting concrete clad beams (beams of series C) as well as the comparison of these results are shown in Fig. 11.

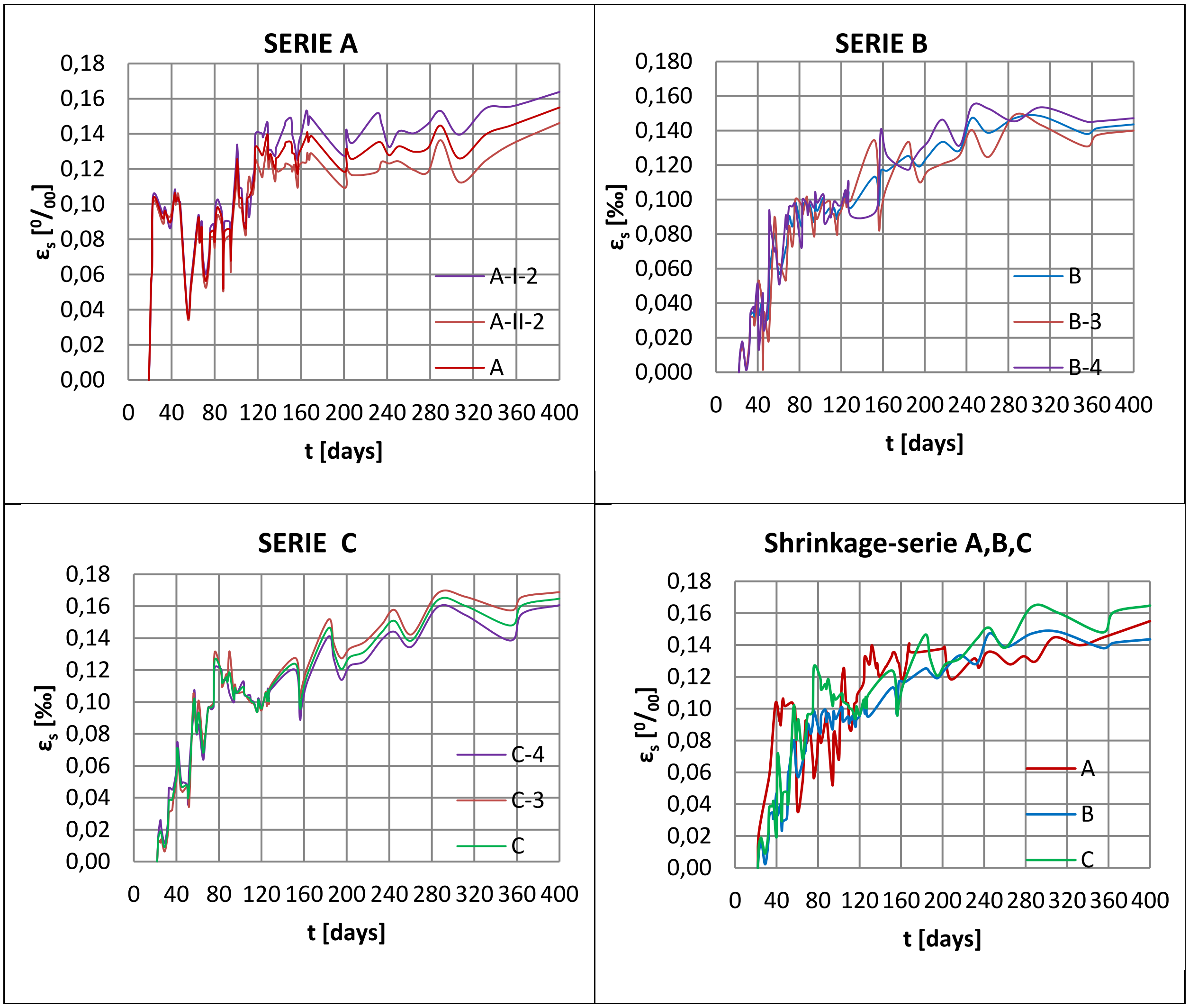


Fig. 11 - The results of shrinkage strains and their comparison for beams from ordinary concrete (series A), for beams from self-compacting concrete (series B) and beams covered with self-compacting concrete (series C).

