

# SVOJSTVA CEMENTNIH KOŠULJICA S DODATKOM POLIPROPILENSKIH VLAKANA I KOMPENZATORA SKUPLJANJA

## THE PROPERTIES OF THE CEMENT SCREEDS WITH THE ADDITION OF POLYPROPYLENE FIBRES AND THE SHRINKAGE-REDUCING ADMIXTURE

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### 1 UVOD

Iscrpno i realno definisanje zahteva koji se postavljaju za građevinske materijale, u zavisnosti od funkcije koju u složenom sistemu objekta konkretan materijal ima, kao i tehnički podaci o svim relevantnim karakteristikama, osnov su za pravilan izbor, primenu i ugradnju pogodnih građevinskih materijala. Danas se savremene konstrukcije grade u kombinacijama raznovrsnih, fizički posebnih ali funkcionalno međusobno povezanih materijala, što nameće potrebu da se materijali posmatraju u sprezi s konstrukcijom. Paralelno s tzv. tradicionalnim materijalima, u primeni je čitav niz novih, industrijski proizvedenih materijala, prilagođenih zahtevima i funkcijama savremenog graditeljstva.

Iako se danas cementna košuljica-estrih u velikom obimu izvodi primenom „gotovih“, fabrički proizvedenih materijala, što predstavlja veliki korak napred, uz koje se najčešće ne dobijaju tehnički listovi s podacima dovoljnim za poznavanje, pravilan izbor i primenu, u okviru klasičnog postupka njihovog izvođenja najčešće se ne propisuju neophodne fizičko-mehaničke, reološke i tehnološke karakteristike datih malterskih kompozicija.

Brojna ispitivanja pokazuju da se svojstva cementnih košuljica, koja po definiciji predstavljaju sloj dobro zbijene

### 1 INTRODUCTION

Exhaustive and realistic definition of the demands that are placed in front of building materials, depending on the function that in the complex system of the facility of specific material, as well as technical data on all relevant characteristics, are the basis for proper selection, implementation and building of suitable building materials. Today, modern structures are built in combinations of various, physically special but functionally interrelated materials, which impose the needs that materials should be considered in conjunction with the construction. In parallel, with the so-called "traditional" materials, a series of new, industrially produced materials are implemented and tailored according to the requirements and functions of modern architecture.

Today, although cement screed to a large extent is carried out using a "finished", factory produced materials, which represents a major step forward, which usually lack technical sheets with data sufficient for knowledge, proper selection and application; the framework of classical procedure of their execution is not normally provided by the necessary physical and mechanical, rheological and technological characteristics of the given mortar composition.

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mešavine, najčešće cementa i sitnog agregata, mogu poboljšati korišćenjem novih materijala boljih svojstava u poređenju sa tzv. tradicionalnim komponentama ove malterske kompozicije.

Tako, na primer, toplotna svojstva košuljica od recikliranog stakla i njihov značaj za energetske efikasnost objekta proučavali su A. Alani i drugi [1]. A. Moriera i ostali istraživali su poboljšane toplotne i zvučne performanse cementnih košuljica, kao i mogućnost smanjenja njihove težine dodavanjem granula plute koja je dobijena kao otpad prilikom proizvodnje [12]. Korišćenje otpadnog materijala kao konstituenta estriha proučavali su i Boehme i ostali, koji su se bavili procenom uticaja recikliranog betona kao agregata, spravljenog od sitne frakcije, u cementnim košuljicama [6].

S obzirom na to što se veoma često i vrlo uspešno ugrađuje u podne konstrukcije izložene izrazito teškom saobraćaju, kao što su podovi industrijskih i komercijalnih objekata, visokoregálnih skladišta, staničnih i bolničkih holova i ostalih sličnih objekata, cementna košuljica je često izložena značajnim opterećenjima, uključujući i koncentrisana opterećenja, koja delujući preko relativno malih površina proizvode visoke lokalne napone pritiska, odgovorne za oštećenja i defekte u košuljici [20].

U građevinskoj praksi veoma često se javlja potreba za sanacijom i popravkom podnih konstrukcija, koje tokom vremena, izložene različitim vrstama opterećenja i drugim uticajima, pokazuju razne oblike deformacija. Oštećenja se obično manifestuju tokom eksploatacije, u nekim slučajevima i odmah nakon izrade, pri čemu se najčešće javljaju na završnim podnim oblogama izvedenim preko estriha. Nekvalitetno izvedena cementna košuljica ima za posledicu velike troškove rekonstrukcije takvog poda, kao i značajne gubitke izazvane prestankom kompletnih aktivnosti u objektu koji je predmet sanacije.

Uprkos savremenim uređajima za izradu podnih obloga, suočavamo se s mnogobrojnim nedostacima u vezi s kvalitetom izrade cementne košuljice. Mnoge greške se ogledaju već u izboru materijala, proizvodnji mešavina, tehnici ugradnje, njihovom dimenzionisanju i pripremama za ugradnju.

Budući da se popravke estriha moraju izvesti u što kraćem vremenskom periodu, neophodno je utvrditi pravi razlog zbog koga je došlo do defekta i predložiti adekvatno rešenje sanacije, kako se ne bismo ponovo suočavali sa istim problemom. Oštećenja objekata, koja ugrožavaju njegovu funkcionalnost, a koja se ispoljavaju tokom eksploatacije, dovela su do promena u načinu projektovanja i odnosu prema održavanju objekta [18].

Ovaj rad imao je za cilj da se putem eksperimentalnog istraživanja i teorijske analize uporedi ponašanje cementnih košuljica koje su napravljene na tradicionalan način, bez dodataka, i cementnih košuljica napravljenih s dodacima mikroarmature i aditiva za smanjivanje skupljanja, ugrađenih na različite načine, a radi definisanja optimalnih kombinacija za formiranje kvalitetnih cementnih košuljica.

Since cement screed by definition represent a well-compacted layer of the mixture, numerous tests have shown that its properties can be improved by using new materials with improved performance compared to the so-called "traditional" components of this mortar composition.

Thus, for example, the thermal properties of the screed of recycled glass and its importance for the energy efficiency of the building have been studied by A. Alan and others [1]. A. Morier and others investigated the enhanced thermal and acoustic performance of cement screed, as well as the possibility of reducing their weight by adding cork granules obtained as waste during production [12]. Using waste materials as constituents of the screed have been studied both by Boehme and others who were dealt in impact assessment of recycled concrete as aggregate, made with fine fraction in cement screeds [6].

Since industrial and commercial facilities, high-bay warehouse, station and hospital lobbies and other similar facilities are exposed to extremely heavy traffic, cement screed is very often and very successfully embedded in these floor structures which is often exposed to significant loads, including concentrated loads, which acting through a relatively small area produce high local stresses of pressure responsible for damage and defects in the screed [20].

In construction practice, there is often a need for rehabilitation and repair of floor structures, which over the time, are subjected to various loads and other influences that result in various forms of deformation. The damage is usually manifested during the exploitation, in some cases immediately after manufacture, in which most often occur on the final floor covering made through the screed. Poorly designed cement screed has resulted in huge costs of reconstruction of this floor, as well as the substantial losses caused by the complete cessation of activity in the house which is the subject of renovation.

Despite modern devices for floor coverings manufacture, we are faced with numerous shortcomings regarding manufacturing quality of cement screed. Many errors are reflected already in the choice of materials, production mixture, technical installations, and their dimensioning and embedding preparations.

Since the screed repairs must be carried out in the shortest possible period of time, it is necessary to determine the true reason why there has been a defect and propose an adequate solution for the repair, in order to avoid the same problem. Damage to buildings jeopardizing its functionality, which manifest themselves during the exploitation, led to a change in the way of designing and maintaining a relationship with the building [18].

Throughout experimental research and theoretical analysis this paper has an objective to compare the behaviour of cement screeds made in traditional way without additives, and cement screeds made with microfibre reinforcement and additives to reduce shrinkage, embedded in different ways, in order to define optimal combination for the formation of high-quality cement screed.

## 2 VRSTE CEMENTNIH KOŠULJICA

Zbog svojih dobrih svojstava (ravnomerno naleže na konstrukciju, nema izrazite deformacije, dovoljno je ravna i može da nosi veliki broj različitih vrsta podnih obloga) cementna košuljica se ubraja u najčešće primenjivanu vrstu podnih podloga. U zavisnosti od načina izvođenja, ima noseću funkciju, a takođe može da predstavlja element za zaštitu od vlage, toplotnu i zvučnu izolaciju.

Cementna košuljica-estrih u standardu SRPS EN 13318:2011 [26] definiše se kao horizontalno izveden sloj cementnog maltera, koji se postavlja na nosivu, najčešće betonsku podlogu ili preko razdelnih, odnosno izolacionih slojeva, čija je svrha da ispuni jednu ili više sledećih funkcija:

- da postigne određeni definisani nivo;
- da se koristi kao osnova za podne obloge;
- da se koristi kao nosiva površina.

U zavisnosti od načina na koji se cementne košuljice postavljaju na noseću podlogu, mogu se podeliti u tri osnovne grupe:

- monolitne;
- vezane;
- nevezane.

*Monolitne košuljice* izrađuju se dok je betonska podloga još uvek u plastičnom stanju, dakle, u isto vreme kada se izvodi i betonska osnova. Kod debljina monolitnog estriha većih od 40 mm postoji rizik gubitka athezije između košuljice i baze, zbog različitog skupljanja. Da bi se dobila dobra athezija između košuljice i betonske bazne konstrukcije, važno je poznavati fenomen pojave prisustva vode na gornjoj površini svežeg betona i ovaj problem rešiti na jedan od sledećih načina:

- odmah nakon zbijanja betona, pre nego što se pojavi voda na površini;
- nakon rešavanja problema s površinskom vodom, kada je ona uklonjena ili isparila.

Neposredno postavljanje je pogodno zbog toga što nema potrebe za pripremom bazne konstrukcije, za razliku od drugog načina kada je potrebno detaljno čišćenje, odnosno adekvatna priprema podloge.

*Vezane (spregnute) košuljice* primenjuju se na sloju očvrslog betona, odnosno na betonsku osnovu. Potrebna debljina ove vrste košuljica zavisi od konstruktivnih zahteva, ali ne bi trebalo da bude manja od 25 mm ni veća od 50 mm. U slučajevima kada debljina vezane košuljice, po zahtevu projektanta, treba da bude veća od 60 mm, opravdana je upotreba armature koja ima zadatak da spreči pojavu prsline. Izrada vezane košuljice zahteva perfektnu pripremu podloge, koja mora biti čvrsta, očišćena od masnoća i prašine i premazana adekvatnim kontaktnim premazom. Ovakav estrih se upotrebljava u slučajevima gde nema zahteva za zvučnom ili toplotnom izolacijom, već je potrebno obezbediti određenu visinsku kotu ili učiniti podlogu ravnom.

