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BUILDING MATERIALS AND STRUCTURES

ČASOPIS ZA ISTRAŽIVANJA U OBLASTI MATERIJALA I KONSTRUKCIJA
JOURNAL FOR RESEARCH OF MATERIALS AND STRUCTURES

DRUŠTVO ZA ISPITIVANJE I ISTRAŽIVANJE MATERIJALA I KONSTRUKCIJA SRBIJE
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❸ Vađenje kernova iz kalupa ❹ Izgled uzorka kernova

COVER: ❶ Embedding the mortar mixtures into molds ❷ Filled molds appearance
❸ Removing core samples from molds ❹ Core samples appearance

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FRACTURE TOUGHNESS OF ULTRA HIGH PERFORMANCE CONCRETE SUBJECTED TO FLEXURE

Emanuela MANOLOVA

ORIGINALNI NAUČNI RAD
ORIGINAL SCIENTIFIC PAPER
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1 INTRODUCTION

Ultra High Performance Concrete (UHPC) is a developing composite material with optimized structure, using industrial waste materials like silica fume, fly ashes, GGBFS and metakaolin, which generates economic benefits and at the same time creates structures, which are more strong, durable and sensitive to environment. Created at the beginning of 1990 in France and Canada, nowadays it is a worldwide material, successfully used in Germany, Denmark, Holland, Great Britain, Japan, Korea, Australia, etc. UHPC represents a new class of cement based materials with compressive strength over 200 MPa, achieved by high quantities of high class of cement, mineral admixture, quartz sand and flour, high class of super plasticizer and incorporation of fibre-reinforcement and thermal treatment. There is no coarse aggregate in the mix composition, because it is the weakest link in the concrete. Introduction of micro steel fibres enhanced deformability of UHPC and thus, flexural strength reaches 50 MPa [1]. At the same time steel fibres overcome the disadvantage of high brittleness and fracture toughness reaches 40 000 J/m^2 [2].

Fracture energy is defined as this energy, necessary for micro-crack formation and at the same time as energy, needed for macro-crack opening. It has an important meaning for UHPC behaviour, compared to other fibre-reinforced composites (FRC). In the literature there are many parameters defining the ductile behaviour of FRC [3; 4; 5]. It is represented by 'fracture toughness', 'fracture energy', 'energy absorption', 'characteristic length', 'ductile length' and 'crack- formation energy', but all these terms have a different physical meaning and dimension. No matter it has a great significance in structures and up to now this kind of research is limited in the world literature [6].

2 METHODOLOGY OF THE EXPERIMENT

2.1 Composition of UHPC

The matrix of UHPC is optimized by carrying out a Mathematically Planned Experiment, presented in details in a previous investigation [7]. The optimal mix is characterized by fine sand (Dmax=0,5 mm), high quantity of cement (more than 900 kg/m^3), high quantity of mineral additive (silica fume – 30% of the mass of cement) and very low water-cement ratio (0,22). A quartz powder is used to obtain a maximum density of the skeleton of granular materials. High quantity of polycarboxylate chemical admixture is used (3,5% of the mass of cement) to achieved a workable mix, with exact plasticity.

Two types of steel fibre-reinforcement are applied ("short" and "long") with different ratio (length L and diameter D) in three variations, totally used in 2% by volume – Table1.

Test samples are prisms with sizes 4x4x16cm. Demolded after 24 hours, they stay in mois t conditions until they are tested in flexure.

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Table 1. Different types of UHPC mixes, acc. to fibre-reinforcement

Signature	Matrix	Short Fibres	Long Fibres	Short And Long Fibres
L=6mm D=0.175mm	-	2.0%V	-	1.0%V
L=13mm D=0.2mm	-	-	2.0%V	1.0%V

2.2 Apparatus

There is no standard methodology for testing UHPC in flexure. Based on the detail literature, outlook are adapted using several standard methods for testing fibre-reinforcement concrete [4, 8, 9, 10].

Flexural behaviour of UHPC is made by simultaneously measuring the vertical deflection and longitudinal deformation in the tensile zone. Test loading is applied with constant speed of deformation, which is prescribed by the standards for fibre-reinforced cementitious composites in flexure. Due to these regulations, loading could be precisely applied, especially in the area of the diagram presenting the residual strength of the post-peak part, which eliminates the imperfections due to crack-formation and large displacements. Testing speed is an essential item – it should be adapted to the sample, in a way that stresses should be redistributed between different components and this effect is successfully noted on the working diagram. Static scheme, which is used for this test is a three-point bending, with one force concentrated in the middle of the span distance (10cm). Samples are directly tested without notching.

This experiment is made by compression testing machine type ShimadzuAG-50kNXplus (Figure 1-a). In standard ASTM C/1609 [10] testing speed is limited due to the size of the sample in accordance with the span distance. In our case test samples are even smaller than the smallest mention in the standard (350/100/100 mm); therefore, the minimum required testing speed - 50 μm/min was used. *TrapeziumX* Software of the compression testing machine simultaneously detects the loading *F* [N] and vertical deflection Δ [mm] of the machine. In fact, there is a difference between the detected displacement Δ [mm] and deflection of the sample δ [mm], due to the reaction of the machine i.e. due to the deformation of its components. In this case, its own deformation is around 0.15-0.25 mm and could be neglected, especially when samples are tested with similar stiffness. Therefore, it is assumed that diagram „F-Δ“ coincides with **„**F- δ**“.**

By measuring the longitudinal deformation „ε" in tensile zone the moment of cracking could be identified, and therefore the influence of fibre-reinforcement has been estimated. An electrical-resistant gauge *KYOWA* (KFG-5-120-C1-11L1MR) - fig.1-b was used during the experiment, wherein the electrical signal, caused by the change of the resistance of the gauge (following the deformation of the substrate), was converted into relative longitudinal deformation by the specific constant of the gauge.

2.3 Fracture toughness

For determination of the fracture toughness G_f, [*N.mm*] of UHPC an adapted methodology was used, based on the standards ASTM C 1609/C [10] and ASTM 1018-97 [8], using obtained working flexural diagrams „F-δ" and "F-ε". Fracture toughness G_f is calculated, according to the deflection δ, formed at the so called 'first crack' in the diagram 'load-deflection' („F-δ").

a) Compressive machine with constant speed of vertical deflection

b) Electrical-resistant gauge for measuring the deformation in the tensile zone

Figure 1. Apparatus

ASTM standards give a numerical method for determination of the deflection δ in FRC, but it cannot be applied in the case of UHPC, due to much bigger deformations (more than 10 times), compared to ordinary FRC. According to the standard ASTM 1609/C 1609M-10, first crack appears in the interval from 0 to L/600 (L is the span distance). In the case of UHPC - it means L/600=0,16666mm. Experimental results give a defection δ in the range of 0.40-0.50mm (Figure 2). Therefore, an analysis of the recorded diagrams „*F-δ*" and *"F-ε"* has been made for each sample due to estimate an exact moment of the first crack formation. A visible leap could be seen in both diagrams due to the formation of the first crack – in the diagram „*F-δ*" it is next to the long linear area, while in the diagram *"F-ε"* the inclination is changing visually.

Then, according to the prescriptions of ASTM C 1018-97, the so called 'characteristic points' of the deflection are calculated based on the diagram „*F-δ*", as a function of the deflection *δ,* obtained by the first crack. These characteristic points correspond to deflection 3.*δ* and *5,5.δ* – Figure 3.

Fracture toughness *Gf*, expressed in N.mm, is calculated as the area under the diagram, up to each one of the characteristic points of the diagram, i.e. as the energy needed for the first crack (G_f=A(δ)), the energy up to deflection 3.δ ((G_f =A(3.δ)) and the energy of deflection equal to 5,5.δ ((G_f=A(5,5. δ)). These values of the fracture toughness (the areas) are used for determination of the toughness indexes (I_5 and I_{10}) and the residual strength factor $R_{5,10}$.

