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Development of Autogenous Shrinkage Deformation and Strength Parameters in Self-Consolidating Concrete with Light and Natural Aggregate

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Development of Autogenous Shrinkage Deformation and Strength Parameters in Self-Consolidating Concrete with Light and Natural Aggregate

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Abstract. The concrete during the curing exhibits volume changes caused by different factors: chemical reactions during hydration, surface drying, external temperature or carbonisation. Each aforementioned factor imposes different type of shrinkage that constitutes to the overall shrinkage of concrete. In case of the concretes with a low water/cement ratio, significant influence on the overall shrinkage has the autogenous shrinkage. This type of shrinkage is a result of self-desiccation that sucks out the water from capillary pores during the hydration.
The article presents the results of the test on the autogenous shrinkage performer in accordance with modified ASTM C1581. To reduce the autogenous deformations caused by the shrinkage, the authors implemented internal curing by using presoaked lightweight aggregate. The tests were performed on cement mortars and self-consolidating concretes with water/cement ratio of w/c=0.28. The mortars were made with use of fine natural aggregate 0-2 mm and fly ash lightweight aggregate 0-4mm. To produce concrete authors used natural aggregate 0-2 mm and 2-8 mm and fly ash lightweight aggregates 0-4 mm and 4-8 mm. Designed self-consolidating mixes were tested to determine their rheological properties. The concrete compressive strength and tensile splitting strength was determined after 1, 3, 7 and 28 days. The autogenous deformations were registered every 500 s during 28 days. The shrinkage was determined on slab samples 35x150x1100 mm. The samples simulated linear expansion of ring specimen used in ASTM method. Study analyses the influence of the type of aggregate on the development of autogenous deformations and strength properties of young self-consolidating concretes. Studies have shown that presoaking of the light aggregate changes the development of deformation. Internal curing caused swelling instead of shrinkage during the hydration stage, reducing the overall autogenous shrinkage.

1. Introduction

The development of mechanical properties and autogenous deformation in High Performance cement composites progresses simultaneously. The highest rate can be observed in the first 24 hours. During the setting and hardening of concrete the physical-chemical reactions, facilitate the increase of mechanical properties and shape the mechanisms responsible for autogenous deformation. The rate and development of material properties depend mostly on the composition of the mix and the amount of water. Deficit or excess of the water, incorporated in the water-cement ratio or from the internal curing method is responsible for occurrence of the swelling or shrinkage during the hydration phase. Considering the mechanical properties of the concrete, the increase in the water amount causes the decrease in strength by several percent [1]. Internal curing however in a minimal way affects the mechanical parameters [2]. Comparison of the development of both parameters is possible after the first, 24 hours, when the composite enters hardening phase. Use of higher amounts of cement and mineral additives significantly influences the tightness of binder matrix, the temperature rise during hydration and compressive strength of the High-Performance Concrete [1,3].

There are several calculation models for determination of the autogenous shrinkage based on the strength properties. The most popular and normalized models include CEB MC90-99 and EC-2. The models assume that the value of autogenous shrinkage of the composite in a given period of time is proportional to the mean or characteristic compressive strength. The algorithms are prepared for ordinary concretes with recommended component ratios, including low binder amount and high water/cement ratio. For High-Performance Concretes with lower w/c ratio and higher volumes of binder the use of correlation equations can be inaccurate, resulting in lower values of material properties. The phenomenon was described in various studies [4,5].

The study presents an analysis of development of autogenous shrinkage and strength properties in High-Performance Concretes with natural and lightweight aggregates. Performed analysis allowed drawing conclusions on the influence of used aggregate on the development of strength and autogenous deformations.

2. Mixture proportions and specimens

The tests were conducted on four different High-Performance Self-Consolidating Concretes (HPSCC) with different type and gradation of the aggregate. The composites C-1 and C-2 were made using only fine aggregate, while C-3 and C-4 with fine and coarse natural and lightweight aggregate. The lightweight coarse aggregate used in the C-3 composite was pre-soaked for 30 minutes. The binder for all aggregates consisted of Portland Cement CEM I 42.5 R, silica fume, and fly ash. The water/cement ratio and volumetric cement/aggregate ratio was the same for pairs of composites C-1, C-2 and C-3, C-4. The content of composites is presented in table 1.