*Nevezane (plivajuće) cementne košuljice* postavljaju se iznad izolacionog sloja koji odvaja košuljicu od betonske baze i treba da ima minimalnu debljinu od 50 mm. U slučaju da se postavlja na stišljivi sloj, kao što je, na primer, neka termoizolaciona ploča, debljina estriha treba da iznosi najmanje 70 mm.

U praksi se još surećemo s *tekućim estrihom*, koji

## 2 TYPES OF CEMENT SCREED

Cement screed is one of the most frequently used type of floor surface due to its good properties such as, it evenly rest against the construction, there is no extreme deformation, it is flat enough and it can carry a large number of different types of floor coverings. Depending on the mode of performance, it has a supporting function, and can also represent an element for protection from moisture, heat and sound insulation.

Cement screed in the standard SRPS EN 13318:2011 [26] is defined as a horizontally constructed layer of cement mortar, which is placed on a support, usually concrete surface or by partial or insulating layers, whose purpose is to fulfil one or more of the following functions:

- to achieve a certain defined level,
- to be used as the basis for floor coverings,
- to be used as a bearing surface.

Depending on the way the cement screeds mounted on the carrier substrate can be divided into three basic groups:

- monolithic,
- bounded,
- unbounded.

*Monolithic screeds* are made while the concrete base is still in a plastic state, thus at the same time when performing and concrete basis. In monolithic screed thickness greater than 40mm there is a risk of loss of adhesion between the covering and the base, due to differential shrinkage. In order to obtain good adhesion between the covering and the concrete base structure, it is important to know the presence of the phenomenon of appearance of water on the upper surface of the fresh concrete and to solve this problem by one of the following way:

- immediately after compacting concrete, prior the water appears on the surface,
- after solving the problem with surface water, when it is removed or evaporated.

Immediate setting is suitable because there is no need for preparing base construction, as opposed to the other way when you need extensive cleaning, or adequate surface preparation.

*Bounded (coupled) screeds* are applied to the layer of hardened concrete or on a concrete foundation. The required thickness of this kind of screed depends on the structural requirements, but should not be less than 25mm or more than 50mm. In cases where the thickness of the bounded screed, at the request of the designer should be larger than 60mm, the use of reinforcement that should prevent cracking is justified. Production of the bounded liner requires perfect preparation of the substrate, which must be firm, free of grease and dust and coated with appropriate contact coating. This screed is used in cases where there is no requirement for sound or thermal insulation; it is necessary to provide a specific height datum or make a flat surface.

*Unbounded (floating) cement screeds* are placed on the top of insulating layer that separates screed from concrete base and should have a minimum thickness of 50 mm. In the case when it is placed on the compressible layer, such as, for example, an insulating plate, the thickness of screed should be at least 70 mm.

In practice, we still meet with the liquid screed, which can be floating or bounded. It is rarely used in our

može biti plivajući ili vezani, a koji se zbog visokih cena kod nas ređe primenjuje nego u razvijenim zemljama Evrope. Tekući estrih se može kao potpuno gotov proizvod nabaviti u betonarama i mikserima transportovati na gradilište ili se upakovan u vreće na gradilištu meša s vodom i ugrađuje.

*Izravnavajuće mase* koriste se kada podlogu treba samo izravnati, kada sloj treba da je manje debljine i ne može se izvesti estrih ili onda kada estrih nije površinski dobro obrađen.

### 3 SVOJSTVA CEMENTNIH KOŠULJICA

Osnovna svojstva cementnih košuljica variraju u zavisnosti od vrste upotrebljenog agregata, od razmere mešanja komponenata, upotrebljene količine vode, stepena poroznosti, količine i vrste dodataka, ali pre svega od ostvarene zbijenosti očvrslog materijala [19].

Pri uobičajenoj konfiguraciji, kada je granulometrijska kriva agregata u području koje je preporučeno Pravilnikom za beton i armirani beton [17], *zapreminska masa estriha* kreće se od  $1850 \text{ kg/m}^3$  do  $2100 \text{ kg/m}^3$ . Kod estriha koji imaju veće klase čvrstoće, zapreminska masa je veća i iznosi oko  $2300 \text{ kg/m}^3$ .

*Poroznost* klasično izvedenih cementnih košuljica u najvećem broju slučajeva menja se po njihovoj debljini, pri čemu je najmanja na gornjoj površini, a najveća u donjim zonama. Ovo je posledica tehnologije izvođenja estriha, kada se primenjuje postupak zaglađivanja gornje površine motornom gladilicom (helikopterom) ili ručno. Pri krutoj (zemno-vlažnoj) konzistenciji mešavine, odstranjivanje zaostalog vazduha prisutnog u svežoj malterskoj kompoziciji veoma je teško, što za posledicu ima poroznost od preko 3%.

*Specifična toplota c*, koja praktično znači brzinu zagrevanja ili hlađenja materijala, za cementne košuljice iznosi  $c=1050 \text{ J/kgK}^\circ$ .

*Koeficijent toplotne provodljivosti  $\lambda$* , koji predstavlja sposobnost materijala da kroz svoju masu prenese toplotu, kao posledicu razlike u temperaturi između njegovih dveju površina, za cementni estrih iznosi oko  $\lambda=1,4 \text{ W/mK}^\circ$  [10].

*Termički koeficijent linearnog širenja  $\alpha_t$*  za cementni estrih iznosi  $\alpha_t = 10\text{--}12 \times 10^{-6} (1/^\circ\text{C})$  i predstavlja dilataciju pri promeni temperature za  $1^\circ\text{C}$ . U slučaju cementnog estriha može se reći da je termička stabilnost veća ukoliko je košuljica homogenija i kompaktnija, odnosno ako je termički koeficijent  $\alpha_t$  manji.

*Faktor otpora difuziji vodene pare  $\mu$*  jeste otpor koji građevinski element pruža vodenoj pari i čija vrednost predstavlja gustinu materijala u poređenju s vazduhom za koji taj koeficijent iznosi  $\mu=1$ . Faktor otpora difuziji vodene pare kod skoro svih cementnih kompozicija može se uzeti da je  $\mu=30$  [14].

U slučajevima tankih betonskih elemenata, kod kojih je velika površina izložena isparavanju, kao što je slučaj s cementnim košuljicama, veoma je teško izbeći pojavu prslina. *Veličine skupljanja*, izražene u vidu promene jedinične dužine posmatranog materijala, za cementni estrih iznose  $0,5\text{--}1,0 \text{ mm/m}^1$ .

*Dozvoljena odstupanja* vezana za pravilnost površine estriha, vodeći računa o vrsti poda koja će se primeniti, zavise od mnogih faktora. Za veće površine podova, koji se koriste u uobičajene svrhe, dozvoljeno odstupanje

country due to high prices in comparison with the developed countries of Europe. The liquid screed can be as fully finished product purchased in concrete plants and transported to the construction site with mixers or packed in sacks and mixed with water on the site and installed.

*Levelling masses* are used when the surface should be levelled only, when the layer should be less thick and cannot be performed screed or when the screed surface is badly treated.

### 3 THE PROPERTIES OF CEMENT SCREED

The basic properties of the cement screed vary depending on the type of used aggregate, the extent of mixing of the components, the amount of used water, degree of porosity, amount and type of additives but primarily on realized compactness of hardened material [19].

*The screed density* ranges from  $1850 \text{ kg/m}^3$  to  $2100 \text{ kg/m}^3$  in a common configuration when the grain size distribution curve of aggregates is in the area recommended by Regulation for concrete and reinforced concrete [17]. For screeds that have larger class strength, the density is higher at about  $2300 \text{ kg/m}^3$ .

*Porosity* of conventionally rendered cement screed in most cases changes by their thickness, the lowest being on the top surface, and the largest in lower areas. This is due to the screed technology construction, when applying the procedure of smoothing the upper surface by engine smoother (choppers) or manually. In the (earth-damp) consistency mixture, removal of residual air present in fresh mortar composition is very difficult, which results in a porosity of more than 3%.

*The coefficient of specific heat c*, which actually means the speed of heating or cooling of materials, for cement screed amounts to  $c=1050 \text{ J/kgK}^\circ$ .

*The thermal conductivity coefficient  $\lambda$* , which represents the ability of materials to transfer heat through their mass, as a result of the temperature difference between two surfaces for cement screed is about  $\lambda=1,4 \text{ W/mK}^\circ$  [10].

*The thermal coefficient of linear expansion  $\alpha_t$*  for cement screed is  $\alpha_t = 10\text{--}12 \times 10^{-6} (1/^\circ\text{C})$  and represents a dilatation in temperature change about  $1^\circ\text{C}$ . In the case of cement screed thermal stability is higher when the screed is more homogenous and more compact, respectively when the thermal coefficient  $\alpha_t$  is lower.

*Diffusion resistance of water vapour  $\mu$*  is the resistance that construction element provides to water vapour and whose value is the density of the material in comparison with the air for which the coefficient is  $\mu=1$ st Resistance factor to diffusion of water vapour in almost all cement composition should be  $\mu=30$  [14].

In the case of thin concrete elements, in which a large surface is exposed to evaporation, as it is the case with cement screed, it is very difficult to avoid the appearance of cracking. *The sizes of shrinkage*, expressed in the terms of changes in unit length of the observed materials for cement screed amounts to  $0.5\text{--}1.0 \text{ mm/m}^1$ .

*The permitted tolerances* related to regularity in the surface of the screed depend on many factors taking into account the type of floor to be applied. For larger floor surfaces that are used in common purpose, the

je  $\pm 15\text{mm}$ . Veća tačnost može biti zahtevana u manjim prostorijama po linijama pregradnih zidova, u blizini otvora za vrata i gde treba da se instalira specijalizovana oprema direktno na podu, kao i u slučajevima visokih zahteva kod industrijskih podova.

#### 4 EKSPERIMENTALNO ISTRAŽIVANJE

Da bi se utvrdio uticaj dodataka mikroarmature i kompenzatora skupljanja na fizičko-mehaničke i deformacione karakteristike cementnih košuljica, u Laboratoriji za materijale Građevinskog fakulteta Univerziteta u Beogradu, realizovan je program eksperimentalnih istraživanja malterskih kompozicija na bazi cementa kao veziva, rečnog agregata (0/4mm), vode, polipropilenskih vlakana i aditiva protiv skupljanja.

Pri planiranju eksperimentalnog dela istraživanja pošlo se od pretpostavke da je optimalni sastav cementne košuljice moguće definisati na osnovu analize komponentnih materijala, izbora odgovarajućeg postupka ugradnje, kao i da optimalna količina mikroarmature i aditiva protiv skupljanja imaju povoljan uticaj na svojstva cementne košuljice.

