Long-Term Parameters of New Cement Composites

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Abstract. Since the beginning of the 20th century, scientists and cement composite technologists are working on developing various types of new structural multi-component cement composites. Several obstacles prevent more widespread use of these newly developed cement composites in construction. One of the main problems is insufficient information about the long-term properties, which are essential in ensuring the safe and long exploitation of structures. The purpose of this research is to determine the long-term properties of several new cement composites: ultra-high strength cement composite with PVA fiber "cocktail" (2% by volume), with micro silica and nano silica additive; ultra-high strength cement composite with 1% montmorillonite mineral nano-size particles; reference composition. Test specimens were prepared and subjected to constant compressive load in permanent room temperature and level of moisture. There were properties such as compressive strength, modulus of elasticity, shrinkage as well as uniaxial creep deformations investigated in the laboratory. Afterward parameters of long-term properties were determined. The obtained results showed that after approximately 90 days of loading the creep coefficient values of new cement composites were 0,5–3; specific creep values were 30–55 microstrain/MPa; creep modulus was 2–90 GPa. The experimental study proves that new elaborated mixes can be successfully used in the production of concrete, thus potentially decreasing the use of cement, which would lead to the reduction of carbon dioxide released into the atmosphere.

Keywords: Creep coefficient · Specific creep · Creep modulus · New cement composite

1 Introduction

Nowadays the construction material industry is developing rapidly, with an ever-increasing tendency towards the use of new materials. Scientists and cement composite technologists are working on developing various types of new structural multi-component cement composites. The findings include mixtures with reduced quantity of cement and smaller aggregate dimensions, different types of fibers being used as disperse reinforcement, introduction of various chemical additives and a lowered water-cement ratio, as well as substituting some of the cement with recycled materials, etc. (Fathifazl et al. 2011; Fehling et al. 2014; Girskas et al. 2016; Kazanskaya and Smirnova 2018; Smirnova 2018; Šinka et al. 2018; etc.). The newly developed cement

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composite matrices in general have improved physical properties, e.g., their microstructure—cement paste accounts for the larger part of the volume, and the porosity was reduced, thus leading to cement composites with smaller water absorption and better frost resistance properties (Grinfeld et al. 2014; Lu and Poon 2018; Prisco et al. 2009; etc.). Although the effect on these properties has been conscious there are still several obstacles that prevent more widespread use of these newly developed cement composites in construction. One of the main problems is insufficient information about the long-term properties, which are essential to ensure safe and long exploitation of structures.

2 Materials and Methods

One of the goals of the experiments was to find out whether the new cement composites can be competitive and whether their long-term properties are equivalent to high strength cement composites (HSCC) (the compressive strength 40–120 MPa; w/c ≤ 0.4) (Neville 2002; Naaman and Reinhardt 2003) and ultra high strength cement composites (UHSCC) (the compressive strength 120–400 MPa; w/c ≤ 0.2) (Naaman and Reinhardt 2003; Gilbert and Ranzi 2011).

During the research following cement composites were made and tested (see Table 1), where appeared designations of various cement composites, which were used in the graphs.

Cement composite compositions were made by the design rules of recipes. The cement composite mixtures were prepared using a double shaft laboratory mixer (BHS, 3 kW, 20–100 rpm). For determination of the compressive strength cubes of 100 × 100 × 100 mm, prisms of 40 × 40 × 160 mm and cylinders of Ø47 × 190 mm were used (see Fig. 1). The compressive strength of the specimens was determined in the compression machine “Controls”, model No. C56G2, with an accuracy of ±1% and a measurement range of 0–3 kN; the loading speed was 0.8 MPa/s.

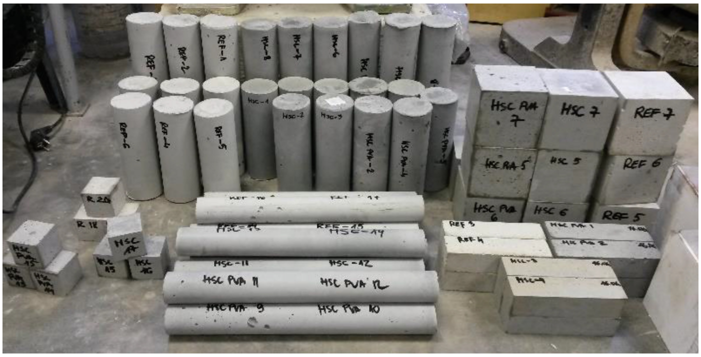

Fig. 1. Demolded specimens (RTU lab).

