NEKA SVOJSTVA BETONA ULTRA VISOKIH ČVRSTOĆA

SOME PROPERTIES OF ULTRA-HIGH STRENGTH CONCRETE

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1 UVOD

Razvoj novih građevinskih materijala, a posebno kompozitnih materijala sa cementnom matricom omogućava projektovanje i izvođenje sve složenijih i zahtevnijih konstrukcija. Upotreba ovakvih materijala sa znatno poboljšanim fizičko-mehaničkim svojstvima ostavlja projektantima širi spektar mogućih rešenja, a konstrukciju čini racionalnijom, trajnijom i estetski prihvatljivijom. Mogućnosti primene raznih vrsta vlakana (polipropilenska, čelična, staklena,...) u kompozitnim materijalima privukla je pažnju velikog broja istraživača širom sveta [1,2].

Krajem osamdesetih godina prošlog veka betoni visokih svojstava (HPC) su se pojavili kao novi materijali u gradnji industrijskih hala i marketa, a u odnosu na klasični beton sadržali su silikatnu prašinu. Primena superplastifikatora novih generacija je omogućila manju količinu potrebne vode u svežoj mešavini. Sa znatno smanjenim vodovezivnim faktorom ovaj beton je bio obradljiv, a čvrstoća pri pritisku u starosti od 28 dana iznosila je preko 70 MPa. Trajnost je takođe bila poboljšana u odnosu na klasične betone [2].

Krajem prošlog veka razvijena je nova vrsta betona, čiji je vodovezivni faktor bio ispod 0.2, sa čvrstoćama pri pritisku većim od 150 MPa, sa većim sadržajem cementa sa povećanom finoćom mliva kao vezivnog materijala i dodatnim sadržajem silikatne prašine nazvana betoni ultra visokih svojstava (UHPC), odnosno betoni

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1 INTRODUCTION

The latest technical innovations in building materials, especially cement based composites; satisfy increasingly sophisticated requirements in design and construction. The use of these products with significantly improved physical-mechanical properties provides design engineers wider spectrum of offered solutions; while construction itself becomes the construction with better cost control, durability and better esthetic properties. An opportunity to use different types of fibers (polypropylene, steel, glass) at composites production gained interest at large number of scientists worldwide [1, 2].

In 1980s High Performance Concrete (HPC) was launched as new material applied in production plants and trade centers construction, with silica fume content, as main characteristic compared to ordinary concrete. Application of superplasticizers that belong to the group of new superplasticizers generation, enabled lower water content that is needed for fresh mixture. With significantly decreased water/binder ratio this concrete was workable, and compressive strength, at 28 days age, was over 70 MPa. Durability was improved compared to the ordinary concrete, as well [2].

Twenty years later, the new kind of concrete was generated, with water/binder ratio that was lower than 0.2, with compressive strength that was higher than 150 MPa, with higher content of cement with increased fineness of grinding, and silica fume that was added; it

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ultra visokih čvrstoća (UHSC). Razvoj hemijskih dodataka u betonu je omogućio tako značajnu redukciju vode. Mnogi autori u svetu od tada intenzivno proučavaju njihova svojstva, strukturu i tehnologiju izrade. Od običnih betona se razlikuje prema sastavu, strukturi, načinu izrade i nege, a karakteriše ih relativno visoka cena po 1m^3 mešavine [3].

Upotrebom UHSC povećava se stepen iskorišćenosti prirodnih materijala [4], jer se dobija materijal sa visokim mehaničkim karakteristikama koji je ujedno i otporan na hemijsku koroziju. Primena ovog materijala može biti opravdana i sa ekonomskog aspekta pošto su dimenzije elemenata znatno manje, a elementi trajniji i otporniji na agresivne uticaje sredine.

2 PRAVILA ZA PROJEKTOVANJE I ODABIR KOMPONENTNIH MATERIJALA

Za postizanje većih vrednosti čvrstoća pri pritisku potrebna je posebna pažnja pri izboru i kompatibilnosti komponentnih materijala (cement, agregat, mineralni i hemijski dodaci, vlakna) i tehnologije betona (proizvodnja, ugradnja, nega, transport, kontrola kvaliteta). Iz tih razloga je projektovanje sastava i proizvodnja betona ultra visokih čvrstoća složeniji posao od istog postupka kod klasičnog betona.

Mehanička svojstva ovog betona se povećavaju upotrebom kvalitetnih komponentnih materijala, povećanjem broja kontakata između čestica, homogenizacijom mešavine, a samim tim i redukovanjem poroznosti i defekata unutar strukture. Povećanje broja kontakata između čestica i homogenizacijom betona moguće je ostvariti upotrebom velike količine veziva, redukovanjem vodovezivnog faktora, smanjivanjem ukupne količine agregata i veličine najvećeg zrna agregata [9]. Smanjenje poroznosti postiže se upotrebom niskoga vodovezivnog faktora i upotrebom superplastifikatora, ali uz uslov da se osigura potrebna obradljivost u svežem stanju, te zamenom dela cementa pucolanskim dodacima.