##### 4.1 Sastav ispitivanih malterskih mešavina

Za potrebe eksperimenta, po programu istraživanja, predviđeno je spravljanje i ispitivanje svojstava tri različite vrste malterskih mešavina za cementne košuljice, koje su ugrađivane na dva načina: ručno i vibriranjem. Serije su označene na sledeći način:

- Serija I – etalon, uobičajena cementna mešavina za cemente košuljice (cement+agregat+voda);

- Serija II – cementna mešavina s dodatkom mikroarmature (cement+agregat+voda+mikroarmatura);

- Serija III – cementna mešavina s dodatkom mikroarmature i aditiva protiv skupljanja (cement+agregat+voda+mikroarmatura+aditiv protiv skupljanja).

Uzorci su, nakon mešanja, ugrađeni u kalupe napravljene za potrebe ispitivanja, dimenzija 40x40x4,5cm (slika 1) i u propisane trodelne kalupe dimenzija 4x4x16cm (slika 2). Svaka serija malterske mešavine ugrađena je na dva načina: ručno i vibriranjem na vibro-stolu, na osnovu čega su usvojene oznake 1 (ugrađena ručno) i 2 (ugrađena vibriranjem). Uzorci oblika prizme, dimenzija 4x4x16cm, ugrađeni na način kako to propisuje standard SRPS EN 196-1:2008, obeleženi su oznakom 3. Uzorci su negovani pokrivanjem vlažnom jutanom tkaninom tri dana, a dalje u laboratorijskim uslovima na vazduhu ( $H_r=65\%$ ,  $T=20 \pm 3^\circ\text{C}$ ).

permitted tolerance is  $\pm 15\text{mm}$ . Greater accuracy may be required in smaller rooms along the lines of partition walls, near the door opening and where the specialized equipment is installed directly on the floor, as well as in the cases of high demand for industrial floors.

#### 4 THE EXPERIMENTAL RESEARCH

In order to determine the influence of microfibre reinforcement and shrinkage-reducing admixture to the physical-mechanical and deformation characteristics of cement screed, Laboratory of Materials of Civil Engineering, University of Belgrade, has realized a program of experimental research of mortar compositions based on cement as a binder, river aggregate (0/4mm), water, polypropylene fibres and additives against shrinkage.

When planning the experimental part of the research we started with the assumption that the optimum composition of cement screed can be defined based on the analysis of component materials, selecting the proper embedding procedure, as well as the fact that optimal amount of microfibre reinforcement and shrinkage-reducing admixture have a favourable influence on the properties of cement screed.

##### 4.1 The composition of the tested mortar mixtures

For the purposes of the experiment, and according to the research program, the preparation and testing of the properties of three different types of mortar mixture for cement screed installed in two ways, manually and by vibrations, has been envisaged. The series are identified as follows:

- Series I - reference mixture, common cement mixture for cement screed (cement+aggregate+water),

- Series II - cement mixture with the addition of microfibre reinforcement (cement+aggregate+water+microfibre reinforcement),

- Series III - cement mixture with the addition of microfibre reinforcement and shrinkage-reducing admixture (cement+aggregate+water+microfibre reinforcement+shrinkage-reducing admixture).

After mixing the samples are placed in molds made for the purposes of testing, dimensions 40x40x4,5cm (Figure 1) and in the prescribed three-part molds dimensions 4x4x16cm (Figure 2). Each series of mortar mixture is incorporated in two ways: manually and by vibrating on the vibrating table, on the basis of which they adopted codes 1 (placed by hand) and 2 (placed by vibrating). The prism-shaped samples, dimensions 4x4x16cm, placed in the manner prescribed by the standard EN 196-1: 2008, are marked 3. The samples were cured by covering with wet jute fabrics for three days and afterwards they remained in laboratory conditions on the air ( $H_r=65\%$   $T=20 \pm 3^\circ\text{C}$ ).



Slika 1. Ugradnja cementnog maltera u kalupe za prizme  
Figure 1. Embedding cement mortar in molds for prisms



Slika 2. Ugradnja malterske mešavine u kalupe  
Figure 2. Embedding the mortar mixtures into molds

U fazi projektovanja sastava malterskih kompozicija kao polazna tačka uzet je vodocementni faktor 0.38, koji se usvaja iskustveno, zbog uslova da konzistencija cementnih košuljica treba da odgovara opisu „vlažno kao zemlja”. Količine komponentnih materijala sračunate su približno na osnovu pretpostavljene zapremine mase i vodocementnog faktora, kao i usvojene konstantne razmere mešanja cementa i agregata 1:3 (tabela 1), uz korišćenje tzv. masene jednačine [14].

In the design phase of ingredients of mortar composition, water-cement ratio 0.38 has been taken as the starting point which is proved by experience, because of the conditions that the consistency of cement screed should fit the description "wet as a ground." The quantities of component materials are calculated approximately based on an assumed density and water-cement ratio, as well as the adopted constant proportions of mixing cement and aggregate 1: 3 (Table 1) using the so-called mass equation [14].

Tabela 1 Količine materijala za  $1m^3$  malterske mešavine  
Table 1 Quantities of materials for  $1m^3$  of the mortar mixtures

Seriya Series	Cement Cement $m_c$ (kg)	Agregat Aggregate $m_p$ (kg)	Voda Water $m_v$ (kg)	Vlakna Fibres $m_{vl}$ (kg)	Aditiv Additive $m_{ad}$ (kg)	Zapreminska masa Density $\gamma_{m\ sv}$ ( $kg/m^3$ )	$m_v/m_c$	$m_a/m_c$
Seriya I Series I	479,5	1438,5	182	/	/	2100	0,38	3
Seriya II Series II	502	1506	191	1,0	/	2200	0,38	3
Seriya III Series III	500	1500	180	1,0	10	2191	0,36	3

#### 4.2 Komponentni materijali

Kako je primarni cilj istraživanja bio utvrđivanje uticaja dodatka na svojstva cementnih košuljica, sve serije malterskih mešavina napravljene su sa istim tipom cementa, vrstom i granulometrijskim sastavom agregata i pijaćom vodom.

Za izradu uzoraka cementnih kompozita, na kojima su vršena ispitivanja, korišćen je portland cement PC 42,5 R, proizveden u fabrici cementa „Lafarge” iz Beočina, specifične mase  $\gamma_{sc}=3100\text{ kg/m}^3$ . Pre upotrebe, hemijske, fizičke i mehaničke karakteristike cementa ispitane su u Institutu IMS Beograd, shodno standardu SRPS EN 196-1; 196-2; 196-3.

Kvalitet peska, pri spravljanju cementnih košuljica, ima veliki uticaj na kvalitet konačnog proizvoda. Agregat koji je korišćen u eksperimentu jeste prirodni pesak

#### 4.2 Composite materials

As the primary objective of the research was to determine the effect of additives on the properties of cement screed, all series of mortar mixtures are made with the same type of cement, type and granulometric composition of aggregate and drinking water.

The research was carried out on the samples of cement composites made of Portland cement PC 42.5 R, produced in cement factory "Lafarge" in Beočin, having specific mass  $\gamma_{sc}=3100\text{ kg/m}^3$ . Chemical, physical and mechanical properties of cement are, prior to use, tested at The Institute of the IMS in Belgrade, in accordance with standard EN 196-1; 196-2; 196-3.

The quality of the sand, when making cement screeds, has a large impact on the quality of the final product. The aggregate that was used in the experiment

„Moravac”, frakcije 0/4 mm, koji je prethodno testiran u laboratoriji, specifične mase  $\gamma_{sa}=2600 \text{ kg/m}^3$ .

Pri izradi malterskih kompozita za ispitivanje cementnih košuljica treba upotrebljavati isključivo čistu vodu. Za spravljanje uzoraka je korišćena voda iz gradskog vodovoda, tako da nije bilo potrebno sprovoditi ispitivanja njenog fizičkog i hemijskog sastava.

#### 4.2.1 Vlakna

Poznato je da malteri, kao kompozitni materijali, vrlo slabo prihvataju i podnose napone zatezanja, za razliku od napona pritiska, pa je upotreba vlakana postala nezaobilazni element pri izradi estriha. Upotrebom vlakana omogućava se da se u velikoj meri eliminišu poznati nedostaci klasičnih maltera i betona - niske čvrstoće pri zatezanju i male žilavosti. Njihovom upotrebom se ostvaruju i dopunski efekti poput smanjivanja mogućnosti pojave prslina usled skupljanja cementa, te obezbeđenje tiksotropnosti mešavina u svežem stanju [25], a mogu takođe da doprinesu povećanju otpornosti na habanje kompozita, boljoj adheziji za podlogu na kontaktu „starog” i „novog” betona, povećanoj otpornosti pri dinamičkim uticajima, kao i povećanju otpornosti na dejstvo požara [8].

Rezultati brojnih izvršenih ispitivanja na malterima i betonima pokazali su efikasnost polipropilenskih vlakana u kontroli plastičnog skupljanja betona [2] kao i to da je njihovo prisustvo neophodno, posebno u tankim betonskim elementima [24] poput cementnih košuljica.

Poznata pojava izdvajanja viška vode na površini nakon spravljanja i ugrađivanja maltera („bleeding”), upotrebom polipropilenskih vlakana može se u velikoj meri ublažiti, zato što vlakna svojim izuzetnim brojem i homogenim rasporedom presecaju sistem kapilarnih pora i time usporavaju difuziju vode [15].

Osnovni parametri koji utiču na kvalitet maltera, vezani za vlakna, jesu količina i tzv. faktor oblika ( $l/d$ ) koji daje odnos između dužine vlakana ( $l$ ) i njihovog prečnika ( $d$ ). Ono što polipropilenska vlakna posebno preporučuje kao mikroarmaturu za malterske mešavine za cementne košuljice jeste veoma povoljan faktor oblika  $l/d$ , jer je efekat smanjenja ukupnih deformacija skupljanja veći s vlaknima veće dužine, tj. s višim vrednostima faktora oblika ( $l/d$ ) [8].

Polipropilen je dobar termoizolacioni i elektroizolacioni materijal, ima visoku hemijsku otpornost, neporozan je i, u principu, ima hidrofobnu površinu. Hemijski je inertan, ima visoku otpornost u uslovima agresivnog delovanja kiselina i soli. Ni alkalna sredina, koja je karakteristična za maltere, nema značajnijeg uticaja na promenu kvaliteta ili trajnosti polipropilenskih vlakana. Slaba strana ovih vlakana je nepostojanost na povišenim temperaturama, nizak modul elastičnosti i velike deformacije tečenja.