Table 1. Mix design

Mix	w/c	c/a	Cement [kg/m³]	Mineral additives [kg/m³]		Water [kg/m³]	Superplasticizer [kg/m³]	Aggregate [kg/m³]			
								Natural		Light Pollytag	
				Fly Ash	Silica Fume			0 - 2	2 - 8	0 - 4	4 - 8
C-1	0.28	0.62	795	127	67	222	18	1100	-	-	-
C-2	0.28	0.62	795	127	67	222	24	-	-	550	-
C-3	0.34	0.23	450	72	38	155	8.0	624	1072	-	-
C-4	0.34	0.23	450	72	38	155	7.0	-	-	310	540

Before the core tests, the preliminary rheological tests (Slump Flow Test) were conducted to evaluate the flowability of the mix. The mix with only fine aggregate exhibited flow of D = 240 mm in accordance with [6]. The concrete mix C-3 reached the flow of D = 590 mm t_{500} = 5.0 s, while the C-4 mix reached D = 610 mm in t_{500} = 6,0 mm. Obtained results allowed to classify the mixes as self-consolidating.

The measurement of the autogenous shrinkage was conducted on three insulated concrete samples of 35x150x1100 mm dimensions. The measurement of the displacement was made using digital dial gauges during first 28 days of curing. The evaluation of the mechanical properties included compressive strength and splitting tensile strength. Tests were conducted on 10x10x10 cm after 1,3,7 and 28 days.

3. Results and discussions

The development of autogenous deformation and mechanical parameters are expressed in the assumed time period. The autogenous deformation was measured every 500 s, while the strength development was determined for four different time points.

Figures 1 and 2 present the comparison of the autogenous shrinkage development with development of compressive strength and splitting tensile strength respectively for C-1 composite.

Figure 3 presents the degree of material parameter development for C-1 composite in a given day to the overall strength at 28 days.

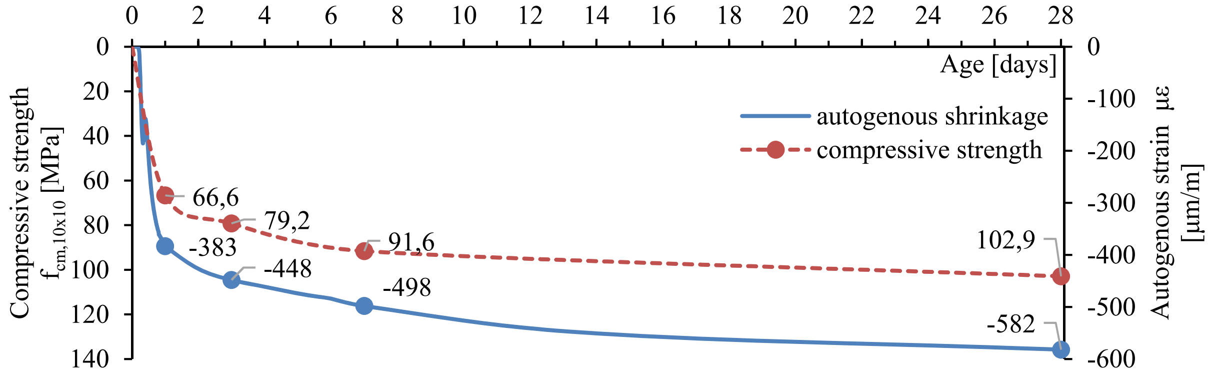

Figure 1. Development of compressive strength and autogenous shrinkage of C-1 composite