Dodatkom znatno manje količine vode u sadržaj mešavine nego kod klasičnog betona smanjuje se razmak između čestica cementa i mineralnih dodataka u svežem stanju. Na taj se način smanjuje se i kapilarna poroznost, a mnogo je manji i prostor koji moraju popuniti produkti hidratacije.

Smanjenje vodovezivnog faktora i upotreba mineralnih dodataka pozitivno utiču i na poboljšanje mehaničke veze cementnog kamena i agregata, kao najslabije karike u strukturi ovog betona. Najbolji mineralni dodatak je silikatna prašina koja sa vrlo malim česticama (10-ak puta manjim od zrna cementa) i velikom specifičnom površinom utiče na povećanje sadržaja u mešavini koji okružuje cementne čestice i povećanjem reaktivnosti na ubrzanu hidratizaciju. Osim toga silikatna prašina reaguje sa slobodnim CaO, najlošijim sastojkom cementa, stvarajući pritom CSH gel.

Hidrotermalna obrada uzoraka može negativno uticati na trajnost ovog materijala, a uzrok tome može

was new product category, named Ultra High Performance Concrete (UHPC), or Ultra High Strength Concrete (UHSC). Innovations in chemical admixtures for concrete and mortar enabled crucial decrease in water content. Since that time, many scientists and investigators worldwide have investigated the properties, structure and manufacturing technology. Compared to the ordinary concrete there is difference in constituent components, structure, manufacturing technology and curing regime, there is relatively high cost per 1m^3 of concrete [3].

Application of UHSC increases the amount of natural component materials that are used [4], as in this way material with high mechanical properties, with high level of corrosion resistance is obtained. Financially, this type of material can provide cost control, as its dimensions are significantly lower, produced elements have increased durability as well as aggressive environment influence resistance.

2 RECOMMENDATION FOR DESIGN AND CHOICE OF COMPOSITE MATERIALS

In order to obtain higher compressive strength, while choosing mixture components, compatibility and other factors must be considered regarding component materials (cement, aggregate, mineral and chemical admixtures, fibers) and concrete technologies (production, workability, curing, transportation, quality control). Thus, Ultra High Performance Concrete design, and concrete production are more complex technological requirements, than in the case of ordinary concrete.

These concrete's mechanical properties are increased if the high quality component materials are used, if the number of particle interactions is increased, by mixture homogenization, at the same time by decreasing of structural failures and by porosity decrease. Increase of particle number interactions and better concrete homogenization can be provided by high content of binder, by decrease of water/binder ratio, by decrease of total aggregate amount and by maximum aggregate size decrease [9]. Porosity decrease is obtained if low water/binder ratio is used, if superplasticizers are applied, in the case that the request considering the certain level of workability in fresh concrete is fulfilled; and if partial cement content replacement by puzzolane additives was made.

Significantly lower amount of water added to the mixture than in the case of ordinary concrete, decreases the distance between cement particles and mineral additives in the state of fresh concrete. In this way capillary porosity decreases, and space that should be filled by hydration products decreases significantly, as well.

Water/binder ratio decrease and mineral additives applications improve the mortar and aggregate mechanical binding, which is the critical point in this concrete's structure. Silica fume is the best mineral additive because of its extremely small particle size (approximately 10 times smaller than cement particles) and its large specific surface. Thus silica fume influences surrounding of cement particles and increases hydration due to increased reactivity. Additionally silica fume gets in chemical reaction with free CaO Molecules, which are the cement's ingredients with low properties. As a result biti smanjena vlažnost u uzorku tokom zaparivanja, odnosno visok sadržaj silikatne prašine u mešavini [4].

Povećanjem vrednosti čvrstoće pri pritisku betona raste i njegova krtost. Ova pojava se može rešiti dodatkom vlakana u sastav betona. Glavni razlog upotrebe vlakana u slaboj, krtoj matrici je poboljšanje duktilnosti cementne matrice. Intenzitet poboljšanja svojstava zbog mikroarmiranja vlaknima varira zavisno od količine i vrste dodanih vlakana, prionljivosti vlakana i cementne matrice i kvaliteta same cementne matrice.

Da bi se dobili betoni ultra visokih čvrstoća, čije su čvrstoće pri pritisku veće od 150 MPa , potrebno je, osim prethodno nabrojenog, držati se i sledećih osnovnih načela [1,3]:

– povećanje homogenosti eliminisanjem krupnog agregata

– povećanje zapreminske mase ugrađenog betona optimizacijom granulometrijskog sastava tako da se postigne najveća kompaktnost

– poboljšanje mikrostrukture hidrotermalnom obradom ugrađenog betona

– količina vode u betonu maksimalno se smanjuje pa tako ta količina nije dovoljna za hidrataciju cementa; ovo načelo dovodi do toga da se smanjuje količina slobodne vode koja isušivanjem može dovesti do stvaranja mikroprslina, a nehidratizovani cement se ponaša kao reaktivni mikroagregat visokog modula elastičnosti koji može naknadno hidratizovati

– poboljšanje duktilnosti dodavanjem veće količine vlakana.

of this chemical process C-S-H gel is obtained .