Kod primene polipropilenskih vlakana, njihova dužina treba da bude 3-3,5 puta veća od najkrupnijeg zrna agregata u mešavini (4 mm), zbog čega su korišćena vlakna dužine 12 mm. Za ova eksperimentalna ispitivanja korišćena su monofilamentna, talasasta polipropilenska SIKA FIBER vlakna, dužine 12 mm, proizvođača „Sika” Švajcarska, uobičajenog doziranja 900 do 1000 g/m<sup>3</sup> maltera (tabela 2).

is a natural sand "Moravac" of fraction 0/4mm, which was previously tested in the laboratory of the specific mass  $\gamma_{sa}=2600 \text{ kg / m}^3$ .

Clean water should be used exclusively while preparing mortar composites for testing cement screed. Thus, water from the municipal water supply was used for the preparation of the samples; therefore, there was no need to conduct a test of its physical and chemical composition.

#### 4.2.1 Fibres

It is known that mortars, as composite materials, very poorly accept and bear the tensile stress, as opposed to compressive stress. Therefore, the use of fibre has become an indispensable element in the preparation of the screed. Its usage largely enables removal of common disadvantages of conventional plaster and concrete - low tensile strength and low toughness. Furthermore, its usage results in some additional effects such as: reducing the risk of shrinkage cracks of cement, providing thixotropic mixture of fresh state [25], and may also contribute to increase of abrasion resistance of composites, better adhesion to the substrate to contact the "old" and "new" concrete, increased resistance to dynamic impacts, increasing resistance to fire [8].

The results of numerous tests carried out on plasters and concrete have demonstrated efficacy of polypropylene fibres in controlling plastic shrinkage of concrete [2] and that their presence is necessary, especially in thin concrete elements [24] such as cement screeds.

The common phenomena of separation of excess water on the surface after the preparation and implementation of plaster ("bleeding"), using polypropylene fibres can be greatly alleviated, because fibres with their exceptional number and homogeneous pattern intersect the system of capillary pores and thus slow down the diffusion of water [15].

The main parameters that influence the quality of the mortar, related to fibres are the quantities and the so-called aspect ratio ( $l/d$ ), which provides the ratio between the fibre length ( $l$ ) and their diameter ( $d$ ). What polypropylene fibres specially recommended as fibre reinforcement for the mortar mixture for cement screeds is very convenient aspect ratio  $l/d$ , because the effect of reducing the total shrinkage deformation is higher with fibres of higher length, i.e. higher values of the aspect ratio ( $l/d$ ) [8].

Polypropylene is a good thermal insulation and electrical insulation material; it has a high chemical resistance, it is non-porous, and in principle, has a hydrophobic surface. It is chemically inert, has a high resistance to the conditions of aggressive action of acid, and the salts as well. Moreover, alkaline environment, which is characteristic of mortars, has insignificant effect on the change of quality or durability of polypropylene fibres. The drawback to these fibres is volatility at elevated temperatures, low modulus of elasticity and creep deformation.

When using the polypropylene fibres, their length should be 3-3.5 times higher than the coarsest aggregate in the mix (4mm), due to which were used fibres including the length of 12 mm. Therefore, the monofilament, wavy polypropylene SIKA FIBER fibres,

of the length of 12mm, of the usual dosage of 900 to 1000 g/m<sup>3</sup> mortar were used (Table 2).

**Tabela 2. Osnovna svojstva polipropilenskih vlakana Sika Fiber deklarirana od strane proizvođača**  
**Table 2. The basic properties of polypropylene fibres "Sika Fiber" declared by the manufacturers**

Parametri Parameters	Deklarisana svojstva Properties
Osnovni materijal Basic material	Polipropilen (100%) Polypropylene (100%)
Tip vlakana Type of fibres	Monofilamentna, talasasta vlakna Monofilament, wavy fibres
Specifična masa $\gamma$ Specific mass $\gamma$	0,9 g/cm <sup>3</sup>
Broj vlakana Number of fibres	120 miliona/kg 120 millions/kg
Dužina Length	12 mm
Prečnik d Diameter d	0,040 mm
Faktor oblika (l/d) Aspect ratio (l/d)	300
Čvrstoća pri zatezanju Tensile strength	360MPa
Modul elastičnosti Module of elasticity	2 500MPa
Tačka razmekšavanja Softening point	160 °C
Otpornost u alkalnoj sredini Resistance in the alkaline solution	otporna resistant

#### 4.2.2 Aditiv protiv skupljanja

S obzirom na to što je skupljanje neizbežno svojstvo očvršćavanja maltera, aditivi protiv skupljanja (kompenzatori skupljanja) počeli su da se koriste osamdesetih godina prošlog veka kako bi se izbegla pojava pukotina i izvijanja usled skupljanja sušenjem.

Kada je reč o tankim betonskim elementima, kod kojih je velika površina izložena isparavanju, kao što je slučaj s cementnim košuljicama, veoma je teško izbeći pojavu prslina u svežem malteru. Ukoliko gubitak površinske vlage premašuje 0,5kg/m<sup>2</sup>/h negativni kapilarni pritisci se razvijaju unutar betona izazivajući unutrašnje pritiske [11]. Kompenzatori skupljanja nove generacije ne deluju bubrenjem betona u ranoj fazi očvršćavanja, nego sprečavanjem evaporacije vode koja ga uzrokuje, odnosno sprečavanjem skupljanja okvašenih površina kapilara pri isparavanju vode. Naročito su efikasni u kombinaciji sa superplastifikatorima nove generacije, kada uobičajeno skupljanje betona možemo smanjiti za 30% do 70% [3].

Napravljeni su na bazi propilen-glikola i deluju tako da kad vodom napunjene pore, veličine od 2,5 do 50 nm, počnu da gube vlagu, oblikuju zakrivljene meniskuse, a površinski napon vode povlači zidove pora ka unutra (slika 3). Prema [22] sa smanjenjem površinskog napona vode smanjuje se i sila koja deluje tako što istiskuje vodu iz kapilarnih pora, što rezultira smanjenjem skupljanja. Dodatak aditiva protiv skupljanja, osim što utiče na skupljanje od sušenja, povećava obradljivost betona [16]; kompatibilan je s drugim dodacima i poboljšava vodonepropusnost betona.

Kako se ne treba oslanjati samo na pozitivna dejstva

#### 4.2.2 Shrinkage-reducing admixture

Given that the shrinkage is an inevitable feature of the mortar hardening, shrinkage-reducing admixture (shrinkage compensators) started its application in the eighties of the last century in order to avoid cracking and deflection due to drying shrinkage.

In the case of thin concrete elements, in which a large area is exposed to evaporation, as is the case with cement screeds, it is very difficult to avoid the occurrence of cracks in the fresh mortar. If the loss of surface moisture exceeds 0.5 kg/m<sup>2</sup>/h negative capillary pressures are developed within the concrete, causing internal pressures [11]. The shrinkage-reducing admixture of the new generation do not act in swelling concrete in the early stages of hardening, but in preventing the evaporation of water that causes it, furthermore, in preventing shrinkage of wetted surface capillary in water evaporation. They are particularly effective in combination with superplasticizers of new generation, usually when the shrinkage of concrete can be reduced by 30% to 70% [3].

They are designed on the basis of the propylene glycol and operate so that when the water-filled pores, a size of 2.5 to 50 nm start losing moisture and form a curved meniscus, the surface tension of walls pulls the walls of the pore towards inside (Figure 3). According to [22], with a reduction in the surface tension of water, the force acting in the way that displaces the water out of the capillary pores is reduced as well, which results in reduced shrinkage. The addition of additive against shrinkage affects of drying shrinkage, and enhances the workability of concrete [16]; it is compatible with other



aditiva protiv skupljanja, već treba sagledati uticaj i na ostala svojstva [4] pokazano je u istraživanjima drugih autora [21] iz kojih se vidi da ova vrsta dodataka može delovati na produžavanje vremena vezivanja i smanjenje čvrstoće pri pritisku.

Preporučena potrošnja od 2% na masu cementa (6-10 kg/m<sup>3</sup> betona) relativno je velika doza, zbog čega je uzeta u obzir prilikom pripreme recepture. Dodavanje aditiva doprinosi povećanju poroznosti, pa je količina vode smanjena za količinu upotrebljenog dodatka.

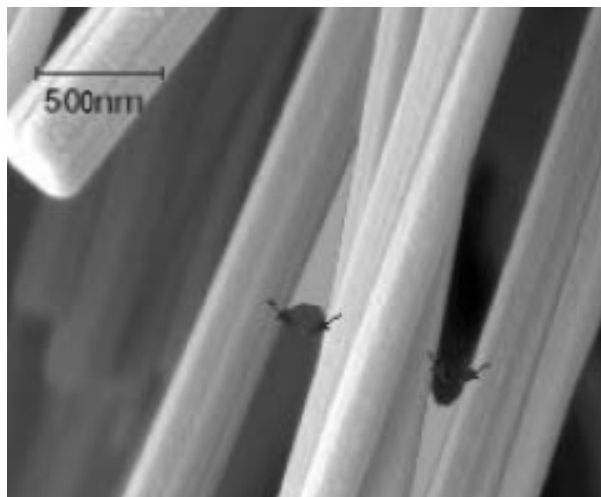
U eksperimentalnim istraživanjima korišćen je aditiv protiv skupljanja Sika Control - 40, proizvođača „Sika“ Švajcarska, doziran u količini od 2% od mase cementa.

additives and improves waterproof quality of concrete.

One should not rely only on the positive effects of additives against shrinkage, but should consider the impact of other properties [4]; it has been shown in the studies by other authors [21] who show that this type of additives can act on extending the setting time and compressive strength reduction.

The recommended consumption of 2% of cement mass (6-10 kg / m<sup>3</sup> of concrete) is relatively a large dose, which is taken into account during the preparation of the recipe. Adding additives contributes to an increase of porosity, and the amount of water is reduced for the amount of used additive.

In this experimental research, shrinkage-reducing admixture Sika Control-40, produced by "Sika" Switzerland, dosed at 2% of the cement mass was used.