From the diagrams we see that movement results in three months are more pronounced but after that time they begin to be stabilized. Finally note that the largest strain of shrinkage has in the repaired beams (series C). At time t = 400 days difference between the normally concrete beams and self-compacted concrete beams results is 7% (A-B), A-C is 14% while for self-compacted concrete beams and repaired beams (BC) results differ for 6%.

Creep strains on compression and tensile zone of the beams and the neutral axis position are presented in Figure 12. These diagrams are presented for different time, starting from time t=40 day until the time t=400 days.

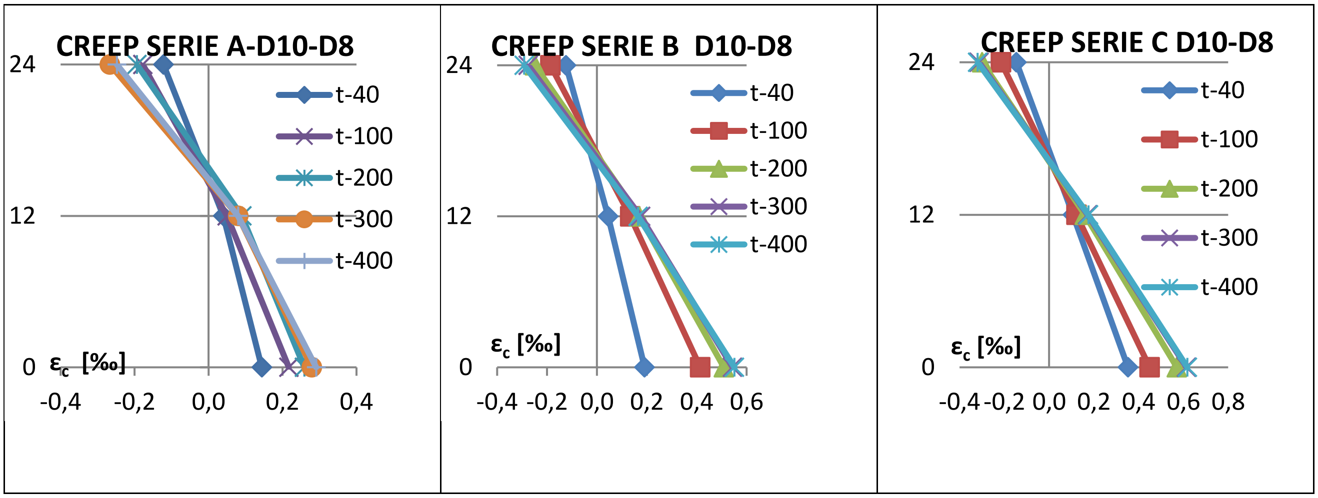
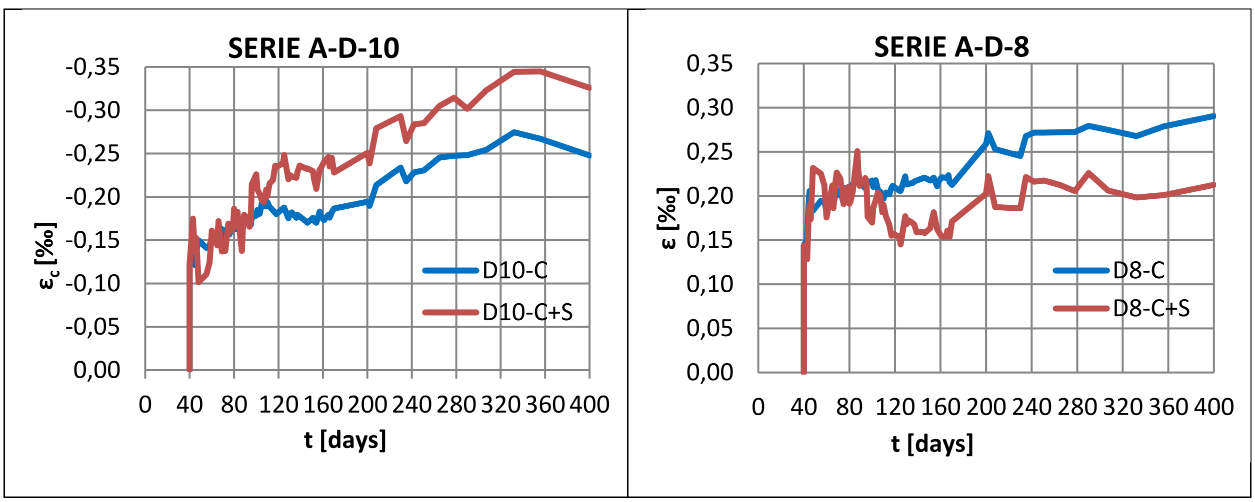