After becoming of a certain age, the specimens were prepared for testing. Before that, specimens were weighted, and measured. For determination of creep strain (in

Table 1. Various cement composites.

Mix designation	Description	*Compressive strength, MPa	Long-term test specimen type	Storage regime	Long-term loading regime	*Specimen age, days
HSC PVA MS	Ultra-high strength cement composite with PVA fiber “cocktail” (2% by weight/mass), + micro silica	112	Cylinder Ø47 × 190 mm, air-dry	t = 23 ± 1 °C, RH = 35 ± 3%	90 days - constant static load corresponding to 25% of the ultimate stress; 30 days - *recovery period	28
HSC PVA NS	Ultra-high strength cement composite with PVA fiber “cocktail” (2% by weight/mass) + micro silica + nano silica	110	Cylinder Ø47 × 190 mm, air-dry	t = 23 ± 1 °C, RH = 35 ± 3%	90 days - constant static load corresponding to 25% of the ultimate stress; 30 days - *recovery period	28
HSC MS REF (reference for HSC PVA NS)	Ultra-high strength cement composite with micro silica + nano silica	128	Cylinder Ø47 × 190 mm, air-dry	t = 23 ± 1 °C, RH = 35 ± 3%	50 days - constant static load corresponding to 25% of the ultimate stress;	28
HSC M	Ultra-high strength cement composite with 1% *montmorillonite mineral nano-size particles	103	Prism 40 × 40 × 160 mm, air-dry	t = 23 ± 1 °C, RH = 35 ± 3%	90 days - constant static load corresponding to 30% of the ultimate stress; 30 days - *recovery period	51

(*continued*)

Table 1. (*continued*)

Mix designation	Description	*Compressive strength, MPa	Long-term test specimen type	Storage regime	Long-term loading regime	*Specimen age, days
HSC R (reference for HSC M)	Ultra-high strength cement composite	100	Prism 40 × 40 × 160 mm, air-dry	t = 23 ± 1 °C, RH = 35 ± 3%	90 days - constant static load corresponding to 30% of the ultimate stress; 30 days - *recovery period	51

Notes:

*Compressive strength of cube (100 × 100 × 100 mm), 28 days old specimen.

*Montmorillonite mineral nano-size particles - powder of very fine, especially processed clay particles, applied as an additive and partly replaced cement.

*Recovery period - no load applied

*Specimen age (days) on the long-term testing start date uniaxial compression) and shrinkage strain, the cylindrical specimens (Ø47 × 190 mm) and prismatic specimens (40 × 40 × 160 mm) were used. For all the creep and shrinkage specimens, aluminum plates (10 × 15 mm) were centrally and symmetrically glued to side surfaces in order to provide the basis for strain gauges. Six aluminum plates were glued to one cylindrical specimen, four – to the prismatic specimen.

The strains were measured using Aistov electrical strain gauges with a scale interval of 1 μm and maximum range of ±5 mm or mechanical clock gauges "ИЧ" with a scale interval of 1/100 mm and maximum range of 10 mm. The manufacturer had calibrated the measuring instruments. The strain gauges were attached in such a way that their "knives" were located on the glued plates; strain gauge base – 50 mm. Strain gauges were attached to the specimens with elastic rubber bands. Specimens with attached strain gauges were put into creep lever test stands (see Fig. 2), two specimens in each test stand. Creep lever test stand allows to use the specimens with dimensions ≤ 70 mm, what is more, characteristic to the dimensions of high and ultra-high strength cement composite structures. With these stands, it is possible to apply constant loading to the specimens and to keep it uniform over a long period. Also, it is not necessary to adjust the stress level during the experiments, the calibration curves are linear, no energy resources are consumed, and it is possible to test cement composites with the maximum aggregate dimension ≤ 5 mm, simultaneously ensuring economical use of materials. The lever arm ratio of the creep testing stand was 1:40. The accuracy of the counterweights was 1/100 kg or 0.01%. Therefore, the accuracy of creep levers is $0.01 \times 40 = \pm 0.4$ kg.

Fig. 2. Determination of uniaxial compressive creep strains with the creep lever test stands (RTU lab).