*Slika 3. Šematski prikaz dejstva aditiva protiv skupljanja (izvor: [www.encosrl.it/enco%20srl%20ITA/servizi/pdf/additivi/91.pdf](http://www.encosrl.it/enco%20srl%20ITA/servizi/pdf/additivi/91.pdf))*

*Figure 3. Schematic view of the shrinkage-reducing admixture (source: [www.encosrl.it/enco%20srl%20ITA/servizi/pdf/additivi/91.pdf](http://www.encosrl.it/enco%20srl%20ITA/servizi/pdf/additivi/91.pdf))*

## 5 REZULTATI ISPITIVANJA

Ispitivanje fizičko-mehaničkih i deformacionih karakteristika uzoraka malterskih mešavina za cementne košuljice sprovedeno je preko izvađenih cilindara-kernova prečnika Ø50 mm, koji su u dane ispitivanja imali starost 2, 7 i 28 dana i preko prizmatičnih uzoraka dimenzija 4x4x16 cm, različite starosti. Iz svakog od sanduka-kalupa, u kojima su izrađeni uzorci cementnih košuljica, izvađeno je (slika 4), saglasno standardu SRPS U.M1.049:2000 po 9 cilindara-kernova (slika 5), koji su zatim ispitani. Uzorci napravljeni na ovaj način omogućili su nam da, upoređivanjem u okviru iste vrste, uočimo značaj koji ima način ugradnje.

## 5 TEST RESULTS

Testing the physical-mechanical and deformation characteristics of the samples of mortar mixtures for cement screed was conducted over the extracted cylinders-cores diameter of Ø50mm, which in the days of tests were 2, 7 and 28 days old and over prismatic samples of dimensions 4x4x16cm of different age. From each of the boxes-molds, in which the samples of cement screeds are made, were pulled out (Figure 4), in accordance with the standard of SRPS U.M1.049: 2000 per 9 cylinders (Figure 5), which were then tested. The samples made in this way have enabled us to notice the importance of the method of compacting when comparing the framework of the same species.



Slika 4. Izgled uzoraka  
Figure 4. View of samples



Slika 5. Vađenje kernova iz kalupa  
Figure 5. Removing cylinders from molds

### 5.1 Zapreminska masa

U laboratorijskim uslovima, zapreminska masa cementnog maltera u očvrslom stanju određuje se, saglasno proceduri opisanoj u standardu SRPS EN 12390-7:2010, merenjem masa osušenih uzoraka koji u konkretnom slučaju imaju ili oblik cilindra Ø50 mm ili prizme 4x4x16 cm, uz pomoć poznatog obrasca:

$$\gamma_m = \frac{M_m}{V_m} \left[ \frac{\text{kg}}{\text{m}^3} \right] \quad (1)$$

Na osnovu izmerenih čvrstoća pri pritisku i poznatih zapreminskih masa uzoraka, računskim putem dobijene su vrednosti koeficijena konstrukcijske povoljnosti  $K_{kp}$  koji predstavlja odnos čvrstoće pri pritisku materijala (u MPa) prema njegovoj zapreminskoj masi  $\gamma$  (u  $\text{t/m}^3$ ) (tabela 3)

$$K_{kp} = \frac{f_p}{\gamma} \left[ \frac{\text{MPam}^3}{\text{t}} \right] \quad (2)$$

### 5.1 Density

In laboratory conditions, the density of cement mortar in the hardened state is determined in accordance with the procedure described in the standard SRPS EN 12390-7: 2010, by measuring the mass of dried samples, which in the case of concrete, have either form of a cylinder Ø50mm or prism 4x4x16 cm, with the help of the form:

On the basis of the measured compressive strength and well-known density of samples, the values of coefficients of structural favorability  $K_{kp}$  were obtained by computation, which represents the ratio of material compressive strength (in MPa) according to its density  $\gamma$  ( $\text{t/m}^3$ ) (Table 3).

Tabela 3. Zapreminske mase uzoraka oblika cilindra Ø50 mm i koeficijenti konstrukcijske povoljnosti  $K_{kp}$ , pri starosti od 2, 7 i 28 dana

Table 3. Density of samples in the form of cylinder Ø50mm and structural advantages coefficients  $K_{kp}$ , at the age of 2, 7 and 28 days

Uzorak Sample	Zapreminska masa $\gamma_{2,2}$ Density $\gamma_{2,2}$ ( $\text{kg/m}^3$ )	$K_{kp,2}$ ( $\text{MPam}^3/\text{t}$ )	Zapreminska masa $\gamma_{7,7}$ Density $\gamma_{7,7}$ ( $\text{kg/m}^3$ )	$K_{kp,7}$ ( $\text{MPam}^3/\text{t}$ )	Zapreminska masa $\gamma_{28,28}$ Density $\gamma_{28,28}$ ( $\text{kg/m}^3$ )	$K_{kp,28}$ ( $\text{MPam}^3/\text{t}$ )
I-1	1474.89	1.75	1536.15	2.54	1455.76	5.03
I-2	2091.11	10.39	2080.55	15.99	2075.63	18.93
II-1	1716.46	2.28	1684.33	3.83	1667.69	5.41
II-2	2178.18	12.89	2125.81	17.01	2088.71	20.66
III-1	1571.34	2.58	1527.69	3.73	1503.27	5.39
III-2	2148.84	12.84	2118.62	15.79	2070.51	20.59

Iz priloženih rezultata ispitivanja se vidi da su zapreminske mase uzoraka ugrađenih ručno (1), bez obzira na sastav, znatno niže, i kreću se od oko 1400 kg/m<sup>3</sup> do 1700 kg/m<sup>3</sup>, od zapreminskih masa uzoraka ugrađenih vibriranjem (2), koje se kreću oko 2000 kg/m<sup>3</sup>. Budući da mehaničke karakteristike, kao i niz drugih svojstava betona (maltera), bitno zavise od ostvarene strukture [13] na osnovu zapreminske mase može se zaključiti da se u slučajevima malterskih mešavina za cementne košuljice koje su ugrađivane ručno i gde nije postignuta zadovoljavajuća kompaktnost, koja direktno utiče na poroznost kompozita, logično može očekivati niži nominalni kvalitet. Dodavanje mikroarmature i aditiva protiv skupljanja ne utiče značajno na promenu zapreminske mase (najviše 3,6%).

Koeficijent konstrukcijske povoljnosti  $K_{kp}$ , značajan zbog toga što direktno utiče na težinu konstrukcije, povoljniji je kod ručno ugrađenih kompozita u odnosu na mešavine ugrađene vibriranjem i ne menja se značajno dodavanjem vlakana i aditiva.

## 5.2 Čvrstoća pri pritisku

Čvrstoća pri pritisku, kao najznačajnija mehanička karakteristika cementnih kompozita, s ciljem dobijanja funkcionalne zavisnosti  $f_p=f_p(t)$  (slika 6), ispitivana je na uzorcima izvađenih kernova Ø 50mm, pri starosti od 2, 7 i 28 dana. Rezultati ispitivanja srednjih vrednosti čvrstoća pri pritisku dati su tabelarno (tabela 4).

Tabela 4. Čvrstoće na pritisak uzoraka, pri starosti od 2, 7 i 28 dana  
Table 4. Compressive strength of samples, at the age of 2, 7 and 28 days

Uzorak Sample	$f_{p,2}$ (MPa)	$f_{p,7}$ (MPa)	$f_{p,28}$ (MPa)
I-1	2.58	3.90	7.33
I-2	21.73	33.27	39.30
II-1	3.91	6.44	9.02
II-2	28.07	36.17	43.15
III-1	4.05	5.70	8.10
III-2	27.59	33.45	42.62

Na osnovu rezultata prikazanih u tabeli 4 možemo zaključiti da:

- uzorci svih serija ugrađenih ručno (1), bez obzira na sastav, imaju daleko manje čvrstoće pri pritisku u odnosu na uzorke kod kojih je primenjen postupak vibriranja (2), što je logična posledica manje kompaktnosti;
- malterske mešavine koje sadrže vlakna (II) imaju veće čvrstoće za oko 10% u odnosu na etalon (I), s tim što je prirast čvrstoće izraženiji kod „mladih” kompozita i iznosi oko 30%;
- dodatak aditiva protiv skupljanja neznatno je uticao na pad čvrstoće pri pritisku, serije III imaju manje čvrstoće za 1,5% u odnosu na serije II, s tim što su čvrstoće pri pritisku serija III veće od etalonskih (I) za oko 8,5%.

Funkcionalna zavisnost čvrstoće pri pritisku od vremena prikazana je na sl. 6.

From the attached test results it can be seen that the density of the placed-hand samples (1), regardless of their composition, are significantly lower, ranging from about 1400 kg/m<sup>3</sup> to 1700kg/m<sup>3</sup>, from the density placed by vibrating the samples (2), which is moving about 2000 kg/m<sup>3</sup>. Since the mechanical characteristics, as well as the other properties of concrete (mortar) strongly depend on the realized structures [13], on the basis of its density it can be concluded that in the cases of mortar mixture for cement screeds incorporated by hand and unsatisfactory achieved compactness, which directly affects the porosity of the composite, it can be reasonably expected a lower nominal quality. Adding microfibre reinforcement and shrinkage-reducing admixture fails to influence the change of its density (up 3.6%).

The coefficient of structural favorability  $K_{kp}$  is significant because it directly affects the weight of the structure, and it is more suitable in manually embedded composites compared to mixtures embedded by vibrating and changes insignificantly by adding fibres and additives.

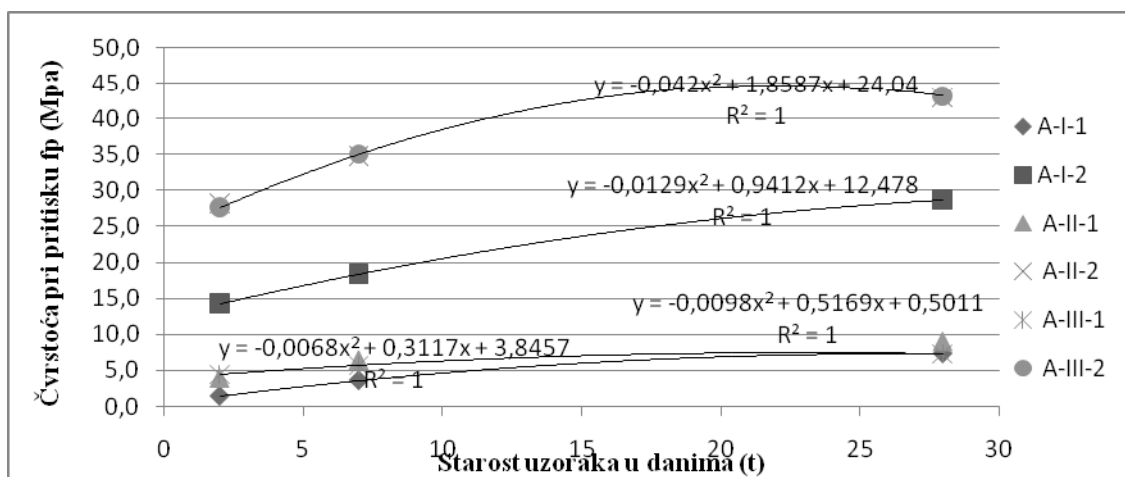
## 5.2 Compressive strength

Due to obtain the functional dependence of  $f_p=f_p(t)$  compressive strength, as the most important mechanical characteristics of cement composites (Figure 6) was tested on the samples of extracted cylinders-cores of Ø 50mm, at the age of 2, 7 and 28 days. The test results of mean values of compressive strength were tabulated (Table 4).