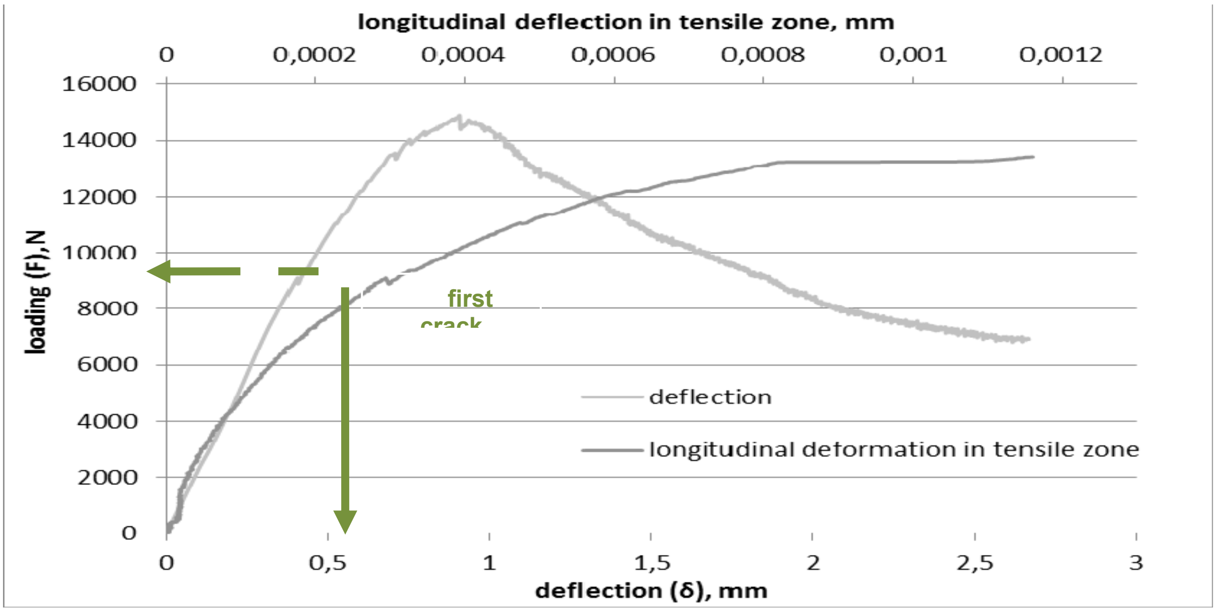

Figure 2. Working diagrams in flexure „F-δ" and "F-ε"

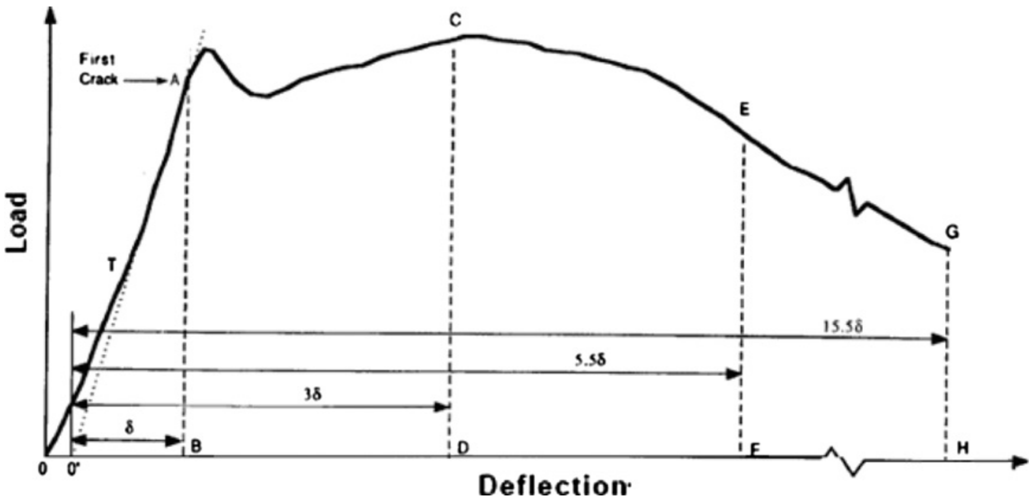

Figure 3. Important characteristics of the 'Load-Deflection' curve, according to ASTM C 1018-97 [8]

Using 1-2% of volume steel fibres in UHPC does not form a large area of residual strength. This effect is more visible by increasing quantity of fibres more than 10% [5]. In this case it is possible to obtain a material with elastic-plastic behaviour and both factors of the residual strength $R_{5,10}$ and $R_{10,20}$ will exceed 100. However, in UHPC, the most frequent amount of used fibres is 2%, which makes factor $R_{5,10}$ mostly reliable.

Each composition was tested by three samples (prisms 4/4/16cm). Diagrams are analysed by selection of the most representative for each composition – for example, in the case where one of the diagrams sharply differs from the other two, it is eliminated from the analysis. Also, the results are eliminated, due to random factors, such as defects in the matrix or other inhomogeneity.

3 ANALYSIS OF THE RESULTS

The results of the calculated fracture toughness, based on the method ASTMC1018-97, according to the vertical deflection, are shown in Figure 4.

Values of the fracture toughness (G_f) confirmed the assumption that short steel fibres contribute to a great extent (based on the large number per unit volume) for matrix unloading, so the first crack appears at higher level of loading, compared to composites with long steel fibres. Obtained values of (G_f) at first crack, i.e. G_f *(δ)* in composites with short steel reinforcement, are more than 50% higher than in the same composites with long steel reinforcement.

G_f *(3δ)* represents the behaviour of the strain-hardening zone, plasticizing and even in the case of partial loss of strength, i.e. G_f *(3δ)* is a general characteristic, which unites the differential effect of fibres (long and short) in different zones. For that reason, G_f *(3δ)* has approximately identical value in compositions with short and long steel fibres. According to ASTMC1018-97, obtained deformation of *3δ* in ordinary fibre-reinforced composites, defines the zone of plasticity. In UHPC, even using long steel fibres, it is situated in the post-peak part of the curve – zone of the residual strength. Therefore it is not an appropriated characteristic for determination of UHPC behaviour with 2% of volume fibres.

In a greater extend G_f *(5,5δ)* represents the fibre contribution into prevention of sudden destruction and expectedly it has a 30% higher value in compositions with long steel fibres. Compositions with hybrid steel fibre-reinforcement (short and long) have much lower values of fracture toughness, but it also has a tendency to increase with large quantities of long steel fibres.

However, three calculated values of the fracture toughness indicate that the combination of short and long fibres has a synergetic effect – this combination needed more energy both for the occurrence of the first crack G_f *(δ)* and the strain-hardening and plasticizing of material G_f *(3δ)* as well as for its peak destruction.

The short fibre-reinforcement increases the matrix crack resistance – they bridge the micro-cracks only during strain localization, so fails to influence much the post-peak part of the load-deflection curve. First crack occurs in larger deformation, which reflects higher value of G_f *(δ)* – Figure 5. Subsequently, using long steel fibres expectedly have a greater contribution to strain-hardening behaviour and obtained hardening. Bearing capacity of the composite increases with large plastic deformation formations, compared to composites only with short steel fibres. The long steel fibres provide bridging stresses across the crack, which is a result of coalesce of micro-cracks. Thus, the fracture toughness defined to a certain deformation of G_f *(3δ)* covers mostly the residual strength of the post-peak part of the curve

