THE EFFECT OF NANO S_iO_2 ON THE STRENGTH OF UHPC

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Summary: *Research on the application of nano materials in cement composites in the world began in the early 21st century. When preparing UHPC, nano SiO2 was used. The aim of the research is to determine the influence of nano-silica, as partial substitution for cement on the mechanical properties of UHPC. The results of the comparative testing of concrete in fresh and hardned state are presented without any substitution of up to 2% of cement with nano SiO2. In order to determine the effect of the nano-silica on the increase in compressive strength and flexural strength, the specimens which were curing in water were tested at the age of 2, 7 and 28 days.*

Keywords: *nanosilica, UHPC, compressive strength, flexural strength*

1. INTRODUCTION

Nanotechnology has been introduced to cement and concrete research because it is able to produce stronger and more durable concrete [1,2]. Jo et al. [3] found that by adding 6% nanoSiO_2 the compressive strength of concrete improves by 152% and 142% at 7 and 28 days, respectively; Li [4] reported that 5% nanoSiO_2 improves compressive strength by 17.5% at 28 days. They believe that this is due to the densification of the paste, transforming of Portlandite into C–S–H gel by means of a pozzolanic reaction and the modification of the internal structure of C–S–H gel, all of which contribute to the cement paste being more stable and more strongly bonded [5].
Recently, nanotechnology is being used or considered for use in many applications and it has also received a lot of attention in building materials, with potential advantages and drawbacks being underlined [6,7]. In this field, a new pozzolanic material, "nanosilica" (NS), produced synthetically in the form of slurry of ultra-fine particles of amorphous silica, was introduced into the market.
With regard to the effect of nanosilica on the rheological behaviourof cementitious mixes, rheometric studies on cement mortars containing superplasticizer [8] or not

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containing superplasticizer [9] show that the addition of nanosilica greatly increases the water demand of cementitious mixes, as compared to the control ones. The only hypothesis is that the presence of nanosilica decreases the amount of lubricating water available within the interparticle voids, as a consequence of a denser solid particle packing produced by silica nanoparticles [9].

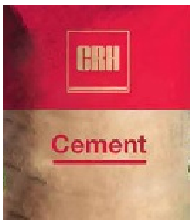
2. EXPERIMENTAL WORK

The aim of the research is to determine the effect of nano silica on the properties of UHPC. The component materials used were tested for chemical and physical-mechanical properties. The fresh UHPC properties in terms of workability were tested. The mechanical properties of hardened UHPC concrete are shown in terms of compressive strength and flexural strength. Samples were cured in ambient conditions in water until the moment of testing for 2, 7 and 28 days.
It is very important to know the properties of the component materials when designing UHPC mixtures.
Considering the characteristics of UHPC concrete as well as its properties in the hardened state, the basic conditions for designing the composition of concrete mixture of very high strengths have been adopted:

- keep the water binding ratio under the limit value of 0.25,
- apply very high cement content> 800 kg/m^3,
- the value of the air content must be reduced to the lowest possible value,
- maximum grain size of the aggregate in the range of 0.5-1mm,
- use appropriate mineral additives,
- the application of silica fume and nanosilica,
- mandatory application of superplasticizer with high water reduction – HWR,

The component materials used in this study are as follows:

- Cement CEM I 52.5 R, CRH – Popovac,
- Silica fume, Sika–Switzerland,
- Nano silica, Evonik – Germany,
- Quartz aggregate 0-0.5 mm – Kaolin, Valjevo,
- Quartz powder$d_{50\%} = 45\mu m$, Srbokvarc – Rgotica,
- Steel fibers (length / diameter =9/0.20mm), Spajić – Negotin,
- Superplasticizer "Sika Viscocrete 20HE" – Sika, Switzerland.

a)


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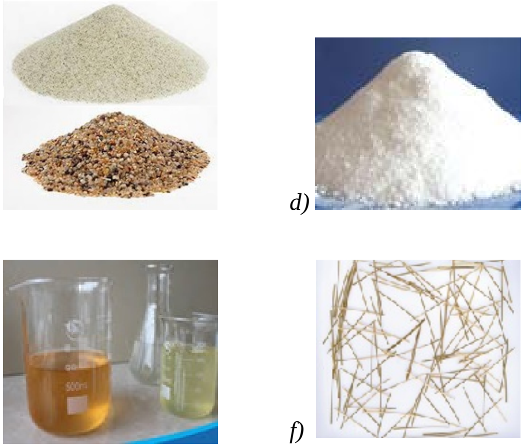

c) *d)* *e)* *f)*

Figure 1. UHPC material used: a) cement, b) silica fume, c)quartz powder and sand, d)nano silicium, e) superplasticizer, f) steel fibers

Cement without additives, CEM I, class 52.5 R, is obtained by grinding process of high quality portland-cement clinker with the addition of an optimal amount of plaster, and the producer CRH – Popovac was used. The chemical, physical and mechanical properties of the cement are shown in Table 1.