Based on the results shown in the Table 4 it can be concluded that:

- regardless of their composition, the samples of all the series embedded manually (1), have far less compressive strength compared to the samples which were subjected to the process of compaction (2), which is a logical consequence of lower compactness;
- mortar mixtures containing the fibres (II) have a higher strength by about 10% compared to an etalon (I), provided that the gain of strength is more pronounced among "young" composite and is about 30%;
- addition of additives against shrinkage has considerably influenced the decrease of compressive strength, the series III have lower strength of 1.5% compared to the Series II, provided that the compressive strength of series III are greater of the reference mixture (I) for about 8.5%.

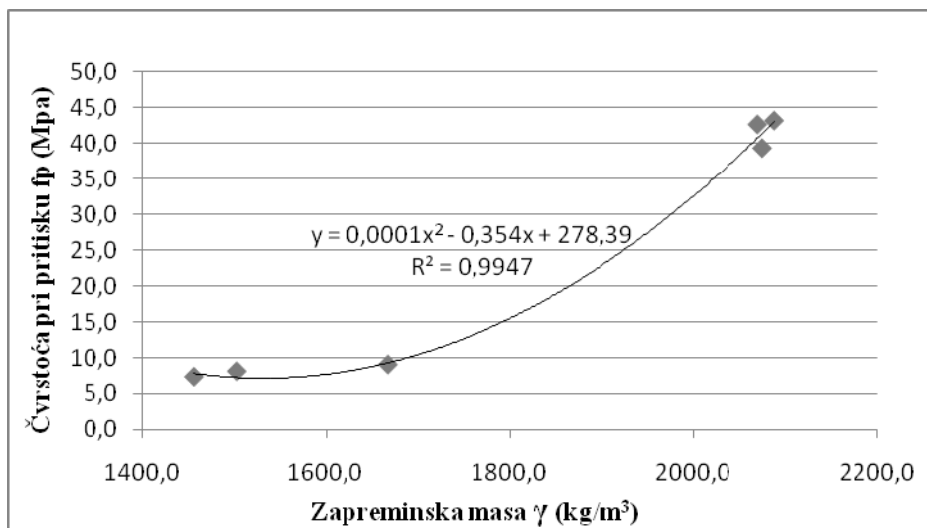
Funkcionalna zavisnost čvrstoće pri pritisku od vremena (Fig. 6).



Slika 6. Funkcionalna zavisnost čvrstoće pri pritisku od vremena  
Figure 6. Functional dependence of compressive strength of time

Čvrstoće pri pritisku u funkcionalnoj su vezi sa zapreminskim masama (slika 7) i one su veće kod uzoraka većih zapreminskih masa (vibrirani uzorci) što dokazuju ispitivanja drugih autora [14].

Compressive strength is in functional correlation with density (Figure 7) and they are higher in samples of larger density (compacted samples) which is proved by testing of other authors [14].



Slika 7. Funkcionalna zavisnost između čvrstoće pri pritisku i zapreminske mase, pri starosti od 28 dana  
Figure 7. Functional dependence between compressive strength and density, at the age of 28 days

### 5.3 Ispitivanje brzine prostiranja ultrazvuka

Nerazorno ispitivanje metodom ultrazvuka ima veoma široku primenu u građevinarstvu i drugim oblastima iz područja tehnike. Ultrazvuk se u praksi koristi kao metoda za određivanje niza svojstava materijala, karakterističnih za cementne košuljice, kao što su: homogenost, detektovanje šupljina i „gnezda” ispod površina, određivanje dubine pukotina, kao i za posredno određivanje zapreminske mase  $\gamma$ , čvrstoće pri pritisku  $f_p$  i dinamičkog modula elastičnosti  $E_D$  betona.

### 5.3 Ultrasonic pulse velocity test

Non-destructive testing method of ultrasound has a very wide application in construction and other fields in technique. In practice, ultrasound is used as a method of determining a range of material properties, typical for cement screeds, such as: homogeneity, detection of voids and "nest" beneath the surface, determining the depth of the cracks, as well as indirect determination of density  $\gamma$ , compressive strength  $f_p$  and dynamic modulus of elasticity  $E_D$  of concrete.

Budući da veličine  $V$ ,  $f_p$  i  $E_D$  stoje u određenoj međuzavisnosti, koja je u najvećoj meri izražena na relaciji zapreminska masa - fizičko mehanička svojstva, metoda ultrazvuka se načelno može primenjivati za određivanje svih svojstava koja su u funkcionalnoj vezi sa zapreminskom masom [14]. Rezultati ispitivanja, dobijeni su u skladu s procedurom opisanom u standardu SRPS.U.M1.042, korišćenjem uređaja *Pundit* (Portable Ultrasonic Non-destructive Digital Indicating Tester), na uzorcima oblika prizme dimenzija 4x4x16 cm.

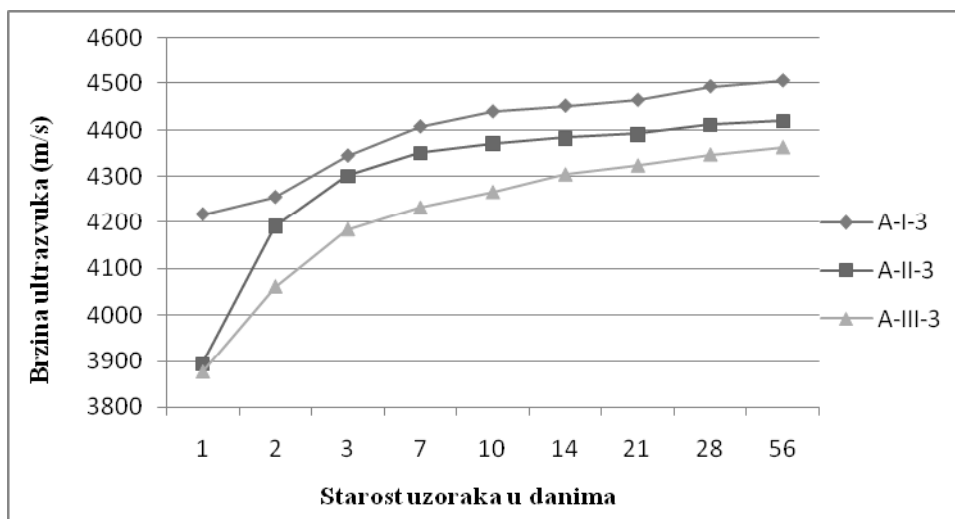
Ako posmatramo rezultate ispitivanja brzine prostiranja ultrazvučnih talasa serija malterskih kompozita, pri različitim starostima, prikazanih u vidu dijagrama (slika 8) možemo uočiti da:

- brzina prolaska ultrazvuka raste s vremenom, što je logična posledica očvršćavanja kompozita;
- vrednosti brzine prolaska ultrazvuka u granicama su od 4300 m/s do 4500 km/s, što karakteriše kvalitet betona (maltera) koji se označava kao *dobar* [5];
- dodaci u vidu mikroarmature i aditiva protiv skupljanja dovode do neznatnog smanjenja (manje od 5%) vrednosti brzine prolaska ultrazvuka.

Due to the value of  $\gamma$ ,  $f_p$  and  $E_D$  stand to a certain interdependence, which is mostly pronounced between the relation of density - the physical and mechanical properties, the method of ultrasound in principle can be applied to determine all of the properties that are in functional relation to the density [14]. The test results were obtained in accordance with the procedure described in the standard SRPS.U.M1.042 using the device "Pundit" (Portable Ultrasonic Non-destructive Digital Indicating Tester), on the samples of prism-shaped dimensions 4x4x16cm.

The results of testing the speed of propagation of ultrasound waves through series of mortar composites at different ages are presented in the form of a diagram (Figure 8). Accordingly, it can be noticed that:

- the speed of passage of the ultrasound increases in time, which is a logical consequence of composite hardening,
- the values of ultrasonic pulse velocity are in the range of 4300 m/s to 4500 km/s, which is characterized by the quality of concrete (mortar), which is referred to as *good* [5],
- the additives in the form of microfibre reinforcement and shrinkage-reducing admixture lead to a slight decrease (less than 5%) of the ultrasonic pulse velocity.



Slika 8. Rezultati ispitivanja brzine prostiranja ultrazvuka  
Figure 8. The results of testing the ultrasonic pulse velocity

#### 5.4 Skupljanje

Na konačne vrednosti skupljanja cementnih košuljica, koje predstavlja reološku deformaciju smanjenja dimenzija maltera u toku vremena bez dejstva spoljašnih sila, utiče veći broj činilaca: temperatura i vlažnost okoline, dimenzije elementa, vrsta i količina cementa, vodocementni faktor, granulometrijski i mineraloški sastav agregata, čvrstoća maltera, način ugradnje i nega i tako dalje. Ovo svojstvo, koje je pre svega povezano sa stanjem vlažnosti cementnog kamena, sastoji se od tri komponente: plastičnog, hidratacionog i hidrauličkog skupljanja [23].

#### 5.4 Shrinkage

Numerous factors, such as: temperature and humidity of the environment, dimensions of the elements, type and quantity of cement, water-cement ratio, size distribution and mineral composition of aggregates, strength of mortar, method of compacting and curing conditions and the like influence the final shrinkage values of cement screed, which represents a rheological deformation, reduction in size of plaster over the time without the action of external forces. This property, which is primarily associated with the state of humidity of cement stone, consists of three components: plastic, hydration and hydraulic shrinkage [23].

S obzirom na to što se uzorci ugrađeni u kalupe, tokom prvih 24 časa nakon spravljanja čuvaju u vlažnom prostoru ( $H > 90\%$ ), a zatim još 48 časova u vodi ( $T = 20 \pm 3^\circ\text{C}$ ), jasno je da se na ovaj način eliminiše uticaj plastičnog skupljanja, koje se javlja u prvih nekoliko časova nakon spravljanja maltera.

Hidrauličko skupljanje javlja se nakon završetka vezivanja cementa, kao posledica isparavanja vode iz kapilarnih pora, zbog čega dolazi do kontrakcije cementnog kamena. Hidrataciono skupljanje nastaje usled odvijanja fizičko-hemijskog procesa hidratacije cementa. Pošto polipropilenska vlakna, koja su u sastavu dve od tri ispitivane mešavine, kao inertan materijal nemaju uticaj na proces hidratacije cementa, ovaj dodatak može da doprinese eventualnom smanjenju isključivo hidrauličke komponente deformacija skupljanja ispitivanih maltera.