Steam-curing regime applied on these samples can affect negatively the material's durability; and the main cause for this process might be decreased humidity, actually high silica fume content in the mixture [4].

By increased compressive strength, its brittleness increases as well. This problem can be solved by adding fibers to the concrete composition. Main cause for fiber applications at low quality, brittle matrix is improvement of ductile characteristics of concrete matrix. Improvement due to fiber reinforcing varies depending on amount and type of fibers added, fiber's adhesive characteristics, matrix adhesive characteristics and the quality of cement matrix itself.

In order to get Ultra High Strength Concrete, with compressive strength higher than 150 MPa [6], the previously mentioned recommendations, as well as the principles that are listed below should be considered [1.3]:

– homogeneousness increase is provided by coarse aggregate elimination

– concrete bulk density increase is obtained by grain size distribution optimization, in order to provide the highest level of compaction

– micro-structure improvement is obtained by steam curing regime

– There is max decrease in concrete water content, and this amount is not sufficient for cement hydration; this is the cause for free water content decrease, thus by its evaporation micro cracks might occur. The non hydrated cement acts as a reactive micro aggregate, with high modulus of elasticity, which can be hydrated additionally.

– ductile properties are improved when higher amount of fibers is added.

3 EKSPERIMENTALNI RAD

3.1 Komponentni materijali i njihova svojstva

U eksperimentalnom radu su korišćeni isključivo komponentni materijali dostupni u Srbiji. Prethodnim ispitivanjima je potvrđena njihova kompatibilnost. Za spravljanje mešavina upotrebljena je voda iz gradskog vodovoda.

3.1.1 Cement

U eksperimentalnom radu korišćene su tri vrste cemenata:

– Cement 1: CEM I 42.5R Lafarge BFC Beočin Srbija

– Cement 2: CEM I 52.5R Lafarge Lukavac Bosna i Hercegovina

– Cement 3: CEM I 52.5R Nexe Grupa Našice Cement Hrvatska

U Tabeli 1 data su hemijska, fizička i mehanička svojstva upotrebljenih cemenata.

3 EXPERIMENTAL WORK

3.1 Component Materials and Their Properties

Component materials that are available in Serbian market are used for this part of work. Previous trials confirmed their compatibility. Water that is used for mixture production is potable water.

3.1.1 Cement

Three kinds of cement were used in this part of work:

– Cement 1: CEM I 42.5R Laffarge BFC, Beočin, Serbia

– Cement 2: CEM I 52.5R Laffarge, Lukavac, Bosnia and Herzegovina

– Cement 3: CEM I 52.5R Nexe Grupa, Našice Cement, Croatia

Table 1. gives chemical, physical and mechanical properties of the cements that are used.

Tabela 1. Hemijska, fizička i mehanička svojstva upotrebljenih cemenata
Table 1. Chemical, physical and mechanical properties of the cements

		Cement		
		Cement 1	**Cement 2**	**Cement 3**
Hemijski sastav % Chemical composition %	SiO_2	20.59	18.62	-
	Al_2O_3	6.10	6.89	-
	Fe_2O_3	2.81	3.91	-
	CaO	63.44	56.37	-
	MgO	1.89	1.98	-
	Na_2O	0.29	-	-
	SO_3	2.69	2.33	2.85
	Cl^-	0.003	-	0.006
Fizička svojstva Physical properties	Zap. masa [kg/m^3] (bulk density)	1470	-	-
	Spec.površ. [cm^2/g] (Spec.surface)	4120	3351	4510
Čvrstoća pri pritisku [N/mm^2] Compressive strength [MPa]	2 dana (days)	29.9	-	28.5
	7 dana (days)	47.2	-	-
	28 dana (days)	61.6	56.24	55.1
Čvrstoća na zatezanje savijanjem [N/mm^2] Flexural strength [MPa]	2 dana (days)	7.0	-	-
	7 dana (days)	7.8	-	-
	28 dana (days)	9.8	9.54	-

3.1.2 Agregat

Za spravljanje mešavina korišćen je kvarcni pesak kao komercijalni proizvod firme Kaolin Valjevo, granulacije od 0-0.5mm. Ispitivanjem granulometrijskog sastava oko 70% zrna agregata se nalazi između 0.2 i 0.4mm. Fizičko-hemijska svojstva kvarcnog peska data su u Tabeli 2.

3.1.3 Silikatna prašina

Kao sekundarno vezivo korišćena je silikatna prašina SikaFume HR, švajcarskog proizvođača Sika. Prema tehničkom listu proizvođača zapreminska masa iznosi 700 kg/m^3, a preko 95% čestica je veličine ispod 0.1μm.