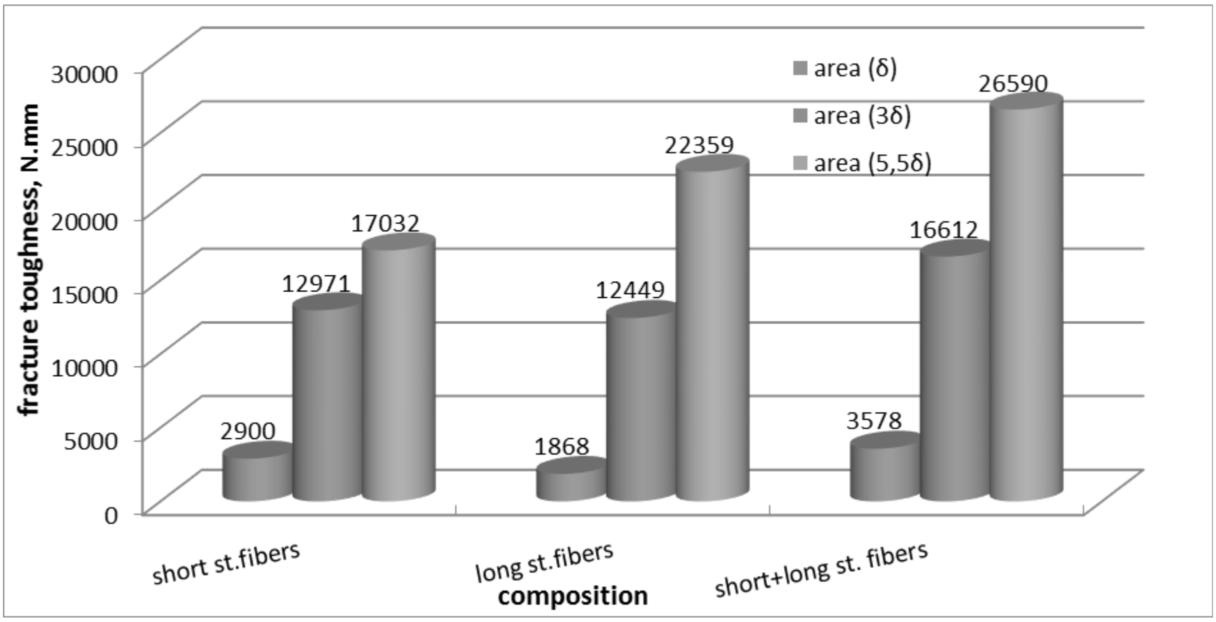

Figure 4. Influence of the type of fibre-reinforcement on fracture toughness of UHPC, according to ASTMC1018-97

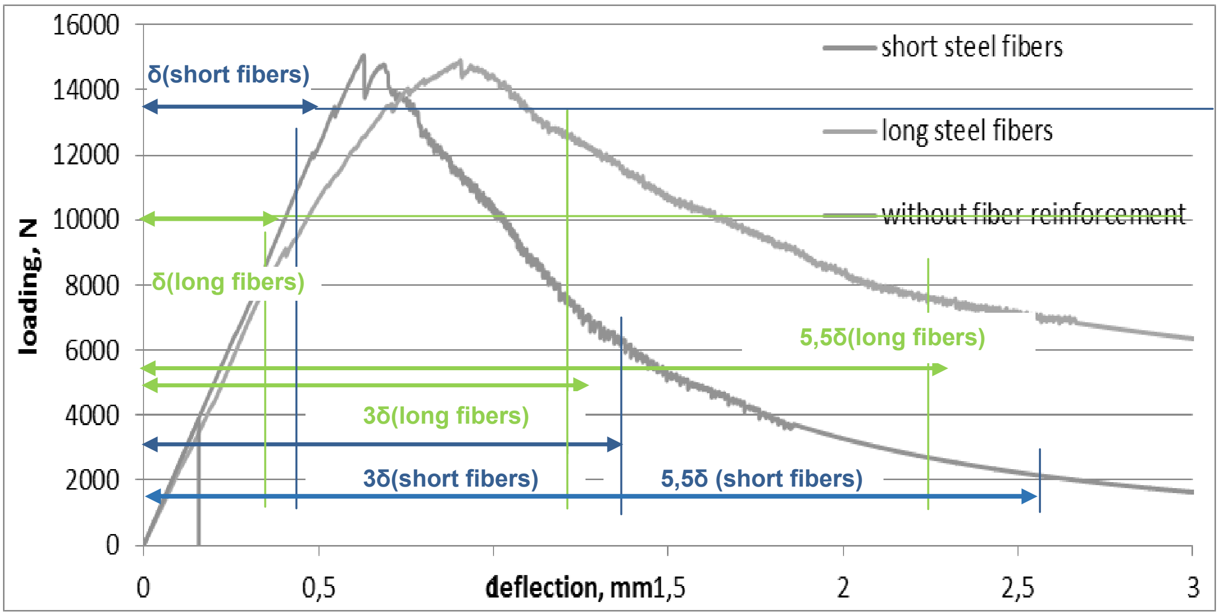

Figure 5. Main characteristics of the working diagram 'load-deflection' of UHPC with short and long steel fibres, according to ASTMC1018-97

Toughness indexes, according to ASTMC1018-97, represent the behaviour of FRC, mostly with elastic-plastic behaviour. Obtained results confirm the conclusions that long steel fibres have a significant contribution to ductile behaviour of UHPC.

Both indexes I_5 and I_{10} are substantially higher. However, the fact that I_5 exceeds 5 and I_{10} has a value over 10, for compositions with long steel fibres, indicates the strain-hardening zone of UHPC, which distinguishes their behaviour from ideal elastic-plastic materials, with defined maximum values of I_5=5 and I_{10} =10 (Figure 6).

Index I_{10} usually matches the contribution of the zone of plastic deformations and its values are from 1 to 10: one is a fully brittle behaviour and 10 correspond to plastic behaviour. In compositions with long fibres this index is equal to 12, although it is mainly due to strain-hardening it means that larger plastic deformations are formed in total. Exceeding the upper limit of ideal elastic-plastic behaviour also occurs in literature [6].

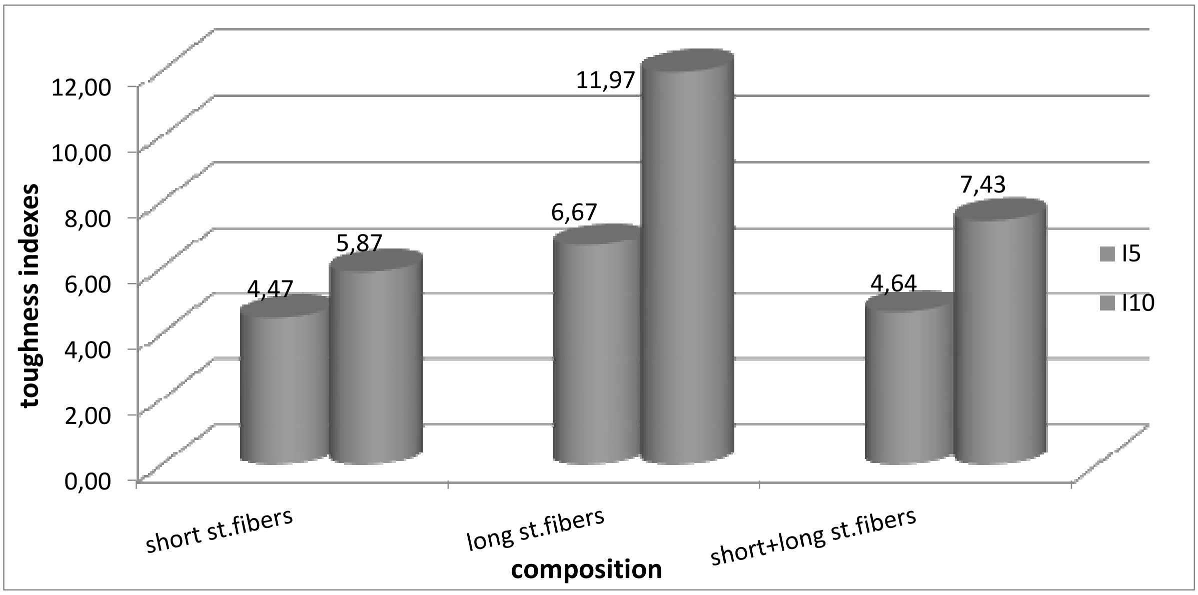

Figure 6. Influence of the type of fibre-reinforcement on toughness indexes of UHPC, according to ASTMC1018-97