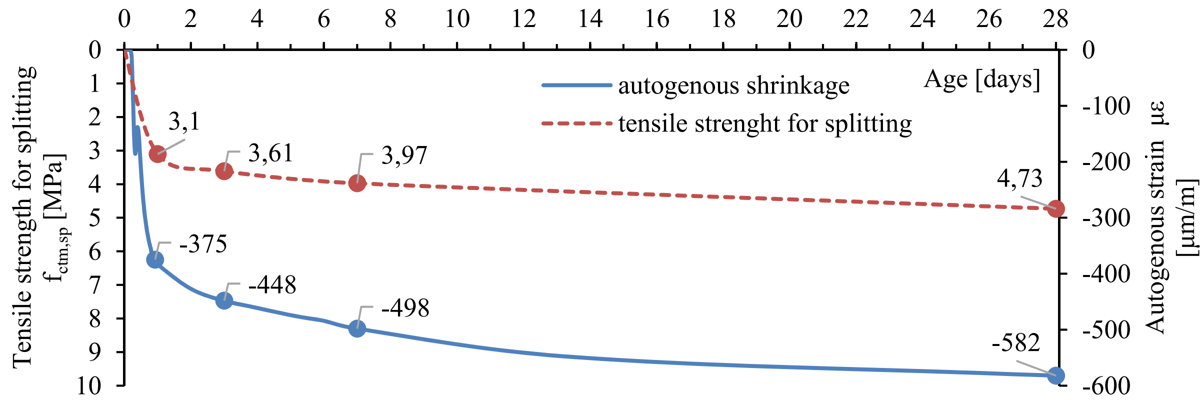

Figure 2. Development of tensile splitting strength and autogenous shrinkage of C-1 composite

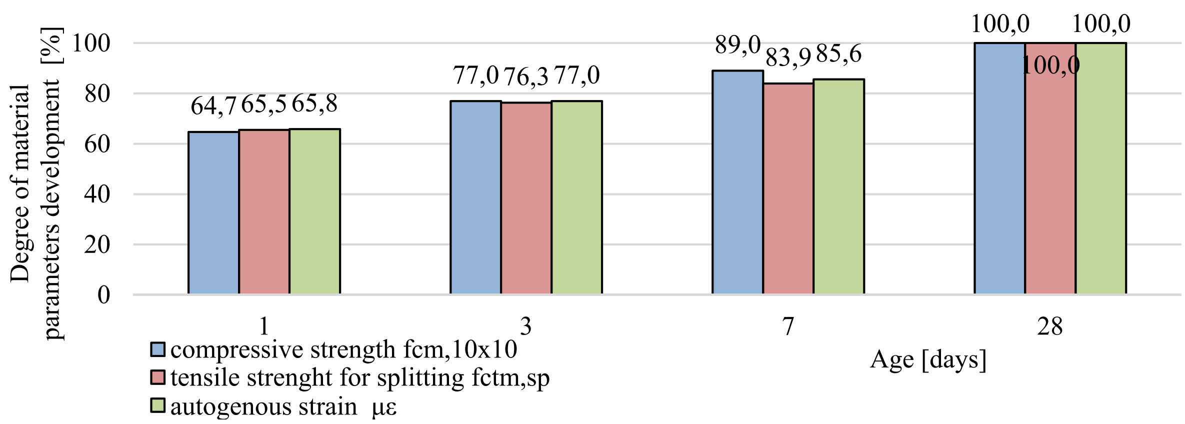

Figure 3. Increment of the shrinkage and compressive strength compared to the total value at 28 days for C-1 composite

Based on the analysis of presented results it can be said:

- The autogenous shrinkage of the C-1 composite constitutes to 65% of the value at 28 days with natural fine aggregate in the first 24 hours and it is concurring with the strength development.
- The development of mechanical properties is in line with the development of autogenous shrinkage also in the hardening phase of the C-1 composite.
- The occurrence of the autogenous shrinkage of the C-1 composite after approximately 12 hours from casting is caused by the water deficit during the setting of the cement.