All the creep specimens were loaded with a constant static load, regularly performing strain readings. To determine correct creep behavior, similarly shaped shrinkage specimens were placed in equivalent environmental conditions and their strain changes were monitored (no load applied to the shrinkage specimens). Conclusions were made based on subtracting shrinkage strain values from the compressive creep values. The basic and drying creep components have not been determined separately. The modulus of elasticity was determined from the elastic strains that occurred at the beginning of the creep test. (Reunion Internationale des Laboratoires et Experts des Materiaux [RILEM] 1998; American Concrete Institute [ACI] 2008).

3 Results and Discussion

During the experimental study the values of strength, deformability, long-term properties of various new cement composites were found and parameters for designing of safe structures were determined, which had not been found before.

Figure 3. shows the cubic compressive strength of various high and ultra-high cement composites (testing 100 × 100 × 100 mm cubes). Values range from 80 to 104 MPa at the beginning of the tests and from 107 to 128 MPa at the end of tests. The largest cubic compressive strength was determined for cement composite without unconventional additives.

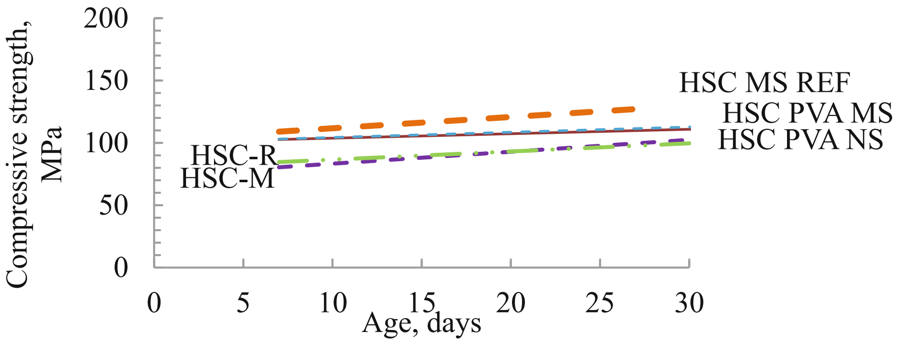

Fig. 3. Compressive strength of different kinds of high and ultra-high strength cement composites.

Creep coefficient (see Fig. 4) shows the proportion of creep strain and elastic strain. Experimental data for various compositions shows that creep coefficient of high and ultra-high strength cement composites was the same as for normal strength cement composites and normal strength cement composites with unconventional additives (Sprince et al. 2018).

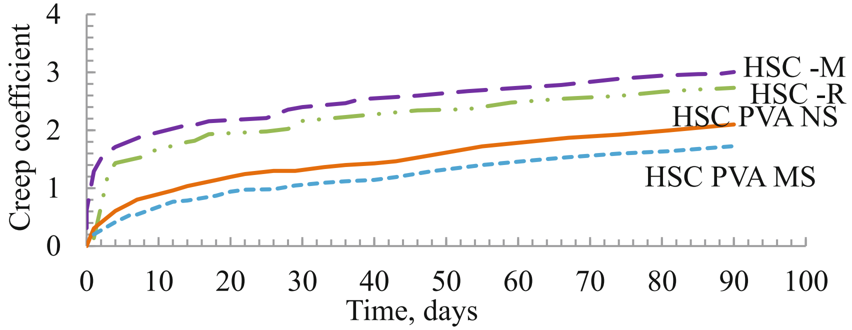

Fig. 4. Creep coefficient in compression of different kinds of high and ultra-high strength cement composites.

The values are within margins of 0.5 to 3, which does not comply with data from literary sources which predict a significant decrease of this coefficient (European Committee for Standardization [CEN] 2004). The smallest creep coefficient values are for ultra-high strength compositions with PVA fibers.

Specific creep (see Fig. 5) is the most objective parameter of long-term loading as it excludes stress effect on long-term strains. Specific creep values are from 30–55 microstrain/MPa. The smallest specific creep values are for ultra-high strength cement compositions.

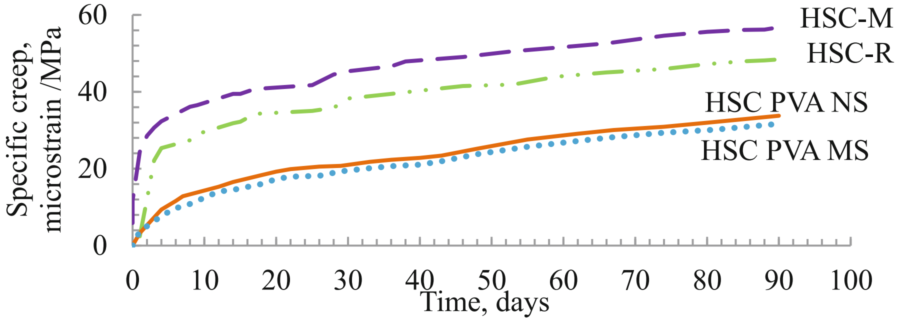

Fig. 5. Specific creep in compression of different kinds of high and ultra-high strength cement composites.