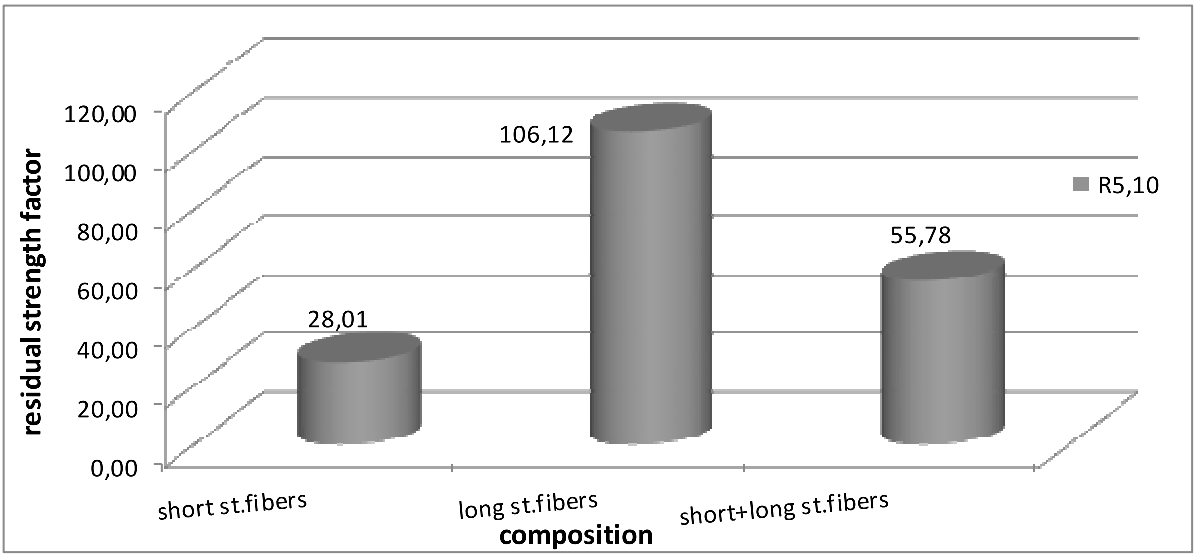

Figure 7. Influence of the type of fibre-reinforcement on residual strength factor of UHPC, according to ASTMC1018-97

Residual strength factor $R_{5,10}$ indicates how fast the strength could be lost, after the maximum force is reached – higher values indicate more ductile behaviour – gradually strength loss, accompanied by plastic deformation formations – in the case of UHPC with intensive micro-cracking, dissolving cracks and extraction of fibres – i.e. dissipation of energy.

It turns out that UHPC behaviour, reinforced with long steel fibres, is closer to ductile (Figure 7). $R_{5,10}$ exceeds 100, which indicates that the material is not ideal elastic-plastic, but it has a "reserve strength" due to the large strain-hardening zone.

Residual strength factor of the composition with short steel fibres is significantly lower ($R_{5,10}$ =28). It means that such kind of composition should not be used for elements, working in seismic areas. Composition with short and long fibres has an intermediate value of $R_{5,10}$ (55,78),i.e.no synergetic effect on residual strength is observed.

4 CONCLUSIONS

Fracture toughness and concrete strength are two primary mechanical characteristics that need to be carefully considered in structural design solutions. Toughness indexes are used to evaluate the capability of structural materials to bear loads with formation of cracks, absorb energy during deformation and carry large deformations with enough residual strength. Fracture toughness has become one of the most important parameters in UHPC, in a way that high strength is always related to high brittleness. Calculation fracture toughness, based on both diagrams in flexure („*F-δ*" and '*F-ε*), could estimate the influence of different type of fibre reinforcement on various parameters of UHPC behaviour – using short steel fibres leads to increasing crack-resistance, but long steel fibres have bigger effect on strain-hardening and ductility of UHPC. Synergy effect is established by using combination of both types of fibres – more energy is necessary for first crack formation and strain-hardening and subsequently plasticizing, due to intensive cracking.

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SUMMARY

FRACTURE TOUGHNESS OF ULTRA HIGH PERFORMANCE CONCRETE BY FLEXURAL PERFORMANCE

Emanuela MANOLOVA

This paper describes the fracture toughness of the innovative structural material – Ultra High Performance Concrete (UHPC), evaluated by flexural performance. For determination the material behaviour by static loading are used adapted standard test methods for flexural performance of fiber-reinforced concrete (ASTM C 1609 and ASTM C 1018). Fracture toughness is estimated by various deformation parameters derived from the load-deflection curve, obtained by testing simple supported beam under third-point loading, using servo-controlled testing system. This method is used to be estimated the contribution of the embedded fiber-reinforcement into improvement of the fractural behaviour of UHPC by changing the crack-resistant capacity, fracture toughness and energy absorption capacity with various mechanisms. The position of the first crack has been formulated based on *P-δ* (load-deflection) response and *P*-ε (load – longitudinal deformation in the tensile zone) response, which are used for calculation of the two toughness indices I_5 and I_{10}. The combination of steel fibres with different dimensions leads to a composite, having at the same time increased crack resistance, first crack formation, ductility and post-peak residual strength.

Key words: Ultra High Performance Concrete, Fracture Toughness, Flexural Behaviour, Impact test, Energy absorption

REZIME

ŽILAVOST PRI LOMU BETONA SA ULTRA-VISOKIM PERFORMANSAMA SA ASPEKTAPONAŠANJA PRI SAVIJANJU

Emanuela MANOLOVA

U okviru rada analizirana je žilavost pri lomu inovativnog konstrukcijskog materijala-betona sa ultra-visokim performansama (UHPC), procenjena s aspekta njegovog ponašanja pri savijanju. Za određivanje ponašanja materijala pod statičkim opterećenjem, upotrebljene su prilagođene standardne metode za ispitivanje ponašanja pri savijanju betona armiranog vlaknima (ASTM C 1609 i ASTM C 1018). Žilavost pri lomu je procenjena na osnovu vrednosti deformacija preuzetih sa dijagrama opterećenje-ugibdobijenog pri ispitivanju slobodno oslonjene grede pod dejstvom opterećenja u sredini raspona, upotrebom servo-kontrolisanog mehanizma. Ova metoda se koristi u cilju procene doprinosa ugrađenih vlakana ponašanju pri lomu UHPC, promenom kapaciteta otpornosti na pojavu prve pukotinem žilavosti pri lomu i sposobnosti absorpcije energije. Položaj prve pukotine je formulisan na osnovu odgovora P-δ (opterećenje-ugib)i P-ε (opterećenje-podužna deformacija u zateznoj zoni), koji su upotrebljeni pri proračunu dva indeksa žilavosti - I_5i I_{10}. Kombinovanje čeličnih vlakana različitih dimenzija daje kompozit koji istovremeno poseduje povećanu otpornost na pojavu pukotine i razvoj prve pukotine, duktilnost i zaostale čvrstoće nakon dostizanja maksimalne čvrstoće.

Ključne reči: beton sa ultra-visokim performansama, žilavost pri lomu, ispitivanje otpornosti na udar, ponašanje pri savijanju, absorpcija energije

PROBLEMS OF LAMELLA FLANGES IN STEEL BRIDGE CONSTRUCTION

Vladimír KŘÍSTEK
Miroslav ŠKALOUD
Shota URUSHADZE
Jaromír KUNRT

ORIGINALNI NAUČNI RAD
ORIGINAL SCIENTIFIC PAPER
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INTRODUCTION

Lamella flanges (see Fig.1) have lately grown popular with the designers of steel bridges, because – in their belief - they provide us with the possibility of avoiding very thick flange plates in steel bridge structures. This belief is based on the assumption that the lamellas are perfectly plane and, therefore, in perfect contact everywhere, so that the loading from one lamella is transmitted into the other via pure compression, and that the perfect interaction of both lamellas is materialized by means of boundary fillet welds connecting both of the two lamellas. This simple assumption is, however, far from reality: it is not in the means of steel fabricators, not even in the means of those who are very progressively equipped, to produce perfectly plane flange lamellas. Then both lamellas exhibit unavoidable initial curvatures which in combination form a gap between the lamellas and consequently the directly loaded lamella is pressed into this gap. As the loading acting on every bridge is many times repeated, the aforesaid phenomenon is also many times repeated, (we can say that the lamellas „breathe“), and then it can be expected that an unavoidable cumulative damage process in the lamellas comes to being. And this phenomenon was really observed by the authors during their activities related to a new bridge structure in the neighbourhood of Prague (Fig. 1) and immediately reminded them of a similar "breathing" phenomenon which the second of them had for several years been studying for slender plate girder webs; some of the results obtained and conclusions drawn being described in [1]

The authors then studied the phenomenon of lamella "breathing" using several methods; the most important among them was an experimental investigation carried out on models simulating the situation encountered in the lamella flanges of the real bridge in the neighbourhood of Prague and already mentioned hereabove.

Figure 1. A lamella flange in composite action with a concrete slab

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EXPERIMENTAL INVESTIGATION

The aim of this investigation was to examine whether, due to the breathing of the lamellas, significant cumulative damage was generated such as to endanger the whole structural system.