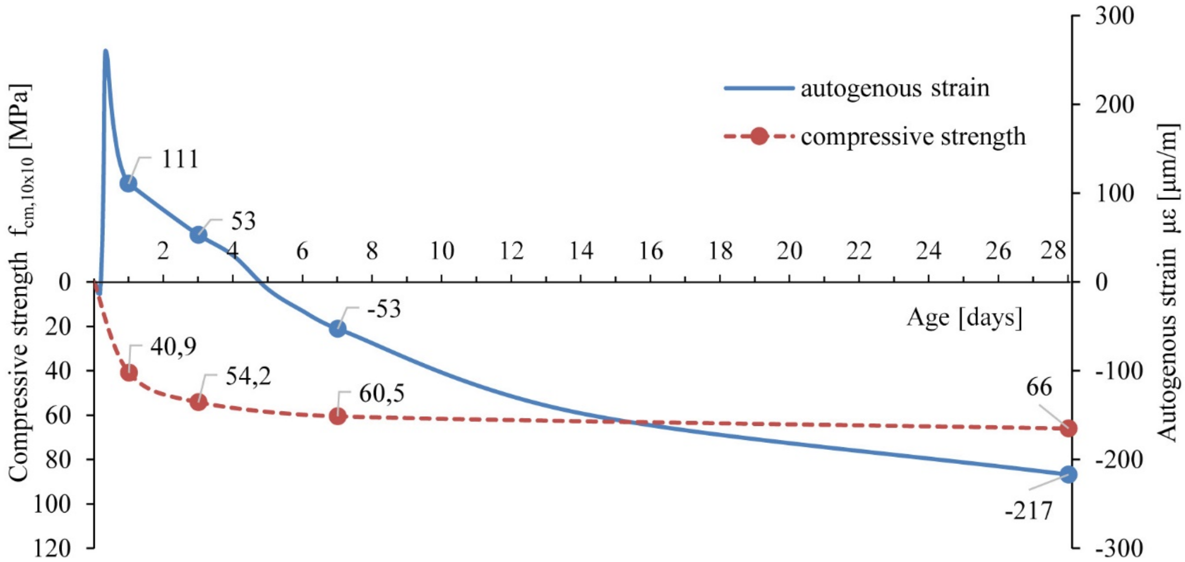

Figure 4. Development of compressive strength and autogenous shrinkage of C-2 composite

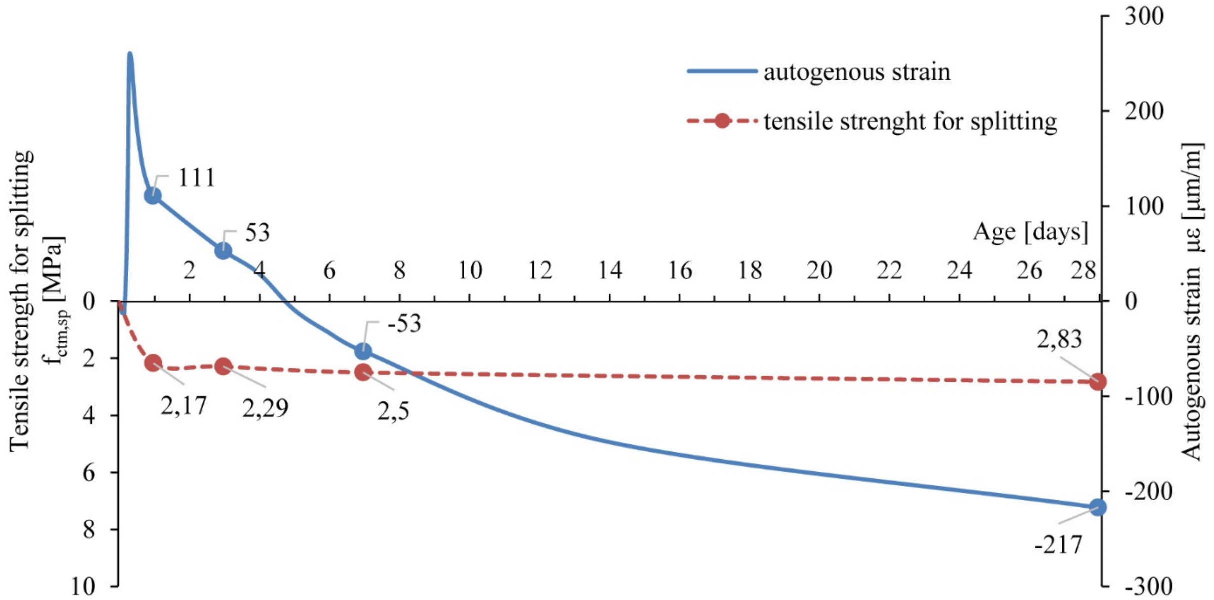

Figure 5. Development of tensile splitting strength and autogenous shrinkage of C-2 composite