Vremenske deformacije skupljanja ispitivane su prema standardu SRPS B.C8.029, na uzorcima izrađenim od cementnog maltera dimenzija  $4 \times 4 \times 16$  cm, sa specijalnim, nerđajućim reperima, pri čemu su uzorci spravljeni u prostoriji u kojoj je temperatura  $20 \pm 3^\circ\text{C}$ , a relativna vlažnost  $55 \pm 5\%$ .

Prvo merenje na uzorcima izvršeno je posle  $72 \pm 0,5$  h (tzv. nulto čitanje), a zatim su merenja sprovedena posle 4, 7, 14, 21, 28, 56 dana i do starosti od oko tri meseca, uz pomoć komparatora na bazi uigibomersata, s podatkom od 0,001mm. Na bazi izmerenih promena dužine merne baze, dilatacije skupljanja su sračunate preko poznatog obrasca:

$$\varepsilon_{sk}(t) = \frac{\Delta l(t)}{l_o} 1000 = \frac{s(3) - s(t)}{l_o} 1000 (\text{‰}) \quad (3)$$

gde upotrebljene oznake predstavljaju:

$\varepsilon_{sk}(t)$  - dilataciju skupljanja pri starosti od  $t$  dana;  
 $\Delta l(t)$  - pramenu dužine merne baze nakon  $t$  dana;  
 $l_o$  - početnu dužinu merene baze, koja iznosi 16 cm;  
 $s(3)$  i  $s(t)$  - čitanja na mernom instrumentu nakon tri dana (nulto čitanje), odnosno nakon  $t$  dana.

Rezultati ukupnog skupljanja svih testiranih malter-skih kompozita u funkciji od vremena prikazani su u vidu tabele (tabela 5) i dijagrama na slici (slika 9).

Na osnovu prikazanih rezultata ispitivanja može se uočiti:

- najmanje skupljanje izraženo je kod malterske mešavine serije III koja u svom sastavu ima polipropilenska vlakna i aditiv protiv skupljanja, za 42,3% u odnosu na etalon I. Uticaj kompenzatora skupljanja, koji deluje sprečavanjem skupljanja okvašenih površina kapilara pri isparavanju vode [3] značajniji je u ovom slučaju od uticaja dodatka mikroarmature;

Given that the samples were embedded in the mold during the first 24 hours after preparation were stored at the wet space ( $H > 90\%$ ), and then another 48 hours in water ( $T = 20 \pm 3^\circ\text{C}$ ), it is clear that the impact of plastic shrinkage that occurs in the first few hours after making the mortar has been eliminated in this way.

Hydraulic shrinkage occurs after the end of the cement bonding as a result of evaporation of water from the capillary pores, which causes contraction of cement stone. Hydration shrinkage is caused by the occurrence of physical and chemical processes of hydration of cement. Since polypropylene fibres, which are composed of two of the three study mixtures, as inert material have no effect on the cement hydration processes; this supplement can contribute to the possible reduction of purely hydraulic components shrinkage of tested mortar.

Testing of timely deformation of shrinkage was done according to the standard of SRPS B.C8.029, on the samples made of cement mortar of dimension  $4 \times 4 \times 16$  cm, with special, stainless benchmarks, with which the preparation of the samples were carried out in a room where the temperature was  $20 \pm 3^\circ\text{C}$ , and a relative humidity  $55 \pm 5\%$ .

The first measurement of the samples was performed after  $72 \pm 0,5$  h (so-called. "zero reading"); then the measurements were taken after 4, 7, 14, 21, 28, 56 days and up to the age of about 3 months, with comparator based on deflection-MERSAT, including the data from 0,001mm. On the basis of the measured change of length of the measuring base, dilatation of shrinkage is calculated through a known equation:

where the used designations represent:

$\varepsilon_{sk}(t)$  - dilatation of shrinkage at the age of  $t$  days,  
 $\Delta l(t)$  - change of length of the measurement base after  $t$  days,  
 $l_o$  - initial length of measured base, which is 16 cm,  
 $s(3)$  i  $s(t)$  - reading on the measuring device after 3 days (zero reading), respectively after  $t$  days.

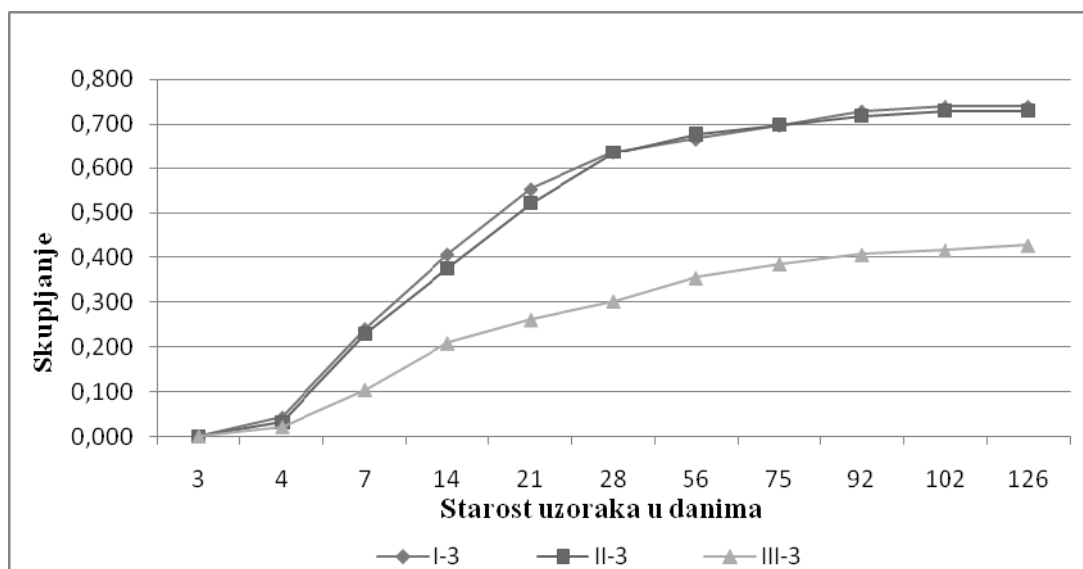
The results of total shrinkage of all tested mortar composites in function of time are shown in the form of table (Table 5 and the diagram (Figure 9).

Based on the shown test results it can be seen that:

- the least shrinkage is expressed in mortar mixtures of series III, which consists of polypropylene fibres and shrinkage-reducing admixture increase of 42.3% compared to reference mixture I. The effect of shrinkage compensators, which acts by preventing shrinkage of wetted surface capillary in water evaporation [3] is more important in this case than the impact of the addition of microfibre reinforcement;

Tabela 5. Rezultati ispitivanja skupljanja, pri različitim starostima  
Table 5. Testing results of shrinkage, at various ages

Starost u danima Age in days	Skupljanje uzoraka $\epsilon_{sk}$ (‰) Shrinkage of samples $\epsilon_{sk}$ (‰)		
	I-3	II-3	III-3
3	0.000	0.000	0.000
4	0.042	0.031	0.021
7	0.240	0.229	0.104
14	0.406	0.375	0.208
21	0.552	0.521	0.260
28	0.635	0.635	0.302
56	0.667	0.677	0.354
75	0.698	0.698	0.385
92	0.729	0.719	0.406
102	0.740	0.729	0.417
126	0.740	0.729	0.427



Slika 9. Skupljanje testiranih serija malterskih mešavina  $\epsilon_{sk}$  (‰)

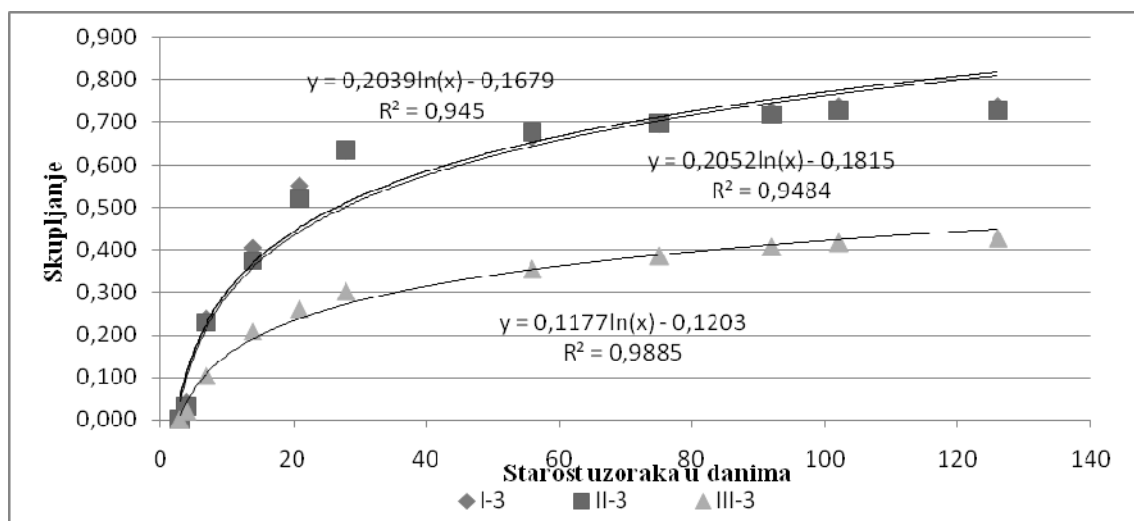
Figure 9. Shrinkage of tested series of mortar mixtures  $\epsilon_{sk}$  (‰)

• rezultati ispitivanja serije II, koja sadrži mikroarmaturu, ukazuju na smanjenje skupljanja od svega 1,5% u odnosu na etalon (serija I), 126-og dana ispitivanja, dok su u ranijim fazama (četvrtog dana) dilatacije skupljanja za 26,2% manje u odnosu na etalon, što se može objasniti činjenicom da su sintetička vlakna veoma efikasna u najranijem periodu, dok je njihov modul elastičnosti manji od modula elastičnosti betona, pa se tako smanjuje pojava prslina i skupljanje prolongira za kasniji period kada je čvrstoća betona veća. Veće hidrauličko skupljanje moglo bi se objasniti upravo zaostalim, prolongiranim skupljanjem iz rane faze očvršćavanja [7].

Funkcionalna zavisnost deformacije skupljanja od vremena za ispitane serije pokazuje jaku korelaciju ( $R^2 > 0,9$ ) za prikazane logaritamske funkcije (slika 10).