The corresponding test specimens were materialised as a transverse cut-out from the lamella flange of the bridge mentioned above, the width of the specimen being 250 mm, and the specimen acting compositely with a concrete slab (this again being compatible with the situation in the bridge concerned). The whole model was tested in the upside-down position, so that the plate elements of the lamella flange were above the concrete slab. The top plate element was repeatedly loaded by a force modelling the reactions of the inclined webs in the system of the whole box girder. The related test set-up is shown in Figs. 2 and 3.

The second experiment already had quantitative objectives and was tailored to the real situation in an ordinary structural lamella system. That is why the gap between the lamella plates was chosen much smaller (as 5.5 mm), with the view to reflect a possible combination of manufacturing tolerances of lamella plates in question.

The loading of the test specimen was carried out by means of an equipment GTM Type AH 500-150 M 161, having a loading capacity, both for static and dynamic testing, up to 500 kN.

The position of the load is shown in Fig.4, the eccentric location of force *F* corresponding to the real position of the webs in the system of the bridge box girder. For deflection measurements, a potentiometer Megatron type CR 18 25 k was used. The applied load was continuously monitored and recorded by a dynamometer Type Series to the GTM with a capacity of 500 kN and a sensitivity of 1mV/V.

Fig. 2. The test set-up used

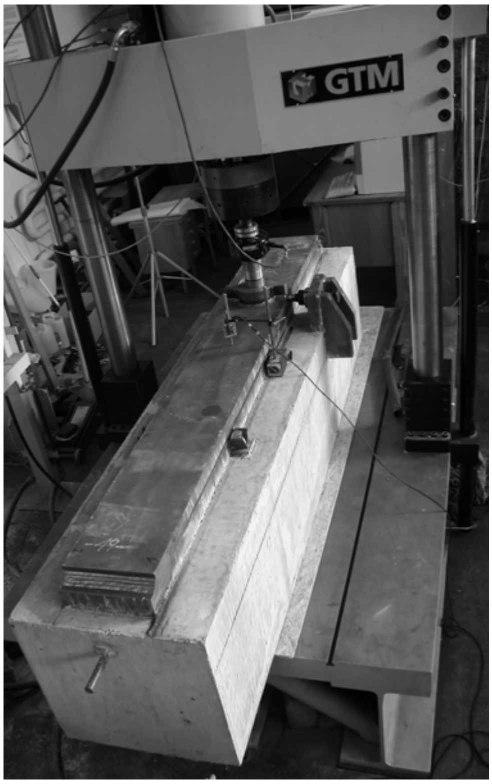

Fig. 3. The test set-up seen from above

In the course of the investigation, two models were tested, and therefore two tests carried out. The first of them started with a static, one-cycle loading experiment (which also provided the authors with useful information), and then was continued by a typical cyclic loading test, during which the model was subjected to many times repeated cycles of loading. The objective of this repeated loading test, which played the role of a pilot test for the whole examination, was to prove that the phenomenon of lamella breathing could significantly affect the performance of a lamella flange system. Therefore the gap between the two lamella plates in this first test was chosen large, namely as 12mm.

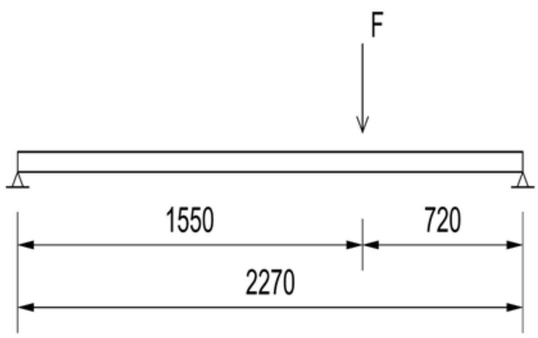

Figure 4. The position of load F in the test set-up

Some interesting results were already obtained by the static test of the first model, where the edges of the lamella plates, exhibiting geometric imperfections, are connected together by boundary fillet welds; the entire system behaving as a spatial one. The top part of the curve given in Fig. 5 shows an increase in the loading force in dependence on the deflection (i.e. on the changes in the distance between the two lamella plates). However, it should be noted at this junctures that, if the lamella plates were performing as simple beams, the system would be substantially softer - as is demonstrated by the lower curve in Fig. 5.

The upper curve in Fig. 5 increases more slowly for higher values of deflection than at the beginning of the loading. This phenomenon, if it is caused by material nonlinearity, could fatally affect the fatigue response of the system affected by the cyclic loading.

The results of the static test were used to determine the maximum amplitude to be safely applied during the cyclic loading (i.e. fatigue) experiment. A sinusoidal frequency of 2 Hz was used, and the cyclic loading was continued until the fatigue crack, generated by the cumulative damage process induced by the repeated loading, reached the whole length of the weld connecting both of the two lamellas.

The welds of the first model cracked completely after 129 353 loading cycles only, i.e. already after a few hours of testing. The crack can be seen in Fig.6. The importance of a real danger of flange lamella breathing and of its impact on the limit state of the whole bridge structure was hence already demonstrated by this pilot test.

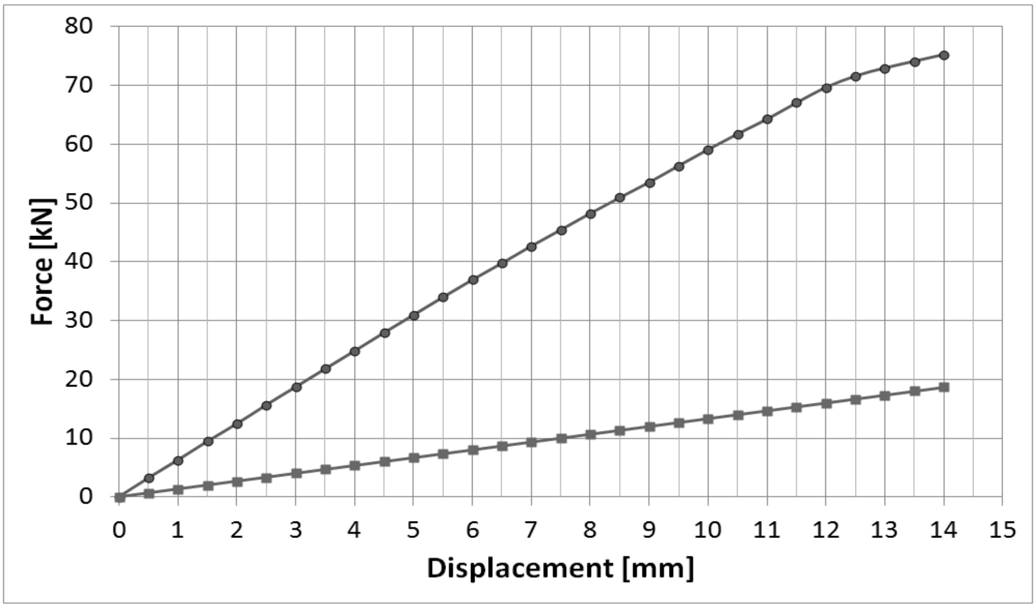

Figure 5. The results of the static test of the first model

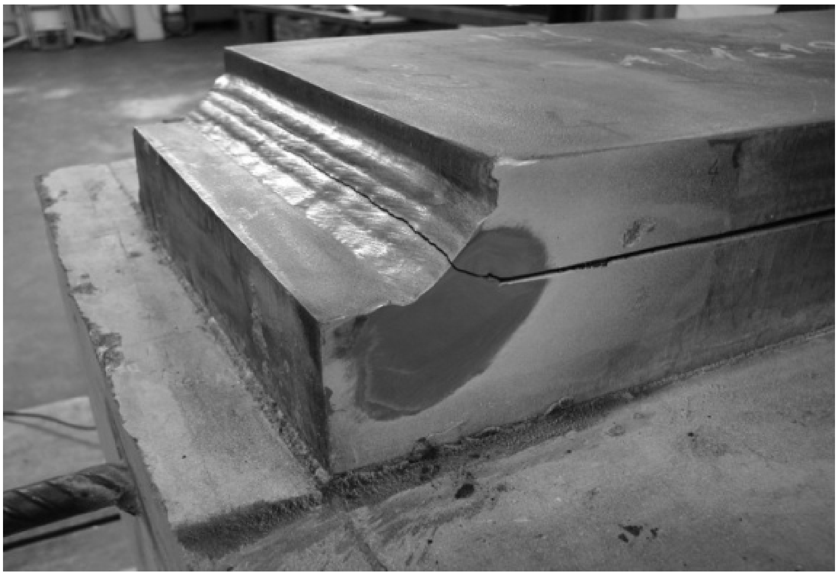

Figure 6. The fatigue crack in the first model after 129 353 loading cycles

Of course, the results of, and the conclusions drawn from, the second test (where the gap between the flange lamellas realistically depicts the situation occurring in ordinary lamella flanges currently used in steel bridge construction) appear to be of a much greater practical importance. There the fatigue crack in the fillet weld initiated at 578 558 loading cycles, then propagated under further repeated loading (Fig. 7), and covered the whole length of the weld (and heralded a complete failure of this weld) after 1 256 293 loading cycles.