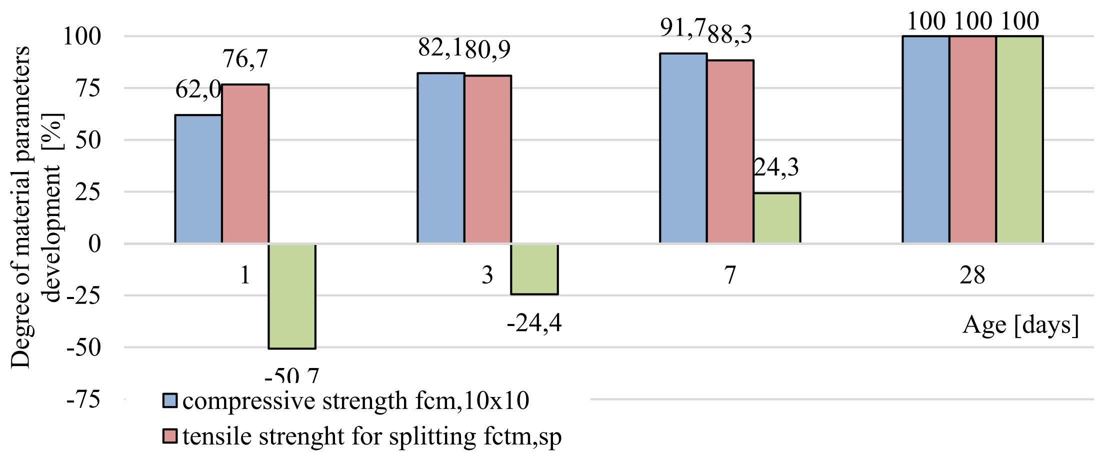

Figure 6. Increment of the shrinkage and compressive strength compared to the total value at 28 days for C-2 composite

Based on the obtained results following conclusions can be drawn:

- In the early stages of cement setting the C-2 composite exhibits autogenous swelling caused by the saturation of the binder matrix pores with water. After approximately 8 hours of curing occurs a rapid development of autogenous shrinkage caused by the decrease of relative humidity in cement matrix pores. This point determines the end of internal curing processes and start of water deficit period that lasts until the end of the tests.
- Continuous development of the autogenous shrinkage in the hardening phase of C-2 composite is correlated with the developed network of capillary pores created during the setting of cement.
- During the setting and hardening phases in the C-2 composite with lightweight fine aggregate, the development of autogenous deformation is not in line with the development of strength characteristics.

Figures 7 and 8 present the comparison of the autogenous shrinkage development with development of compressive strength and splitting tensile strength respectively for C-3 composite.

Figure 9 presents the degree of material parameter development for C-3 composite in a given day to the overall strength at 28 days.

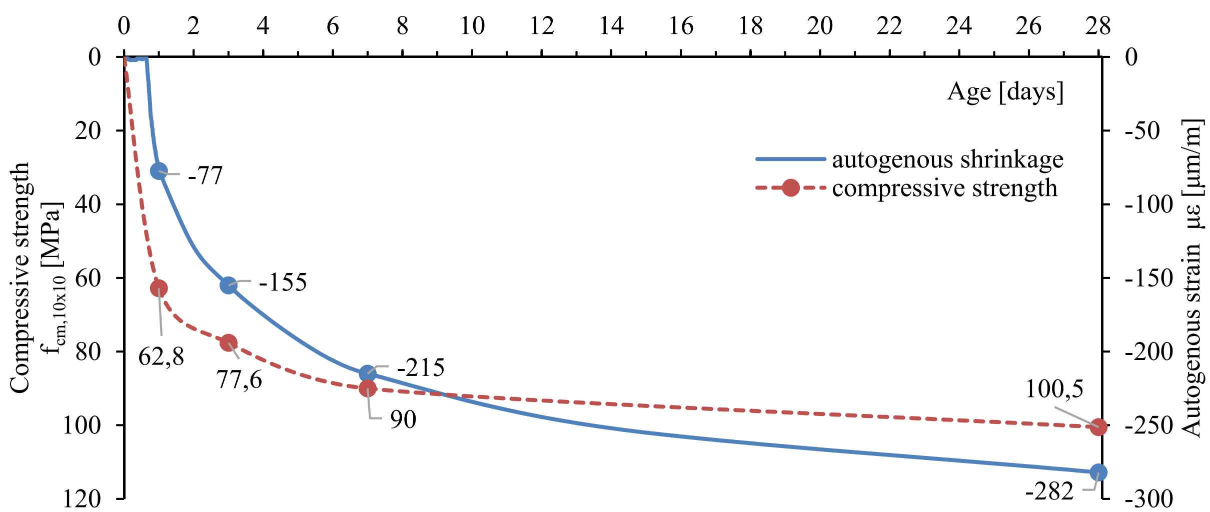

Figure 7. Development of compressive strength and autogenous shrinkage of C-3 composite