Fig. 12 - Creep strains on compression and tensile zone of the beams and the neutral axis

The results of the creep strains together with the shrinkage strains (C+S) and the results of the creep strains (C) in the compression zone (D-10) and in the tensile zone (D-8) for ordinary concrete beams (series A), self-compacting concrete beams (series B) and beams covered with self-compacting concrete (series C) are shown in Figure 13.



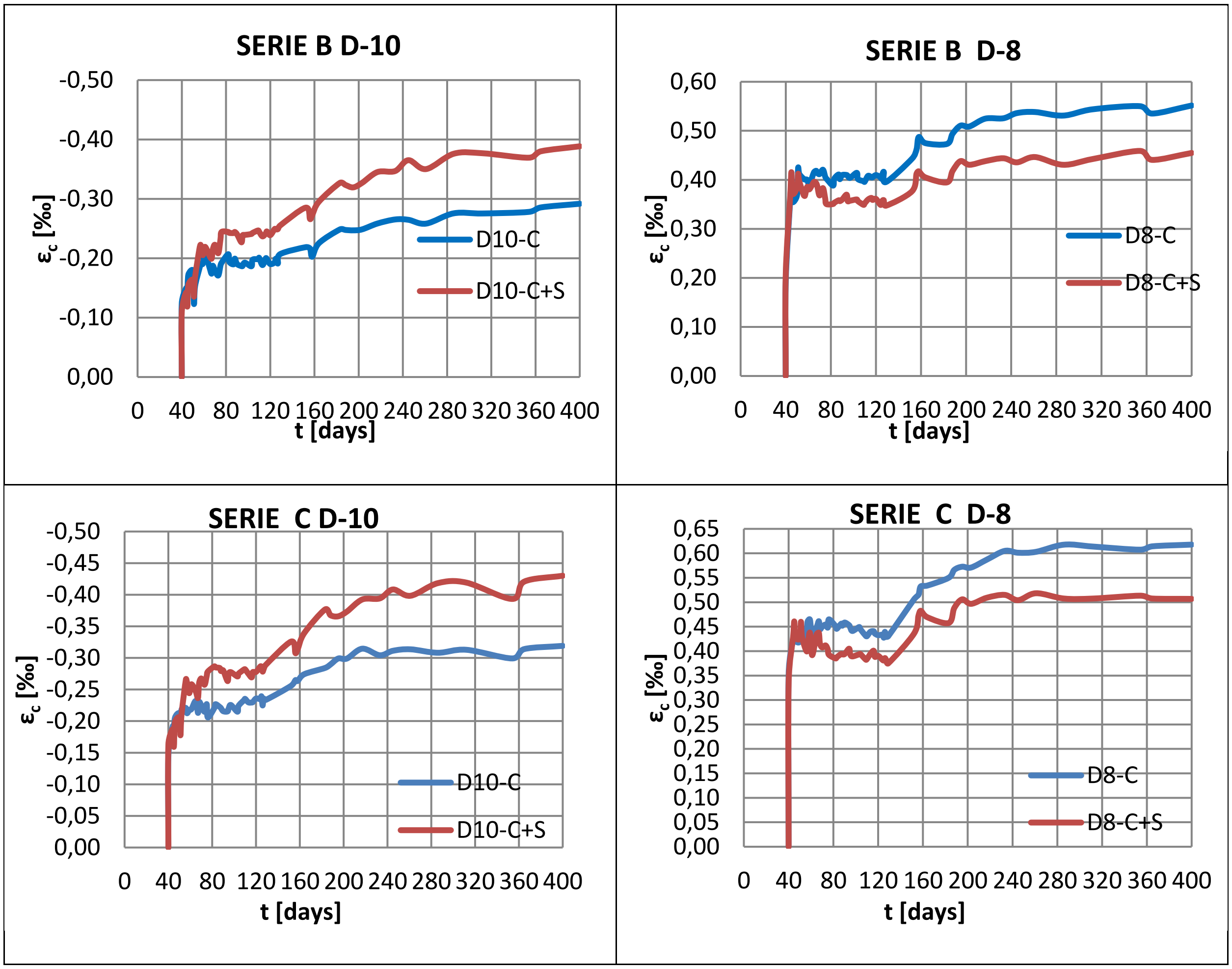


Fig. 13 - The results of the creep strains together with the shrinkage strains (C+S) and the results of the creep strains (C) in the compression zone (D-10) and in the tension zone (D-8).