• test results of series II, which contains the micro-reinforcement, indicate a decrease in shrinkage of only 1.5% in relation to the etalon (Series I), the 126-th day of testing, while in earlier stages (4-th day) the dilatation shrinkage is 26.2% less in comparison with etalon. It can be explained by the fact that the synthetic fibre is very effective in the earliest stage, while their elastic modulus is lower than the modulus of concrete elasticity, so cracking and shrinkage are prolonged for the subsequent period when the concrete strength is greater. Larger hydraulic shrinkage could be explained exactly by backward, prolonged shrinkage of the early stages of hardening [7].

The functional dependence of deformation shrinkage of the time tested series show a strong correlation ( $R^2 > 0.9$ ) for the displayed logarithmic functions (Figure 10).



Slika 10. Funkcionalna zavisnost skupljanja  $\varepsilon_{sk}$  od vremena

Figure 10. Functional dependence of shrinkage  $\varepsilon_{sk}$  of time

## 6 ZAKLJUČAK

Osnovni cilj ovog istraživanja bio je utvrđivanje uticaja koji primena mikroarmature i aditiva protiv skupljanja, a isto tako i način ugrađivanja, imaju u formiranju kvalitetnih cementnih košuljica. Radi definisanja poboljšanih, optimalnih svojstava estriha, upoređivani su uzorci malterskih kompozicija koje su načinjene na tradicionalan način, bez dodataka, sa uzorcima koji su napravljeni s dodacima mikroarmature i aditiva za smanjivanje skupljanja, ugrađeni ručno i vibriranjem.

Na osnovu svega gore navedenog, može se generalno izvući zaključak da je uticaj načina ugrađivanja od presudnog značaja na ostvarenu strukturu cementnog kamena. S obzirom na to što su sve predmetne mešavine spravljene s niskim vodocementnim faktorom, krute i slaboplastične konzistencije, rezultati ispitivanja zapreminskih masa i čvrstoće pri pritisku nedvosmisleno pokazuju da se samo ugrađivanjem nekim od postupaka vibriranja dobijaju vrednosti ovih svojstava koja garantuju visok kvalitet očvrslog cementnog kompozita, s tim što su koeficijenti konstrukcijske povoljnosti tada nepovoljniji.

Zapreminske mase uzoraka ugrađenih ručno znatno su niže (od  $1400 \text{ kg/m}^3$  do  $1700 \text{ kg/m}^3$ ) od zapreminskih masa uzoraka ugrađenih vibriranjem koje se kreću oko  $2000 \text{ kg/m}^3$ , na osnovu čega zaključujemo da se kod cementnih košuljica koje su ugrađivane ručno i gde nije postignuta zadovoljavajuća kompaktnost, može očekivati niži nominalni kvalitet. Dodavanje mikroarmature i aditiva protiv skupljanja ne utiče značajno na promenu zapreminske mase (najviše 3,6%).

Koeficijent konstrukcijske povoljnosti  $K_{kp}$ , značajan zbog toga što direktno utiče na težinu konstrukcije, povoljniji je kod ručno ugrađenih kompozita u odnosu na mešavine ugrađene vibriranjem i ne menja se značajno dodavanjem vlakana i aditiva.

## 6 CONCLUSION

The main objective of this study was to determine the impact of the application of microfibre reinforcement and shrinkage-reducing admixture, as well as a way of its placement in the formation of high-quality cement screed. The samples of mortar compositions made in the traditional way without additives were compared with the samples made with additions of microfibre reinforcement and shrinkage-reducing admixture placed by hand and by vibration due to define the improved, optimal properties of the screed.

Based on aforementioned, it can be generally concluded that the impact of incorporation procedure is crucial to the achieved structure of cement stone. Given that all the respective mixtures have been made with low water cement ratio, solid and slightly plastic consistency, test results of density and compressive strength clearly show that only incorporation of vibration procedures result in obtaining the value of the properties that guarantee high quality of hardened cement composites, provided that the coefficients of structural favorability are disadvantageous.

Density of the samples placed by hand are much lower ( $1400 \text{ kg/m}^3$  to  $1700 \text{ kg/m}^3$ ) than the density of the samples placed by vibration, which are about  $2000 \text{ kg/m}^3$ . Consequently, it can be concluded that in the cement screed which was placed manually and where there is insufficient compactness lower nominal quality can be expected. Addition of microfibre reinforcement and shrinkage-reducing admixture has insignificant influence on the change of density (uppermost 3.6%).

The coefficient of structural favorability  $K_{kp}$  is significant because it directly affects the weight of the structure; it is more suitable in manually embedded composites compared to the mixtures embedded by vibration and changes insignificantly by adding fibres and additives.



Čvrstoće pri pritisku u funkcionalnoj su vezi sa zapreminskom masom i one su veće kod uzoraka većih zapreminskih masa. Međutim, zapreminsku masu treba posmatrati i kao funkciju stepena zbijenosti mešavina pri ugrađivanju, jer pri istom intenzitetu i trajanju vibracija pri ugrađivanju, pojedine mešavine ostvaruju bolju zbijenost od drugih.

Uticaj polipropilenskih vlakana u malterskim mešavinama na čvrstoću pri pritisku je očekivan, cementni kompozit koji sadrže mikroarmaturu pokazuju porast čvrstoće za oko 10% u odnosu na etalon, pri starosti od 28 dana, a u ranijim fazama ovaj priraštaj ide do 30%.

Dodatak aditiva protiv skupljanja neznatno utiče na pad čvrstoće pri pritisku (svega 1,5%) u odnosu na uzorke napravljene s vlaknima.

Rezultati ispitivanja pokazuju da je uticaj aditiva protiv skupljanja značajniji od uticaja dodatka mikroarmature na skupljanje cementnih kompozita, naime mešavine koje sadrže kompenzator skupljanja pokazuju smanjenje dilatacije skupljanja za 42,3% u odnosu na etalon, dok serije koje sadrže mikroarmaturu imaju manje skupljanje za svega 1,5% u odnosu na etalon 126-og dana ispitivanja. U ranijim fazama ispitivanja dilatacije skupljanja su za 26,2% manje u odnosu na etalon kod serija s vlaknima, što predstavlja doprinos vlakana pri smanjivanju pojave prsline kod „mladih” kompozita.

Iako aditiv protiv skupljanja utiče na izvestan pad čvrstoće pri pritisku, njegov uticaj na smanjenje dilatacije skupljanja je velik, što znači da je upotreba ovog aditiva prilikom spravljanja maltera za cementni estrih opravdana, jednako kao i upotreba polipropilenskih vlakana. Ujedno, osnovni problem nastanka oštećenja i deformacija estriha može se uspešno rešavati samo primenom ugrađivanja, nekom od metoda vibriranja.

## ZAHVALNOST

U radu je prikazan deo istraživanja koje je pomoglo Ministarstvo prosvete, nauke i tehnološkog razvoja Republike Srbije u okviru tehnološkog projekta TR 36017 pod nazivom: „Istraživanje mogućnosti primene otpadnih i recikliranih materijala u betonskim kompozitima, sa ocenom uticaja na životnu sredinu, u cilju promocije održivog građevinarstva u Srbiji”.

Compressive strength is in functional correlation with the density and it is higher in the samples of larger density. However, the density should be viewed as a function of the degree of compactness of the mixture during the application because certain mixtures achieve better compactness than the others at the same intensity and duration of vibrations during its application.

The influence of polypropylene fibres in mortar mixtures at the compressive strength is expected. Cement composites containing microfibre reinforcement show an increase in strength by about 10% compared to reference one, at the age of 28 days, and in earlier stages this increase amounts up to 30%.

The addition of shrinkage-reducing admixture show a slight impact on the decrease of compressive strength (only 1.5%) compared to the samples made with fibre.

Test results show that the effect of shrinkage-reducing admixture is more important than the impact of the addition of microfibre reinforcement on the shrinkage of cement composites. Namely mixtures containing compensators of shrinkage indicate decrease in shrinkage dilatation of 42.3% compared to the reference, while the series containing fibre reinforcement have less shrinkage in only 1.5%, as compared to the reference on the 126-th day of the test. In the earlier stages of testing, dilatation of shrinkages are 26.2% lower than the reference in series with fibre, which is a contribution of fibre in reducing the appearance of cracks in the "young" composites.

Although shrinkage-reducing admixture affects the decrease of compressive strength, its impact on reducing the dilation of shrinkage is large, which justifies the use of the additive when preparing mortar and cement screed, as well as the use of polypropylene fibres. At the same time, the basic problem of damage and deformation occurrence of the screed can be successfully solved only by means of incorporating some of the methods of vibration.

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## REZIME

### SVOJSTVA CEMENTNIH KOŠULJICA S DODATKOM POLIPROPILENSKIH VLAKANA I KOMPENZATORA SKUPLJANJA

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U radu smo ukazali na probleme oštećenja koja se javljaju prilikom izrade i eksploatacije cementnih košuljica, opisali vrste i osnovna svojstva i prikazali rezultate ispitivanja dobijene na uzorcima cementnih kompozita spravljenih s dodatkom mikroarmature i aditiva protiv skupljanja. Pri ispitivanju su praćena sledeća svojstva: zapreminska masa, čvrstoća pri pritisku, ultrazvuk, koeficijent konstrukcijske povoljnosti i skupljanje, a pre svega uticaj načina ugrađivanja na kvalitet cementnih košuljica.

Rezultati eksperimentalnih istraživanja pokazuju da upotreba polipropilenskih vlakana i aditiva protiv skupljanja doprinosi poboljšanju mehaničkih i deformacionih svojstava cementne košuljice, kao i da je način ugradnje nekom od metoda vibriranja presudan za izradu kvalitetnog estriha. Izneti stavovi ujedno predstavljaju preporuke pri izvođenju cementnih košuljica u praksi.

**Ključne reči:** cementna košuljica, mikroarmatura, aditiv protiv skupljanja, način ugrađivanja, čvrstoća pri pritisku, skupljanje, ultrazvuk.

## SUMMARY

### THE PROPERTIES OF THE CEMENT SCREEDS WITH THE ADDITION OF POLYPROPYLENE FIBRES AND THE SHRINKAGE-REDUCING ADMIXTURE

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The paper points out the problems of damage that can occur during the preparation and exploitation of a cement screed. There were described the types and properties and presented test results obtained on the samples of cement composites prepared with the addition of fibre reinforcement and shrinkage-reducing admixture. Testing procedure included the following properties: density, compressive strength, ultrasound, coefficient of construction advantages and shrinking, and above all the impact of compaction procedure on the quality of cement screed.

The testing results of experimental research show that the use of polypropylene fibres and shrinkage-reducing admixture contributes to the improvement of mechanical and deformation properties of cement screeds and that installation which includes some method of vibration is crucial for screed quality. The above statements are also recommendations in the execution of cement screed in practice.

**Key words:** cement screed, microfibre reinforcement, shrinkage-reducing admixture, manner of compacting, compressive strength, shrinkage, ultrasound.