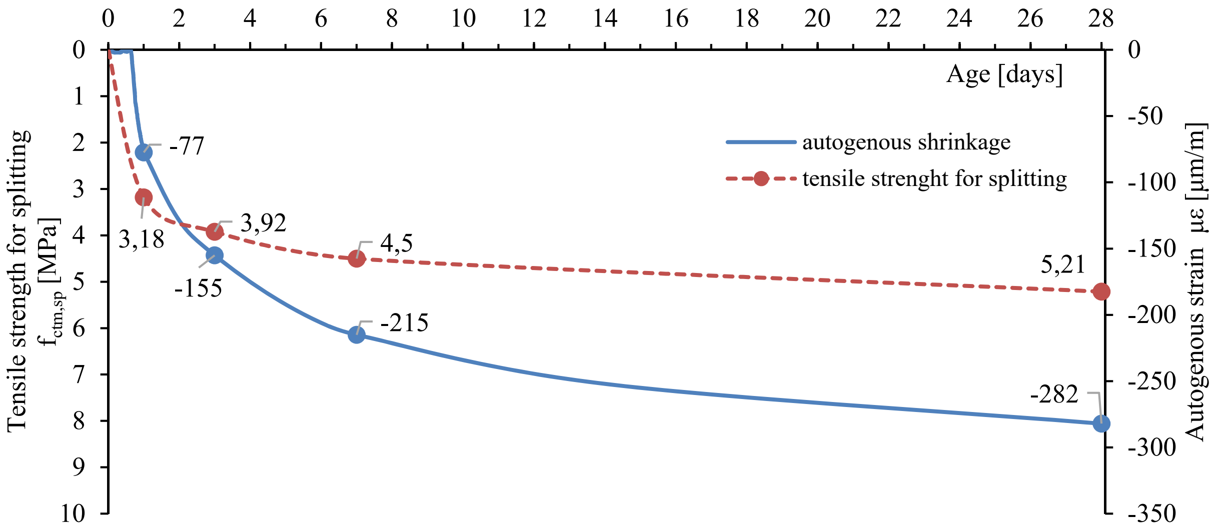

Figure 8. Development of tensile splitting strength and autogenous shrinkage of C-3 composite

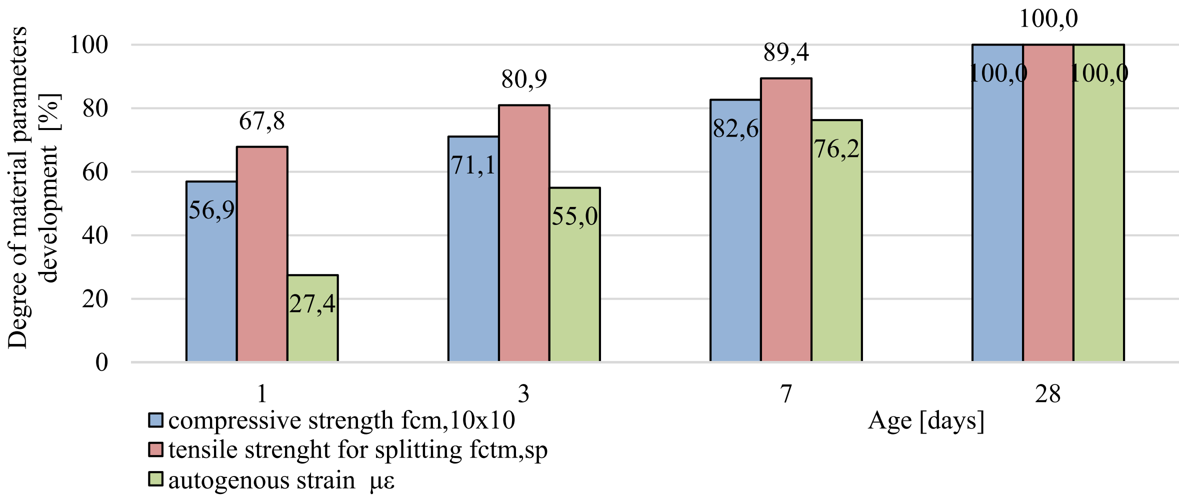

Figure 9. Increment of the shrinkage and compressive strength compared to the total value at 28 days for C-3 composite