CONCLUSION

The experiments carried out by the authors showed that the performance of lamella flanges at their limit state is significantly influenced by a phenomenon which, in the currently-held design concept, has not to date been taken into account. The plate elements of ordinary lamella flanges always exhibit geometrical imperfections, therefore a gap between them always occurs, into which the loaded plate element is pressed under load. This phenomenon is similar to the "breathing" of slender webs, and hence can be called lamella flange "breathing". It is in the nature of this phenomenon, as is the case with "breathing" of slender webs mentioned above (see also [1, 2]), that under many times repeated loads this phenomenon generates a pronounced cumulative damage process and leads, as it became manifest during the writers´ tests, to the initiation and propagation of fatigue cracks in the boundary longitudinal fillet welds connecting the individual lamellas. This, of course, can imperil the safety and useful lifetime of the bridge structure in question, and is of particular significance in the case of important bridges, frequently subjected every day to tens of thousands of loading cycles.

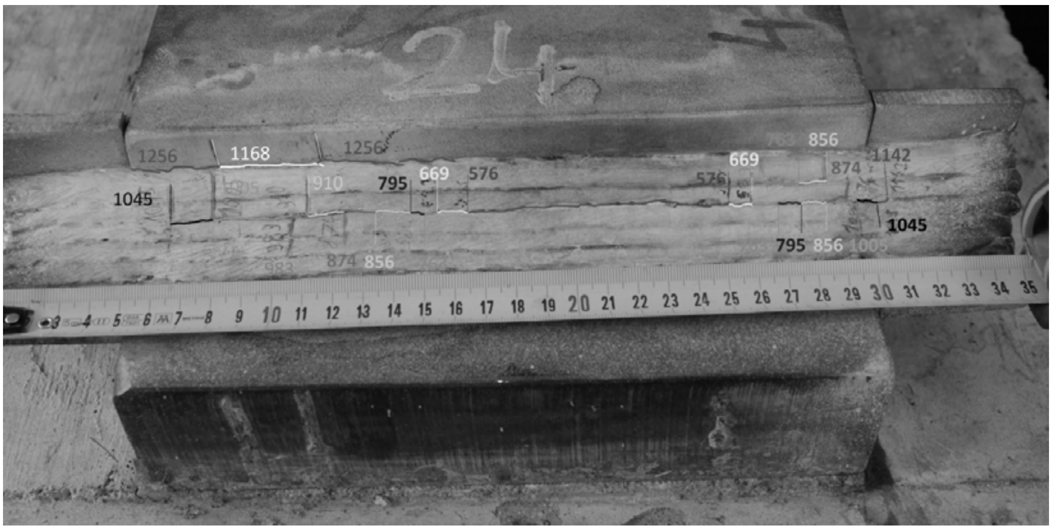

Figure 7. The fatigue crack propagation in the second model

Acknowledgements

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SUMMARY

PROBLEMS OF LAMELLA FLANGES IN STEEL BRIDGE CONSTRUCTION

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Shota URUSHADZE
Jaromír KUNRT

As the plate elements of ordinary lamella flanges always exhibit unavoidable initial geometrical imperfections, a gap always occurs between them, into which the loaded lamella is pressed under load. Given the fact that the loading is many times repeated, the above phenomenon is also many times repeated, a pronounced cumulative damage process being thereby generated. As it was manifested during the authors´ tests, this leads to the initiation and propagation of fatigue cracks in the longitudinal fillet welds connecting the individual lamellas, which can, of course, imperil the safety and useful lifetime of the bridge structure concerned.

Key words: bridges, lamella flanges, repeated loading, breathing, limit states

REZIME

PROBLEMI POJASNIH LAMELA U GRAĐENJU ČELIČNIH MOSTOVA

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Pločasti elementi kod uobičajenih pojasnih lamela uvek su praćene neizbežnim početnim geometrijskim imperfekcijama. Zbog toga se između njih formira slobodan prostor i u njima je pod opterećenjem lamela je pritisnuta. S obzirom da se zadato opterećenje više puta ponavlja, gore opisani fenomen se više puta ponavlja, a na taj način se proces kumulativnog oštećenja izaziva. To se manifestovalo tokom izvedenog našeg ispitivanja, ovo opterećenje izaziva formiranje i propagaciju prslina usled zamora u šava, trouglastog poprečnog preseka, u podužnom prvcu kojim su spojene susedne lamele. Opisano, naravno, ugrožava sigurnost i eksploatacioni vek razmatrane mostovske konstrukcije.

Ključne reči: mostovi, pojasna lamele - flanše, ponovljeno opterećenje, disanje, granično stanje

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

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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 energetsku 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, visokoregalnih 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 prslina. 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.

Izravnjajuće 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 kg/m^3 do 2100 kg/m^3. Kod estriha koji imaju veće klase čvrstoće, zapreminska masa je veća i iznosi oko 2300 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 (helikopterkom) 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 J/kgK^o.

Koeficijent toplotne provodljivosti λ, koji predstavlja sposobnost materijala da kroz svoju masu prenese toplotu, kao posledicu razlike u temperaturi između njegovih dveju površina, za cementni estrih iznosi oko λ=1,4W/mK^o [10].

Termički koeficijent linearnog širenja α_t za cementni estrih iznosi α_t = 10-12x10^{-6} (1/^{o}C) i predstavlja dilataciju pri promeni temperature za 1^{o}C. U slučaju cementnog estriha može se reći da je termička stabilnost veća ukoliko je košuljica homogenija i kompaktnija, odnosno ako je termički koeficijent α_t manji.

Faktor otpora difuziji vodene pare μ jeste otpor koji građevinski element pruža vodenoj pari i čija vrednost predstavlja gustinu materijala u poređenju s vazduhom za koji taj koeficijent iznosi μ=1. Faktor otpora difuziji vodene pare kod skoro svih cementnih kompozicija može se uzeti da je μ =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 0,5-1,0 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 kg/m^3 to 2100 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 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 J/kgK^o.

The thermal conductivity coefficient λ, 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 λ=1,4W/mK^o [10].

The thermal coefficiet of linear expansion α_t for cement screed is α_t = 10-12x10^{-6} (1/^{o}C) and represents a dilatation in temperature change about 1^{o}C. In the case of cement screed thermal stability is higher when the screed is more hemogenous and more compact, respectively when the thermal coefficient α_t is lower.

Diffusion resistance of water vapour μ 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 μ = 1st Resistance factor to diffusion of water vapour in almost all cement composition should be μ =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 0.5-1.0 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 ± 15mm. 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 (Hr=65%, T=20± 3 ^{o}C).

permitted tolerance is ± 15mm. 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 (Hr=65% T=20 ± 3°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 zapreminske 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

Serija 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
Serija I Series I	479,5	1438,5	182	/	/	2100	0,38	3
Serija II Series II	502	1506	191	1,0	/	2200	0,38	3
Serija 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 dodataka 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 γsc=3100 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 γ_{sc}=3100kg/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 γ_{sa}=2600 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 atheziji 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 do1000 g/m^3 maltera (tabela 2).

is a natural sand "Moravac" of fraction 0/4mm, which was previously tested in the laboratory of the specific mass γ_{sa}=2600kg / 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^3 mortar were used (Table 2).