Comparison of the results of creep strains in the compression zone and in the tensile zone of beams from ordinary concrete (series A), beams from self-compacting concrete (series B) and beams covered with self-compacting concrete (series C) as and neutral axis position are shown in Figure 14.

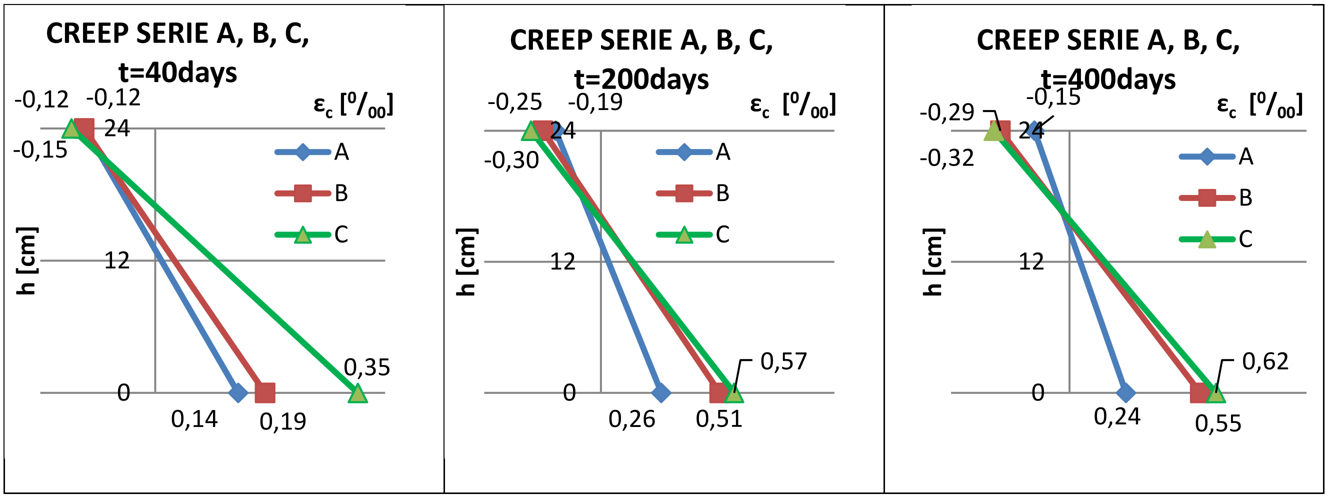


Fig. 14 - Comparison of the results of creep strains in the compressive zone and in the tensile zone for the three types of beams.

In Figure 15 there are presented comparisons of results of creep strains together with shrinkage strains (C+S) and results of creep strains (C) for beams of series A, B and C on compression (D-10) zone and on tensile zone (D-8).