The obtained results allowed to state as follows:

- The C-3 concrete exhibits the autogenous shrinkage already at the setting stage of cement which is caused by the water deficit.
- The value of the autogenous shrinkage C-3 after 24 h constitutes to 28% of the overall value at 28 days and is lower than the corresponding value of strength (approx. 55-70% of the value at 28 days).
- The degree of development of material parameters in the hardening phase (between 1 and 28 days) is lower than the development of the autogenous shrinkage.
- The rate of compressive strength development compared to splitting tensile strength is more concurring with the development of the autogenous shrinkage during the curing of C-3 concrete.

Figures 10 and 11 present the comparison of the autogenous shrinkage development with development of compressive strength and splitting tensile strength respectively for C-4 composite.

Figure 12 presents the degree of material parameter development for C-4 composite in a given day to the overall strength at 28 days.

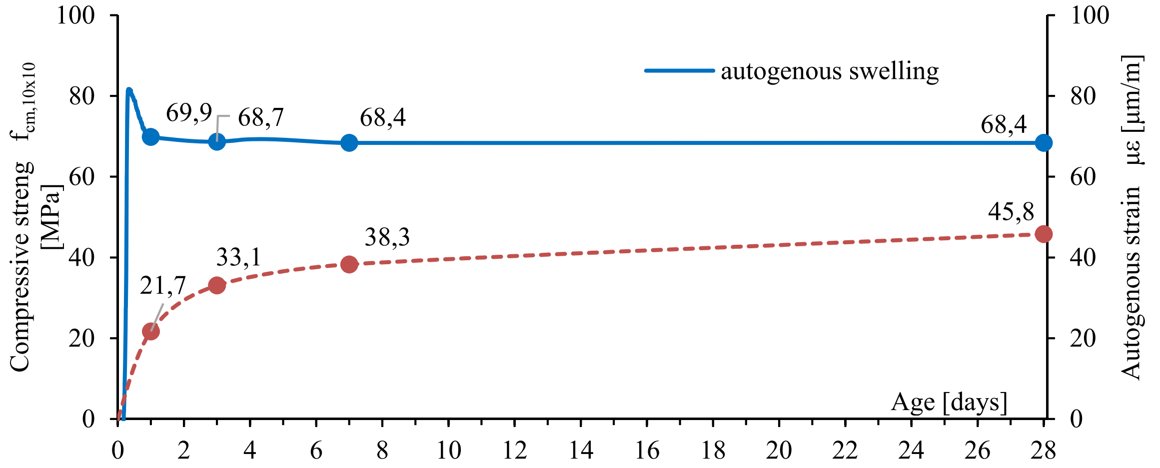

Figure 10. Development of compressive strength and autogenous shrinkage of C-4 composite

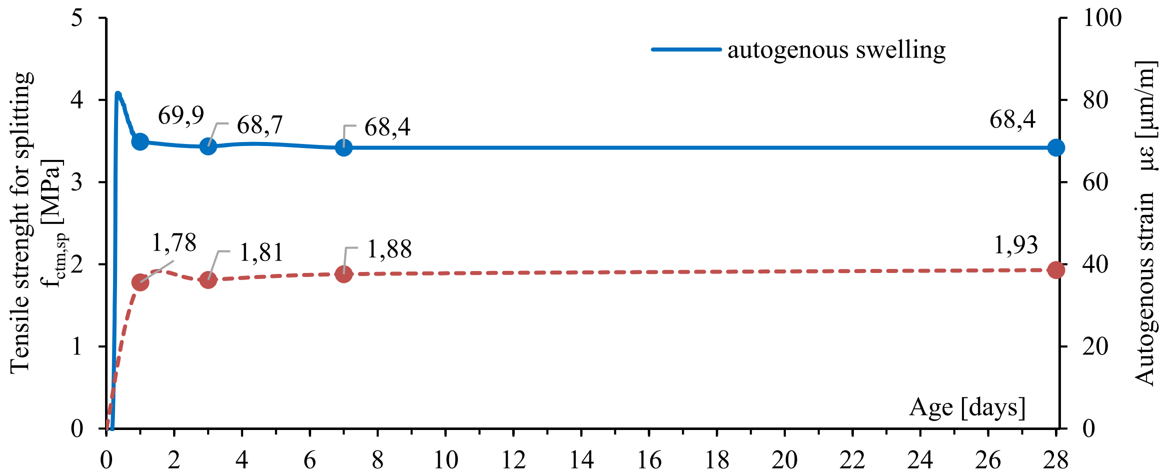

Figure 11. Development of tensile splitting strength and autogenous shrinkage of C-4 composite