3.1.4 Hemijski dodaci

Upotrebljena su četiri superplastifikatora:

- Superplastifikator 1: Mapei Dynamon SX
- Superplastifikator 2: Mapei Dynamon NRG 100
- Superplastifikator 3: Sika Viscocrete 20HE
- Superplastifikator 4: Sika Viscocrete 5800

Hemijski dodaci su pomešani sa vodom dodavani u betonsku mešavinu.

3.1.2 Aggregates

Quartz sand, grained (0-0.5mm), that is commercial product, marketed by Kaolin Valjevo, was used for mixture preparation. Particle distribution testing showed that size of approximately 70% aggregate particles was between 0.2 and 0.4mm. Quartz sand physical-chemical properties are listed in Table 2.

3.1.3 Silica Fume

As secondary binder, silica fume SikaFume HR, Sika, Switzerland, was used. According to manufacturer's technical specification bulk density is 700 kg/m^3, and size of more than 95% particles is smaller than 0.1μm.

3.1.4 Chemical Admixtures

Four superplasticizers were used:

- Superplasticizer 1: Mapei Dynamon SX
- Superplasticizer 2: Mapei Dynamon NRG 100
- Superplasticizer 3: Sika Viscocrete 20HE
- Superplasticizer 4: Sika Viscocrete 5800

Chemical admixtures were mixed with water and added to the concrete mixture.

Tabela 2. Fizičko-hemijski sastav kvarcnog peska
Table 2. Quartz sand physical-chemical properties

Komponenta (Component)	**Kvarcni pesak (Quartz sand)**
SiO_2%	97.54
Al_2O_3%	0.52
K_2O%	0.24
Fe_2O_3%	0.57
Specifična masa [kg/m^3] (Bulk specific gravity)	2695
Zapreminska masa [kg/m^3] (Bulk density)	1330

3.1.5 Čelična vlakna

Korišćena su ravna čelična vlakna (dužina/prečnik = 8/0.175 mm) čija je otpornost pri vučenju ≈ 3000 N/mm^2. Čelična vlakna su obložena mesingom da bi se povećala trajnost i otpornost na koroziju u betonu. Čelična vlakna su komercijalni proizvod srpske firme „Spaić“.

3.2 Sastav betona ultra visokih čvrstoća

Istraživanje je sprovedeno na 16 različitih betonskih mešavina. Sastavi mešavina prikazani su u Tabeli 3. Svaka se pojedinačna mešavina spravljala po tri puta, da bi se pokazala ponovljivost rezultata ispitivanja pojedinih svojstava.

Sastav mešavina odabran je na temelju prethodnih istraživanja da bi se postigle čvrstoće pri pritisku betone ultravisokih čvrstoća. Korišćene su tri vrste cemenata i četiri superplastifikatora. Jedna serija uzoraka je izlagana hidrotermalnoj obradi da bi se uporedila svojstva sa uzorcima koji su nakon prvog dana odležavali u vodi na temperaturi od 20°C. Sve su se mešavine pripremale u standardnoj mešalici za cement i malter zapremine 5l. Sveža mešavina je ugrađivana u metalne kalupe za dobijanje uzoraka 4x4x16cm. Uzorci su zbijani na vibrostolu frekvencije 150 Hz.

3.1.5 Steel Fibers

Steel fibers were used (length/diameter =8/0.175 mm); tensile strength ≈ 3000 MPa. Steel fibers are covered with brass in order to increase durability and resistance to concrete corrosion process. Steel fibers are manufactured and marketed by „Spaic“ company, Serbia.

3.2 Ultra High Strength Concrete Composition

Trial was performed in 16 different concrete mixtures. Mixture composition is shown in Table 3. Each of mixtures was produced three times, in order to follow the certain results tendency in uniformity and reproducibility.

Mixture composition was chosen according to the previous trials in order to provide compressive strength of Ultra High Strength Concrete. Three kinds of cements and four superplasticizers were used. One group of samples was exposed to steam curing regime in order to compare their properties with the properties of the samples that were kept in water, at 20°C, after day 1. All mixtures were made in standard cement and mortar mixer, volume 5l. Fresh mixture was molded, sample dimensions 4x4x16cm. Samples were placed by using vibration table, frequency 150 Hz.