Creep modulus (see Fig. 6) is the proportion of applied stress and creeps strain. This long-term parameter can be used for determining the displacement of long-term loaded structures after a long period. As can be seen, creep modulus tends to decrease within the time which can be explained by the increase in creep strain and total strain. The lower the creep modulus, the less creep in the material.

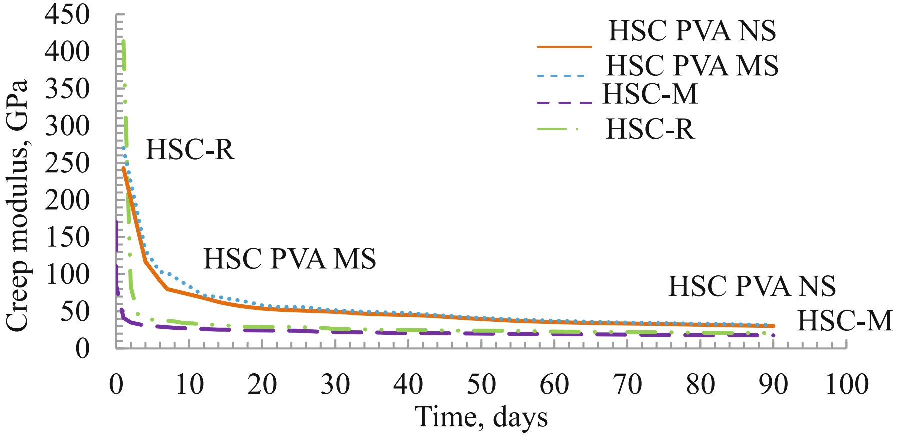

Fig. 6. Creep modulus in compression of different kind of high and ultra-high strength cement composites.

Deformation amount rapidly increases in the first week, then the deformation speed in time decreases and approximately after 60 days significant changes in deformation cannot be observed anymore.

4 Conclusion

Experimentally obtained results for various high and ultra-high strength cement composite tests confirm the hypothesis by various leading researchers (Neville, Brooks, Bazant, Gardner, Lockman, Fanourakis, Gilbert, Ranzi, Baweja, Kim, Wittmann, Rusch and others). The obtained results indicate: the higher the density of cement composite, the stronger it is and strain is lesser (it can be explained by the unfilled gel space relative amount in the hardened cement paste. Gel space ratio is closely related to the amount of cement and water/cement ratio, which is normally decreased to obtain an increase in cement composite strength. Similarly, the hypothesis that, the dryer and more mature the cement composite, the smaller the strain, was confirmed. That can be explained with cement composite chemical processes during its drying. Similarly, it has been experimentally proved that cement composite final strength increases with cement composite age and it is not substantially affected by its subjection to loading. It has been assumed that the difference in specimen's age does not significantly influence the test results.

Similarly, it was experimentally determined that montmorillonite added to cement composites neither significantly improves nor decreases the mechanical and deformability properties.

Nano silica mineral additive does not have a significant effect on parameters of cement composites strength, deformations, long-term properties. The difference in results between cement composites with and without nano silica is within 2–7% margins.

The application of PVA fibers in high and ultra-high strength cement composites does not provide improvements in strength and long-term properties. That can be explained by the fact that distribution of fibers is irregular, random in character, as well as the fact that in mixing process more air is attracted and gaps were formed, and it is technologically harder to work such fibrous cement composite in cement composite molds. Therefore, the cement composite composition is not uniform, it is more porous.

The obtained results show that after approximately 90 days of loading creep coefficients values of new high and ultra-high strength cement composites are the same as for normal strength cement composites 0,5–3; specific creep values are 30–55 microstrain/MPa; creep modulus is 2–90 GPa.

The use of new additives would give an indirect positive effect on the global environment, as, by increasing the use of new unconventional cement compositions and by reducing the dimensions of the cross-sections of structures, the total amount of cement consumption would decrease. By substituting part of the cement with recycled mineral fillers, the use of non-renewable resources and non-biodegradable waste shall also be reduced.

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