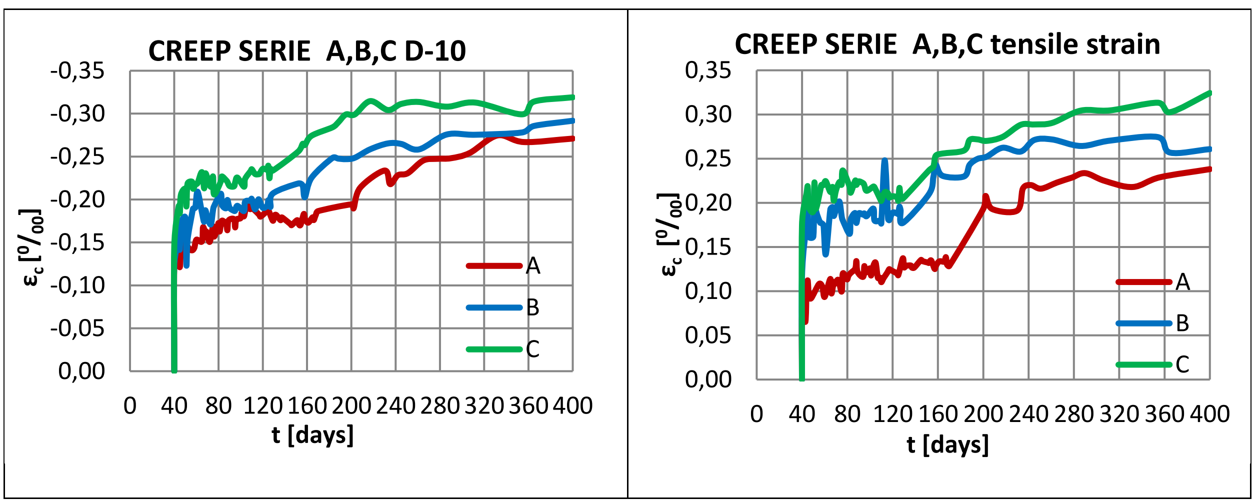


Fig. 15 - Comparison of results of creep strains together with shrinkage strains (C+S) and results of creep strains (C) for beams of series A, B and C.

After time t = 400 day of creep strain in concrete in compression zone for beams of ordinary concrete (series A), beams from self-compacting concrete (series B) differ for 7.2%, strain in tensile zone differ for 47%. For beams of ordinary concrete and beams covered with self-compacting concrete (series C) strains in compression zone differ for 13.7%, strain in tensile zone differ for 53%. The beams from self-compacting concrete (series B) and beams covered with self-compacting concrete (series C) series have these differences in results: Strain in compression zone differ by 7%, strain in tensile zone differ for 10.7% [9] [31].

CONCLUSION

The speed of sound permeability in self-compacting concrete samples is lower than in regular concrete samples.

Self-compacting concrete has better waterproofing results than ordinary concrete.

Analysing the results of testing samples in splitting tensile strength and testing samples in bending, we conclude that self-compacting concrete has lower tensile strength results than ordinary concrete.

From the comparison of experimental results for the modulus of elasticity, we conclude that the results of samples from self-compacting concrete have lower results compared to conventional concrete.

Comparing the diagrams of the results of the coefficient of creep, we notice the same phenomenon as in the case of the results of the tensile strength and the results of the modulus of elasticity, where the samples from self-compacting concrete have a higher coefficient of creep, which is related to the use of aggregates and fly ash for the realization of the self-compacting concrete mix, which content reduces the properties of the tensile strength of concrete. We can say that the experimental results are close to the theoretical results calculated with EC-2.

Strains from shrinkage in self-compacting concrete beams up to the first six months are greater, but with time they approximate, after 300 days, according to the experiment, strains from shrinkage in beams from ordinary concrete are greater. This phenomenon can be explained by the fact of the better cooperation of the reinforcement with the self-compacting concrete (better adhesion).

The results of strains from shrinkage in beams from self-compacting concrete up to the first six months are greater than in beams from ordinary concrete, but over time they approximate, after 300 days according to the experiment the results of strains from shrinkage in beams from ordinary concrete are bigger. This phenomenon can be explained by the fact of the better cooperation of the reinforcement with the self-compacting concrete (better adhesion).

The difference in the results of shrinkage strains for beams from ordinary concrete, beams from self-compacting concrete and for repaired beams is small and after the time t = 400 days the difference is about 7%.

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