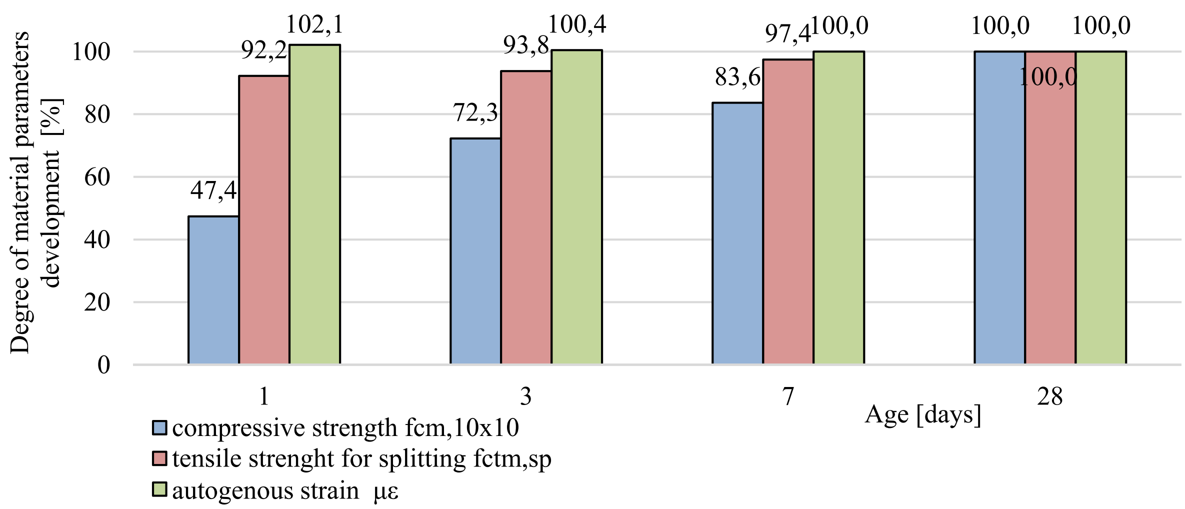

Figure 12. Increment of the shrinkage and compressive strength compared to the total value at 28 days for C-4 composite

Based on the obtained results it was noticed that:

- The C-4 concrete exhibits autogenous swelling during the setting of the cement, which is caused by the saturation of pores in binder matrix with water.
- The value of the autogenous swelling in C-4 composite in the first 24 hours equals the total value at 28 days. This means that the pores in the matrix were saturated with water during the entire testing period.
- The splitting tensile strength after a day equalled to 90% of the total strength at 28 days, while the concrete reached only 50% of its 28-day compressive strength.
- The development and rate of strength parameters gain during the setting and hardening of the concrete is not proportional to the development of the autogenous swelling exhibited by the C-4 concrete.

4. Conclusions

Performed comparison of the development of mechanical parameters and autogenous deformations in High-Performance Concrete with natural and lightweight aggregate allowed stating that:

- Replacing the natural aggregate with lightweight aggregate decreases the rate of strength increase and its overall value.
- The composites C-1 and C-3 with natural aggregate exhibited shrinkage from the very start of setting time.
- Use of presoaked lightweight aggregate (in composite C-2 and C-4) changes the autogenous deformation type from shrinkage to swelling.
- Presoaking the artificial coarse aggregate (concrete C-4) introduces full internal curing during the setting and hardening of concrete.
- Use only of fine lightweight aggregate (C-2 composite) does not provide sufficient internal curing.
- The composites C-1 and C-3 with natural aggregate exhibit similarities in the development of mechanical properties.
- Use of presoaked coarse artificial aggregate disallows the occurrence of similarities between development of autogenous deformation and development of strength properties.
- The calculation models of predicting the value of autogenous shrinkage based only on the strength properties of concrete cannot be used for composites with lightweight aggregate.

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