Tabela 3. Sastav betonskih mešavina
Table 3. Concrete mixture composition

No.	Cement	Kol. (Amount) [kg]	Agregat (Aggregate) [kg]	Silikatna prašina (Silica fume) [kg]	Tip aditiva (Admixture)	Kol. (Amount) [kg]	Čelična vlakna (Steel fiber) [kg]	Voda (Water) [kg]	w/c	w/b
NUH4	cement 1	850	1180	100	Adm. 1	20.0	195	207.0	0.24	0.20
NUH5	cement 2	850	1160	100	Adm. 1	23.0	195	212.0	0.25	0.20
NUH7	cement 2	950	1045	110	Adm. 2	35.4	195	226.6	0.24	0.20
NUH8	cement 1	850	1095	170	Adm. 2	35.4	195	204.6	0.24	0.20
NUH9	cement 1	900	950	200	Adm. 2	34.6	330	198.4	0.22	0.18
NUH10	cement 2	900	950	200	Adm. 2	36.4	330	179.6	0.20	0.16
NUH11	cement 1	850	1050	185	Adm. 2	39.0	330	164.0	0.19	0.16
NUH12	cement 2	1050	900	230	Adm. 2	28.6	300	180.4	0.17	0.14
NUH13	cement 3	900	1050	200	Adm. 1	42.1	230	240.9	0.27	0.22
NUH14	cement 3	850	1020	185	Adm. 1	34.5	330	168.5	0.20	0.16
NUH15	cement 3	850	1020	185	Adm. 3	39.5	330	169.5	0.20	0.16
NUH16	cement 3	850	1020	185	Adm. 4	37.8	330	162.2	0.19	0.16

4 REZULTATI EKSPERIMENTALNIH ISPITIVANJA

4.1 Mehaniča svojstva

Izvršena su ispitivanja betona u svežem i očvrslom stanju. Svih 16 mešavina su bile klase konzistencije S1. Temperatura betona u svežem stanju iznosila je između 22 i 25°C. Zapreminska masa svežeg betona iznosila je od 2610 do 2690 kg/m^3. Čvrstoća na zatezanje pri savijanju je određena ispitivanjem na prizmama 4x4x16 cm, a čvrstoća pri pritisku modifikovanom metodom kocke (ispitna površina 4x4cm).

4 EXPERIMENTAL TRIAL RESULTS

4.1 Mechanical Properties

Fresh and hardened concrete testing was performed. All 16 mixtures were characterized with consistency class S1. Fresh concrete temperature was measured, and temperature was between 22°C and 25°C. Fresh concrete bulk density was between 2610 and 2690 kg/m^3. Flexural strength was determined by testing at concrete prismatic specimens, dimension 4x4x16 cm; and compressive strength was determined by modified cube method (trial surface 4x4cm).

Tabela 4. Eksperimentalni rezultati
Table 4. Experimental results

Beton (Concrete)	Čvrstoća pri pritisku [N/mm^2] (Compressive strength [MPa])			Čvrstoća pri zatezanju savijanjem [N/mm^2] (Flexural strength [MPa])		
	3 dana 3 (days)	7 dana 7 (days)	28 dana 28 (days)	3 dana 3 (days)	7 dana 7 (days)	28 dana 28 (days)
NUH4	90.6	123.8	146.9	16.0	22.5	26.7
NUH5	87.5	113.1	136.3	18.3	23.3	23.9
NUH7	83.1	96.3	131.3	18.3	20.3	28.7
NUH8	88.8	128.1	148.2	15.8	24.8	29.5
NUH9	102.5	125.6	153.1	26.4	28.7	29.8
NUH10	103.1	125.6	155.0	23.1	25.3	25.9
NUH11	100.4	132.5	153.1	20.3	25.6	26.2
NUH12	98.8	123.8	154.4	17.7	21.1	21.9
NUH13	87.5	97.8	128.1	16.9	18.3	22.8
NUH14	88.1	96.9	146.9	20.0	23.6	32.6
NUH15	95.0	115.6	159.4	22.2	25.9	29.5
NUH16	82.5	93.8	170.9	19.7	25.3	30.1

4.2 Skupljanje

Odnos faza u heterogenom materijalu sa cementnom matricom ima značaj pri formiranju mikroprslina, a postaje značajniji kada se tokom hemijskih reakcija pojave i lokalna skupljanja. Sadržaj cementa u ovoj vrsti materijala je izuzetno visok, a da bi se postigle visoka mehanička svojstva usvajaju se izuzetno niski vodovezivni faktori. Visok sadržaj cementa može izazvati probleme sa skupljanjem. Dodavanjem silikatne prašine toplota hidratacije se smanjuje, a time i ublažavaju negativne pojave skupljanja.

Mineralni dodaci imaju različite mehanizme hidratacije u odnosu na cement, jer prvo reaguju sa vodom a potom sa kalcijum-hidroksidom stvarajući produkte hidratacije cementa kroz pucolansku aktivnost. Pri ovoj reakciji nastaje dodatni sadržaj C-S-H gela, smanjije se toplota hidratacije, ali i usporava prirast čvrstoće u ranim starostima. Autogeno skupljanje u ovoj vrsti materijala predstavlja značajan udeo vrednosti ukupnog skupljanja [8]. Na prizmama 4x4x16 mm mešavine NUH16 izmereno je ukupno skupljanje kao zbir autogenog skupljanja i skupljanja usled sušenja od 0.635 mm/m.