Table 1. Properties of cement CEM I 52.5R

Chemical, %		Physical		Mechanical	
SiO_2	18.89	Specific gravity, kg/m^3	3150	Compressive strength, N/mm^2	
Al_2O_3	5.60				
Fe_2O_3	2.61	Specific surface, cm^2/g	4220	2 days	37.2
CaO	63.69			7 days	-
MgO	2.03	Standard consistency, %	29.4	28 days	65.9
Na_2O	0.30				
K_2O	0.73			Flexural strength, N/mm^2	
SO_3	2.70	Initial setting time, min	190		
Cl^-	0.005			2 days	7.1
		Final setting time, min	250	7 days	-
				28 days	10.0

Specific density values were 2200 kg/m^3 for silica fume, and 2695 kg/m^3 for quartz sand. Specific surface area for cement is 3500 m^2/g (Blaine method) and for nano-silica it is 269.31 m^2/g (BET method).

Three types of concrete were made with varying percent of nS. Mixtures with 270 kg/m3 of silica fume, 1% of steel fibers and cement suspension of 0, 1 and 2% by nano silica are designed. Mix proportions for all kind of concrete are shown in Table 2.

Table 2. Concrete mixtures

Material	UnS0f1	UnS1f1	UnS2f1
Cement (kg/m^3)	950	940,5	931
Silica fume (kg/m^3)	270	270	270
Nano silica (kg/m^3)	**0**	**9,5**	**19**
Quartz powder (kg/m^3)	350	350	350
0-0.5mm Quartz sand (kg/m^3)	530	503	495
Water (kg/m^3)	235	235	235
HWR20HE (kg/m^3)	57	57	57
Steel fiber (kg/m^3)	78,5	78,5	78,5
HWR (kg/m^3)	31.9	31.9	31.9
w/b	0.192	0,192	0,192

Nano-silica was first mixed with water to which superplasticizer was previously added, and then added to the dry mixture ofaggregate, cement and silica fume as shown in Figure 3.

Figure 3. Nano-silica with water and superplasticizer added in the dry mixture

Finally, after 5 min when the mixture became fluid, brass coated steel fibers were added and mixing was continued for another 5 min.

To make concrete mixtures, commercial materials available in the domestic market were used. Concrete consistency was tested on all concrete mixes using the method of slump-flow by using a small cone. Test results for slump flow of UHPC are given in Figure 4.

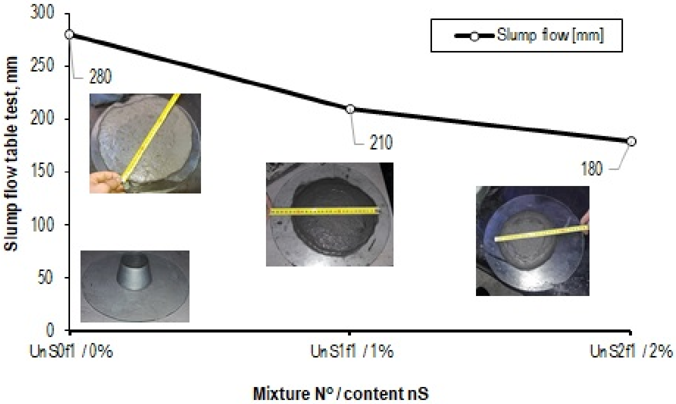

Figure 4. Consistency by slump flow test

UHPC is put into metallic prism shaped molds 40x40x160 mm. The samples were air cured for the first 24h, and then water cured under ambient conditions until the moment of testing. The mechanical properties of UHPC, compressive strength and flextural strength were examined on a prism after curing at the age of 2, 7 and 28 days. First, a flexural strength test was performed and subsequently compressive strength test on parts of the prism by a modified method. Flexural strength testing was performed according to SRPS EN 196-1. The test was carried out on a digital hydraulic press of 300 kN. During the test, a load speed rate of 0.06 MPa s was used. The beam after testing as well as the cross-section is shown in Figure 5.

Figure 5. Testing tensile strength beams and its cross-section

Testing of the compressive strength was carried out on the parts of the prisms using a modified method. Load speed rate is 0.6 MPa/s. The testing is shown in Figure 6.

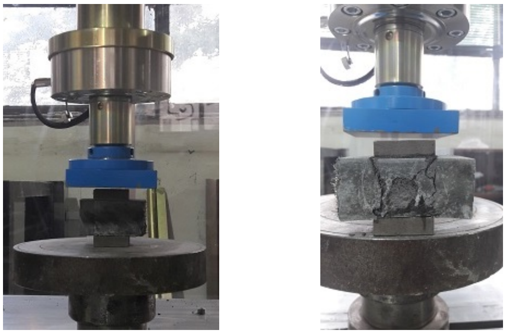

Figure 6. Testing compressive strength UHPC

3. RESULTS AND DISCUSSION

The results of the compressive strength and flexural strengths under 3 point flexure and uniaxial compression, in accordance with the EN196-1 standard are presented in Figure 7 and Figure 8, respectively. The obtained values of compressive strength tests range from 115 to 132 N/mm^2.