Tabela 2. Osnovna svojstva polipropilenskih vlakana SIKA FIBER deklarisana 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
Specifičn a masa γ Specific mass γ	0,9 g/cm^3
Broj vlakana Number of fibres	120 miliona/kg 120 millions/kg
Dužina Length	12 mm
Preč nik 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 ^oC
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^2/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^2/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/m³ 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.

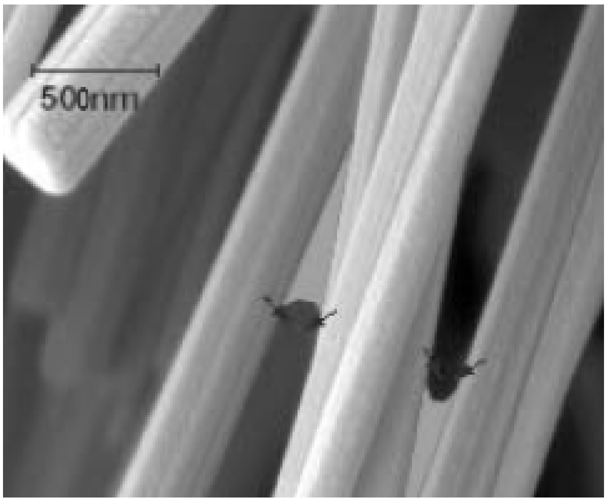
U eksperimentalnim istraživanjima korišćen je aditiv protiv skupljanja Sika Control - 40, proizvođača „Sika” Švajcarska, doziran u količini od 2% od mase cementa.

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 / m³ 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)

Figure 3. Schematic view of the shrinkage-reducing admixture (source: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 sprovodeno 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 konretnom slučaju imaju ili oblik cilindra Ø50 mm ili prizme 4x4x16 cm, uz pomoć poznatog obrasca:

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:

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

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

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 $\boldsymbol{\gamma}$ (t/m^3) (Table 3).

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

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 $\gamma_{,2}$ Density $\gamma_{,2}$ (kg/m³)	$K_{kp,2}$ (MPam³/t)	Zapreminska masa $\gamma_{,7}$ Density $\gamma_{,7}$ (kg/m³)	$K_{kp,7}$ (MPam³/t)	Zapreminska masa $\gamma_{,28}$ Density $\gamma_{,28}$ (kg/m³)	$K_{kp,28}$ (MPam³/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^3 do 1700 kg/m^3, od zapreminskih masa uzoraka ugrađenih vibriranjem (**2**), koje se kreću oko 2000 kg/m^3. 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.

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^3 to 1700kg/m^3, from the density placed by vibrating the samples (**2**), which is moving about 2000 kg/m^3. 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 Čvrstoća pri pritisku

Čvrstoća pri pritisku, kao najznačajnija mehanička karakteristika cementnih kompozita, s ciljem dobijanja funkcionalne zavisnosti *fp=fp(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).

5.2 Compressive strength

Due to obtain the functional dependence of *fp=fp (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).

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:

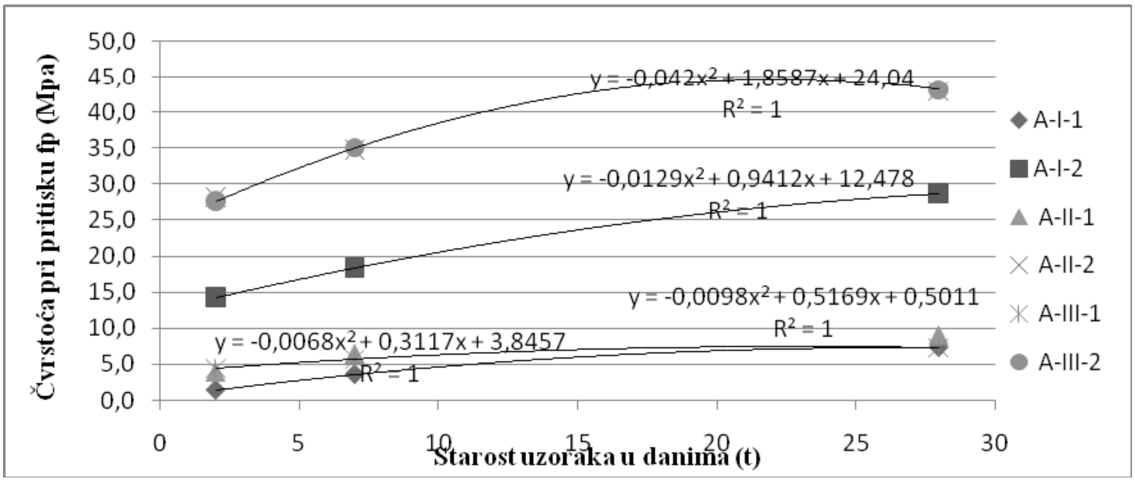
- uzorci svih serija ugrađenih ručno (1), bez obzira na sastav, imaju daleko manje čvrstoće pri pritisku u odnosu na uzorke kod kojih je primenjen postupak vibriranja (2), što je logična posledica manje kompaktnosti;
- malterske mešavine koje sadrže vlakna (II) imaju veće čvrstoće za oko 10% u odnosu 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%.

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

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%.

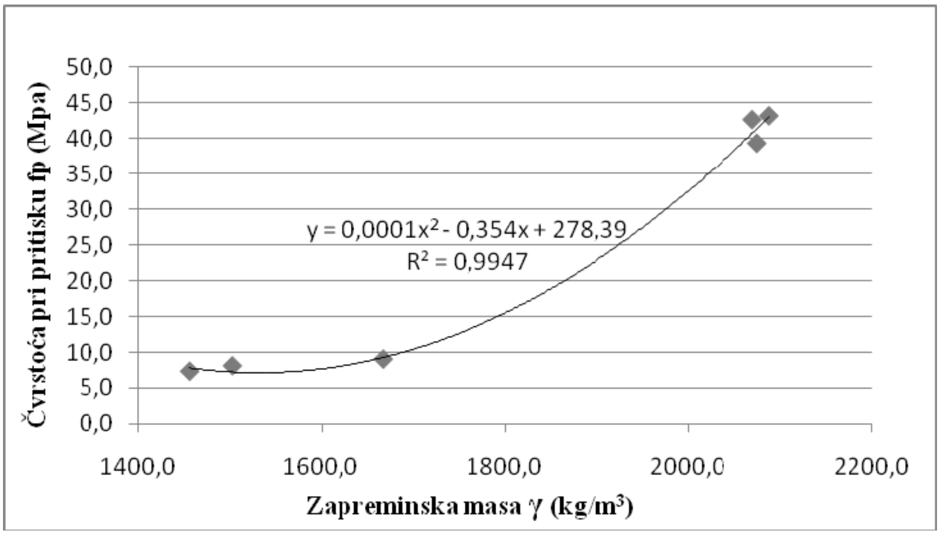
Functional dependence of compressive strength of time (Fig. 6).



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 γ, 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 γ, compressive strength f_p and dynamic modulus of elasticity E_D of concrete.

Budući da veličine γ, 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.

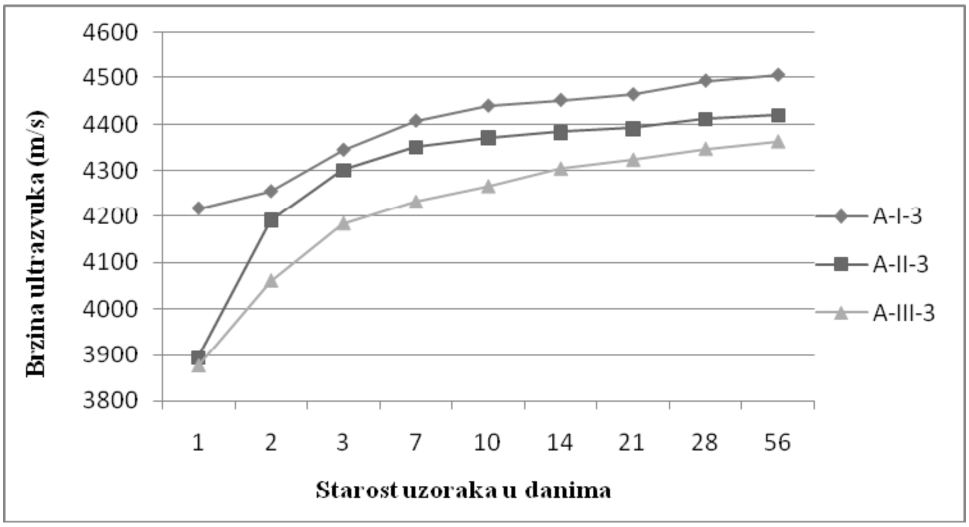
Ako posmatramo rezultate ispitivanja brzine prostiranja ultrazvučnih talasa serija malterskih kompozita, pri različitim starostima, prikazanih u vidu dijagrama (slika 8) možemo uočiti da:

- 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 γ, 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±3°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 4x4x16 cm, sa specijalnim, nerđajućim reperima, pri čemu su uzorci spravljani u prostoriji u kojoj je temperatura 20±3C^0, a relativna vlažnost 55±5%.