4.3 Hidrotermalna obrada uzoraka u ranim starostima

Primena hidrotermalne obrade UHSC uslovljena je potrebom dobijanja visokih ranih čvrstoća, odnosno smanjenjem vremena nege ovog betona i svojstvena je samo u proizvodnji prefabrikovanih proizvoda.

Preliminarna istraživanja izlaganja uzoraka u kojima su umesto kvarcnog peska korišćen prirodni pesak, odnosno uzorci spravljeni bez dodavanja silikatne prašine čak i na povišenim temperaturama nisu dali značajnije rezultate mehaničkih svojstava.

4.2 Shrinkage

Phases' ratio at heterogeneous material with cement matrix is important at micro fractures forming; it becomes even more important when local shrinkage, that is caused by chemical reactions, occurs. Cement content at this type of material is extremely high, and in order to provide high mechanical properties, extremely low water/binder ratios are adopted. High cement content can cause the shrinkage problems. Hydration heat becomes lower by adding silica fume, thus the negative shrinkage effects decrease.

Cement hydration mechanisms are different when mineral additives are used, as they get into chemical reaction with water first, and with Calcium-hydroxide after that, providing cement hydrating products by puzzolanic activity. At this chemical reaction an additional product C-S-H gel is formed, hydration heat is decreased, and strength increase rate at early age is slower.

Autogenous shrinkage at this type of material is significant part of total shrinkage value [8]. At prismatic specimens, dimensions 4x4x16 mm with mixture NUH16, total shrinkage was measured as sum of autogenous shrinkage and dry shrinkage and its value is 0.635 mm/m.

4.3 Steam Curing Regime at Early Age

UHSC steam curing regime is applied as high values of strength at early age are required, actually decrease in curing time for this concrete is applied, and it is the characteristic that is specific only for prefabricated products manufacturing.

Preliminary sample expositions trials performed on specimens with natural sand in concrete composition, instead of fabricated quartz sand, as well as samples that were made without silica fume as additive even at high temperatures did not provide any significant changes in mechanical properties.

Prema doziranju NUH16, nakon mešanja, svež beton je ugrađen u metalne kalupe. Nakon 6 sati odležavanja na temperaturi od 20°C, narednih 18 sati uzorci su izloženi temperaturi od 50°C. Uzorci su potom sledećih 6 dana bili izloženi temperaturi od 80°C, a potom su negovani u vodi na temperaturi od 20°C do starosti od 28 dana [4]. Relativna vlažnost sredine tokom termalne obrade uzoraka je iznosila 95%. U Tabeli 5. dati su rezultati ispitivanja mehaničkih svojstava uzoraka podvrgnutih hidrotermalnoj obradi.

After mixing, according to NUH16 mix specification, fresh concrete was placed in metal moulds. The samples were kept at 20°C, for 6 hours, at 50°C for next 18 hours, at 80°C, for 6 days following, after that they were kept in water at 20°C for curing, until age of 28 days [4]. Relative ambience humidity during steam curing regime was 95%. Table 5 shows results that were provided by mechanical properties testing at samples that were treated by steam curing regime.

Tabela 5. Pritisna čvrstoća uzoraka izloženih režimu nege zaparivanjem
Table 5. Concrete strengths at samples exposed by steam curing regime

Beton (Concrete)	**Čvrstoća pri pritisku [N/mm^2] (Compressive strength [MPa])**			**Čvrstoća pri zatezanju savijanjem [N/mm^2] (Flexural strength [MPa])**		
	3 dana 3 (days)	7 dana 7 (days)	28 dana 28 (days)	3 dana 3 (days)	7 dana 7 (days)	28 dana 28 (days)
NUH16	165.0	175.3	190.9	33.8	35.2	37.4

4.4 Mikrostruktura

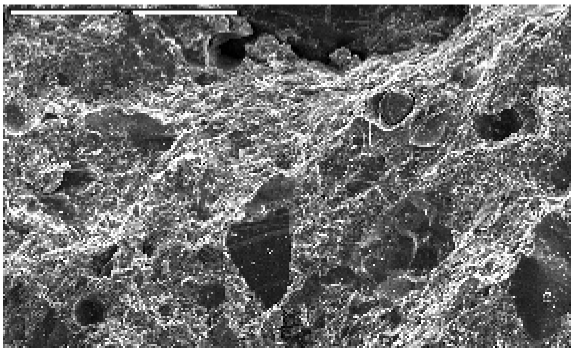
Na prikazanim betonskim mešavinama zapreminska masa je bila znatno veća u odnosu na klasične betone iako se na Slici 1. primećuje pore, kao posledice postojanja uvučenog vazduha, odnosno jedan od razloga postojanja pora je i što pri ugradnji uzorci nisu izlagani dodatnom pritisku. Na Slici 2 je prikazana zona prelaza između agregata i C-S-H faze. Može se uočiti pojava veoma malih mikroprslina na dodiru agregata i C-S-H faze koje se kao što je poznato mogu pojaviti i tokom pripreme uzorka [5].