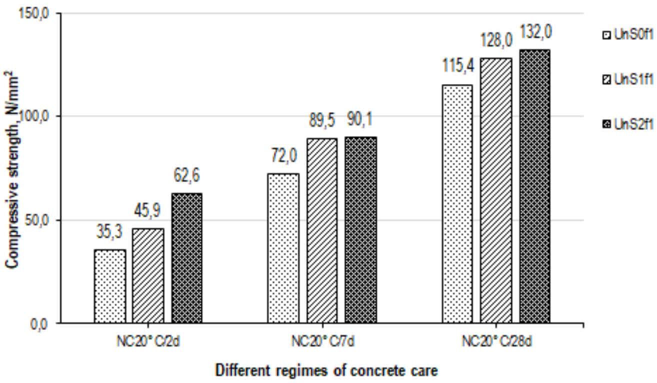

Figure 6. Results of testing compressive strength ofUHPC

The values obtained by testing compressive strength without nano silica and with a cement replacement of 2% nano-silica at the age of concrete of: 2 days range from 35.3 to 62.6 N/mm^2; 7 days range from 72.0 to 90.1 N/mm^2; 28 days range from 115.4 to 132.0 N/mm^2.
Flexural strength testing results without nano silica and with a cement replacement of 2% nano silica at the age of: 2 days range from 12.5 to 15.1 N/mm^2; 7 days range from 14.7 to 16.4 N/mm^2; 28 days range from 17.9 to 18.5 N/mm^2.

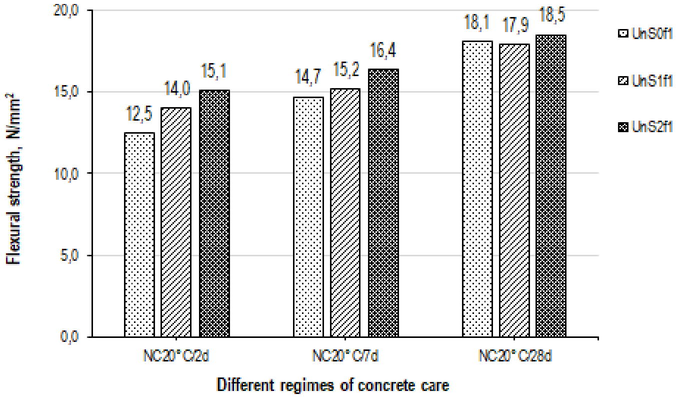

Figure 7. Results of testing flexural strength of UHPC

4. CONCLUSION

The obtained results indicate that the addition of nano silica has an impact on the properties of fresh and hardened UHPC. The consistency of fresh concrete decreases with the increase in the percent of added nano silica. Compared to concrete without nano-silica, considering the consistency of fresh concrete determined by the method of slump-flow, the concrete with 1% of nano silica had a decrease in consistency by 25%, while with 2% nano-silica the decrease in consistency was 35.7%. The mechanical properties of hardened concrete grow with the addition of nano silica. The obtained values of compressive strength tests at the age of 2 days have shown that the concrete with 1% nano silica has 30.0% higher values compared to the concrete without nano silica, while with the content of 2% this value is higher by 77.4%. The obtained compressive strength values at the age of 7 days increase with the increase in the proportion of nano silica. Concrete with 1% nano silica has a 24.3% higher strength value, and with 2% nano silica it is 25.2% higher compared to concrete without nano silica. The final values of compressive strengths at 28 days show that with the addition of 1% nano silica10.9% higher strengths are obtained,while with 2% nano silica these values are 14.4% higher compared to concrete without nano silica. Flexural strength follows the trend of increasing the value of strength by increasing the proportion of nano silica in the concrete mixture. The flexural tensile strength relation at the age of 2, 7 and 28 days for concrete with 1% substitution by nano silica is 12.0, 3.0 and 0.1% compared to concrete without nano-silica. That relation with 2% nano-silica was: 20.8, 11.6 and 0.2%.

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УТИЦАЈ НАНО SiO_2 НА ЧВРСТОЋУ UHPC

Резиме: *Истраживања примене нано - материјала у цементним композитима у светусу почела још почетком 21 века. При справљању UHPC коришћен је нано SiO_2. Циљ истраживања је одређивање утицаја наносилике, као делимичне замене за цемент на механичка својства UHPC . Приказани су резултати упоредних испитивања бетона у свежем и очврслом стању без и са зупституцијом до 2% цемента са нано SiO_2. Да би се утврдио утицај наносилике на прираст чврстоћа при притиску и чврстоћа при затезању савијањем, извршено је испитивање узорака старости од 2, 7 и 28 дана који су неговани у води.*

Кључне речи: *наносилика, UHPC, чврстоћа при притиску, чврстоћа на затезање при савијању*