U mikrostrukturi betona na Slici 3. se vidi da je raspored čeličnih vlakana nasumičan, što je tokom pripreme i mešanja uzoraka i bio cilj. Na slici 4. prikazana je zona prelaza između C-S-H faze i vlakna.

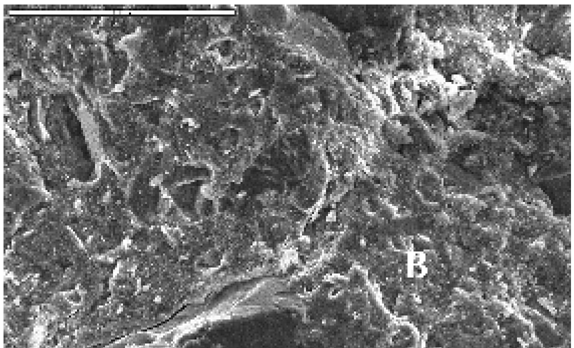
4.4 Microstructural Investigation

Concrete mixtures that were investigated showed bulk density that was significantly higher compared to the ordinary concrete, besides the fact that pores can be noticed (Figure 1); the pores were generated due to entrained air, as samples were not exposed to additional compression. Figure 2 shows transition zone between aggregate and C-S-H phase. Microcracks can be observed at bond between aggregate and C-S-H phase, they can also occur during sample preparation, and it is confirmed by previous investigations [5].

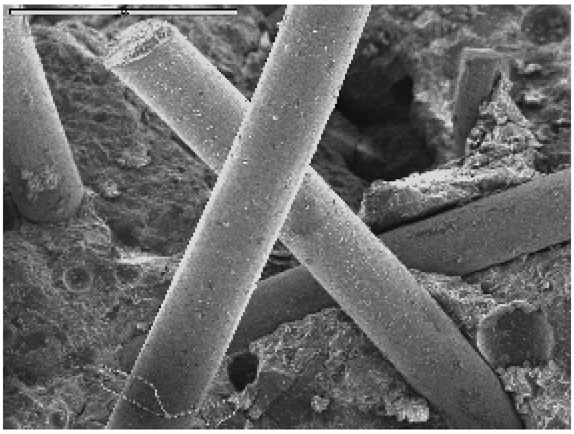
Figure 3 shows random steel fiber distribution, this type of distribution was planned during sample design and mixing. Figure 4 shows transition zone between C-S-H phase and fiber.



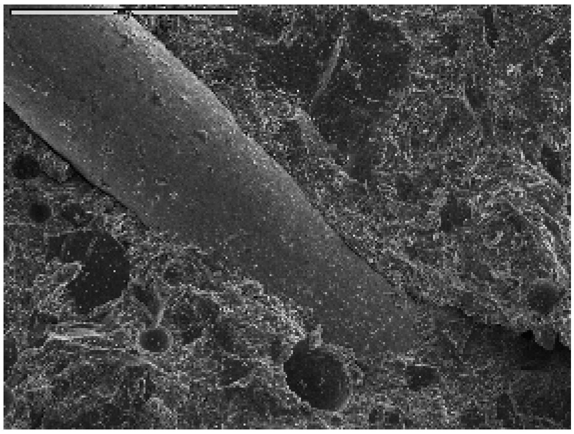
Slika 1. SEM prikaz pora u CSH fazi
Fig. 1. SEM micrograph showing air-entered void in C-S-H



Slika 2. SEM Tranzitna zona između agregata (A) i cementne paste(B)
Fig. 2. SEM micrograph showing transition zone between aggregate (A) and cement paste (B)



Slika 3. SEM Prikaz raspodele čeličnih vlakana
Fig. 3. SEM micrograph showing steel fibers distributed



Slika 4. SEM Tranzitna zona između čeličnih vlakana (A) i cementne paste (B)
Fig. 4. SEM micrograph showing transition zone between steel fiber (A) and cement paste (B)

5 ZAKLJUČAK

U svetu u prethodnih petnaest godina veliki broj istraživača ispitivao je strukturu i svojstva UHSC. U ovom radu namera istraživača je bila da potvrdi mogućnost dobijanja UHSC sa komponentnim materijalima koji su lako dostupni fabrikama betona, odnosno dobijanje materijala sa visokim mehaničkim karakteristikama koji se može spravljati i negovati u uslovima koji su karakteristični za klasične betone.

Eksperimentalni rad prikazan u ovom radu se bazirao na određivanju optimalnog odnosa silikatne prašine i čeličnih vlakana u betonskoj mešavini UHSC. Na osnovu preliminarnih istraživanja, ispitivanja su sprovedena na 12 betonskih mešavina. Količina čeličnih vlakana je varirana od 190 do 330 kg/m^3, odnosno od 2.4-4.2% u odnosu na zapreminu betona. Količina silikatne prašine je varirana u iznosu od 190-230 kg/m^3, odnosno od 10-25% mase cementa. Na osnovu preliminarnih istraživanja i rezultata datih u Tabeli 4, prema [1] može se konstatovati da je dobijen beton ultra-visokih čvrstoća bez hidrotermalnog tretmana.

Na uzorcima betonske mešavine NUH16 izmerene su maksimalne vrednosti mehaničkih svojstava i prema datoj dozaži na ponovo spravljenim uzorcima izmereno je skupljanje sušenjem i primenjena je hidrotermalna obrada data u tački 4.3.

Hidrotermalna obrada uzoraka prikazanih u ovom radu, pokazuje da negovanje na povišenim temperaturama pri režimu prikazanom u tački 4.3 pokazuje prirast oko 12% čvrstoće pri pritisku, odnosno 24% prirasta čvrstoće na zatezanja savijanjem u starosti od 28 dana u odnosu na uzorke koji nisu bili podvrgnuti hidrotermalnoj obradi.

Na osnovu merenja skupljanja u tački 4.2., može se zaključiti da je ukupno skupljanje uzoraka mešavine NUH16 veće od prikazanih u [8] za 15%. Mereno je skupljanje na uzorcima koji nisu izlagani hidrotermalnoj obradi.

Na osnovu merenja skupljanja u tački 4.2., može se zaključiti da je ukupno skupljanje uzoraka mešavine NUH16

5 CONCLUSION

Structure and properties of UHSC have been investigated excessively worldwide, for last 15 years. This trial's scope was UHSC production based on the composites that are available in the market in Serbia, that concrete factories can easily provide; as well as obtaining designed final product: material with high mechanical properties, that can be produced and cured under conditions that are required for ordinary concrete.

Experimental work that was done, was designed in order to determine optimal value of silica fume/steel fibers ratio in UHSC concrete mixture. Following preliminary trials, investigations were performed in 12 concrete mixtures. Amount of steel fibers varied between 190 to 330 kg/m^3, that is 2.4-4.2%, calculated to concrete volume. Amount of silica fume varied between 190-230 kg/m^3, that is 10-25% calculated to concrete volume. According to preliminary trials and results that are shown in Table 4, it can be concluded that Ultra High Strength Concrete was obtained without steam curing regime applied.

Specimens (Concrete mixture NUH16) were tested: max mechanical properties were measured; and according to the concrete mix that was adopted, the new samples were made, and after steam curing regime described in 4.3. dry shrinkage was measured.

The samples in this project were exposed to steam curing regime. It is shown that curing at higher temperatures, using regime described in 4.3, provides approximately 12% compressive strength increase, as well as 24% flexural strength increase at 28 days age concrete, compared to the samples that were not under steam curing regime.

According to the shrinkage measurements described in 4.2., compared to the data that are available [8] it can be concluded that Concrete mixture NUH16 total shrinkage is 15% higher than total shrinkage that was reported previously. Measurements were performed at samples that were not under steam curing regime.

Further investigations should be designed: beam's veće od prikazanih u [8] za 15%. Mereno je skupljanje na uzorcima koji nisu izlagani hidrotermalnoj obradi.

Predmet daljeg istraživanja trebalo bi da bude praćenje ponašanja grede kao konstruktivnog elementa i ispitivanje naponsko-deformacijskih karakteristika pod statičkim i dinamičkim opterećenjem.

behavior as structural element should be investigated, as well as stress-strain properties under static and dynamic load.

ZAHVALNOST

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REZIME

NEKA SVOJSTVA BETONA ULTRA VISOKIH ČVRSTOĆA

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Značajno mesto u primeni novih materijala u građevinarstvu zauzima upotreba betona ultra visokih čvrstoća. Struktura, svojstva i tehnologija izrade ove vrsta betona se intenzivno proučava poslednjih petnaest godina. U ovom radu je prikazana mogućnost dobijanja betona ultra visokih čvrstoća na osnovu eksperimentalnih istraživanja primenom komponentnih materijala dostupnih u Srbiji. Spravljene su tri serije uzoraka sa različitim vrstama cemenata. Korišćena su čelična vlakna dužine 8mm i poprečnog preseka 0.175mm. Prikazana su fizičko-mehanička svojstva betona ultra visokih čvrstoća i analizirana je mikrostruktura ovog kompozita.

Ključne reči: Betoni ultra visokih čvrstoća, čelična vlakna

SUMMARY

SOME PROPERTIES OF ULTRA-HIGH STRENGTH CONCRETE

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Modern civil engineering is characterized with increased application of Ultra-high strength concrete (UHSC). Structure, properties and manufacturing technologies of UHSC are intensively analyzed in the last fifteen years. Possibilities of getting UHSC designed with the materials that are available in Serbian market, were tested in the experimental work; they are shown in this paper. Three series of samples were made with different types of cement. Steel fibers were used: length 8 mm, diameter 0.175 mm. Physical-mechanical properties of UHSC are presented and microstructure of concrete was observed, as well.

Keywords: Ultra-high strength concrete, Steel fiber