Prvo merenje na uzorcima izvršeno je posle 72±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 ugibomersata, s podatkom od 0,001mm. Na bazi izmerenih promena dužine merne baze, dilatacije skupljanja su sračunate preko poznatog obrasca:

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±3°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 4x4x16cm, with special, stainless benchmarks, with which the preparation of the samples were carried out in a room where the temperature was 20±3C0, and a relative humidity 55±5%.

The first measurement of the samples was performed after 72±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:

$$\varepsilon_{sk}\left(t\right)=\frac{\Delta l\left(t\right)}{l_o}1000=\frac{s\left(3\right)-s\left(t\right)}{l_o}1000\ (‰) \qquad (3)$$

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 malterskih 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;

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.

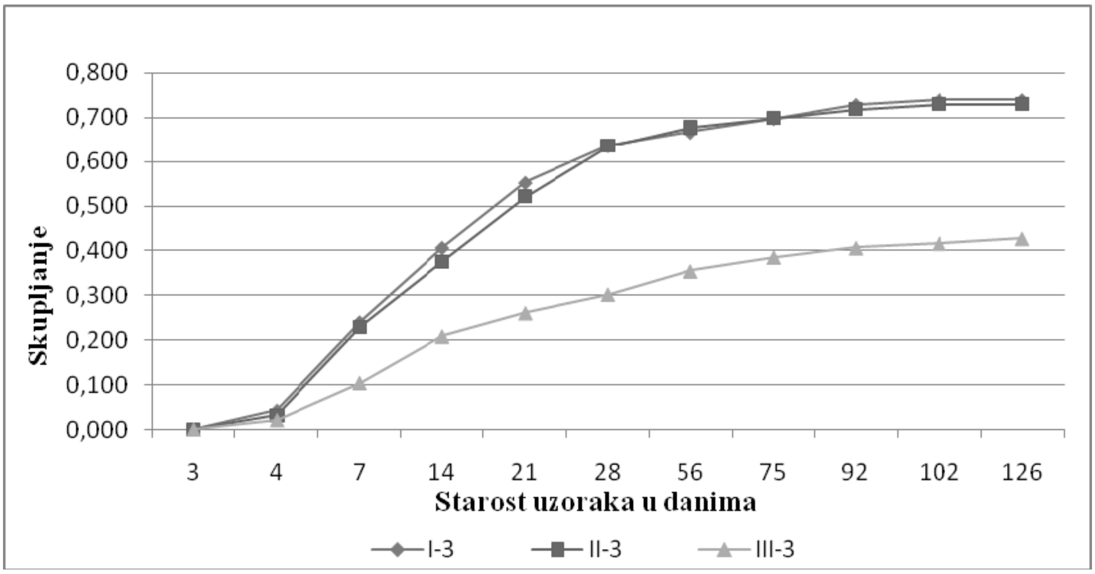
The results of total shrinkage of all tested mortar composites in function of time are shown in the form of table (Table 5 and the diagram (Figure 9).

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 ε_{sk} (‰) Shrinkage of samples ε_{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



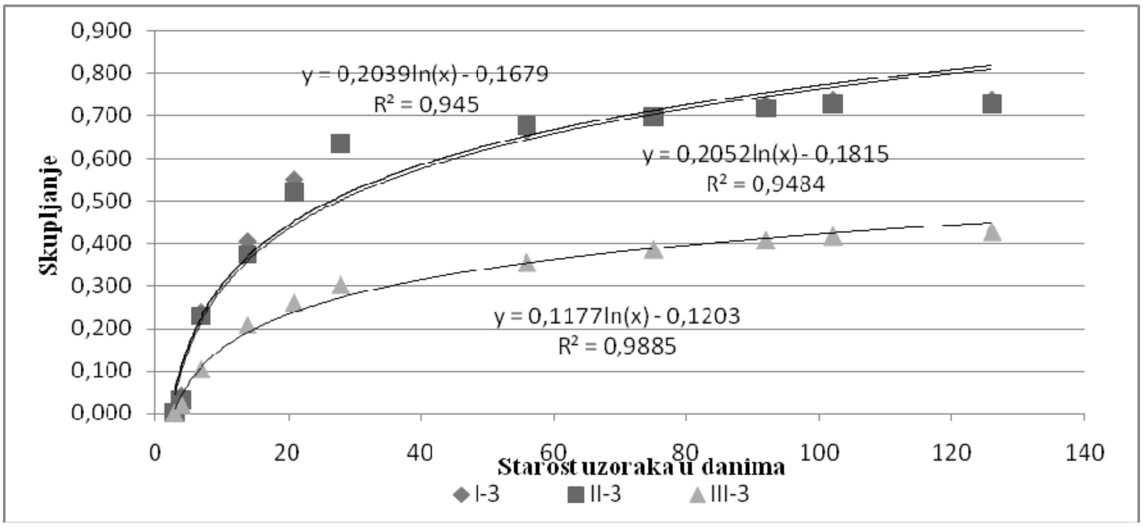
Slika 9. Skupljanje testiranih serija malterskih mešavina Ɛsk (‰)
Figure 9 . Shrinkage of tested series of mortar mixtures Ɛsk (‰)

• 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 Ɛsk od vremena

Figure 10. Functional dependence of shrinkage Ɛsk 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 cementog kompozita, s tim što su koeficijenti konstrukcijske povoljnosti tada nepovoljniji.

Zapreminske mase uzoraka ugrađenih ručno znatno su niže (od 1400 kg/m^3 do 1700 kg/m^3) od zapreminskih masa uzoraka ugrađenih vibriranjem koje se kreću oko 2000 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 kg/m^3 to 1700kg/m^3) than the density of the samples placed by vibration, which are about 2000 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 prslina 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.

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.

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”.

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REZIME

SVOJSTVA CEMENTNIH KOŠULJICA S DODATKOM POLIPROPILENSKIH VLAKANA I KOMPENZATORA SKUPLJANJA

Rada M. RADULOVIĆ
Dragica Lj. JEVTIĆ
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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 kostrukcijske 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

Rada M. RADULOVIĆ
Dragica Lj. JEVTIĆ
Vlastimir RADONJANIN

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.

IN MEMORIAM

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redovni profesor
1951-2016

U Beogradu je, iznenada, 2. januara 2016. godine, u 64. godini, preminuo prof. dr Đorđe Vuksanović, dugogodišnji dekan Građevinskog fakulteta u Beogradu, redovni član Akademije inženjerskih nauka Srbije, istaknuti stručnjak u oblasti građevinskog konstrukterstva i teorije konstrukcija.

Rođen je u Beogradu, od oca Mihaila, profesora istorije, kasnije sekretara Galerije fresaka, i majke, Jelisavete Amočajev, Beloruskinje. Od njih je nasledio snažnu ličnost, intelektualnu radoznalost, marljivost i studioznost i široku rusku dušu. Ove osobine su od njega načinile izuzetnog studenta i kasnije profesora na predmetu Statika konstrukcija.

Osnovno i gimnazijsko obrazovanje stekao je u Beogradu.

Diplomirao je na Građevinskom fakultetu u Beogradu 1974. godine. Na istom fakultetu stekao je stepen magistra 1980. i doktora tehničkih nauka 1988. godine.

Po diplomiranju se zaposlio kao stručni saradnik u Inženjerskom računskom centru Građevinskog fakulteta. Na Katedri za tehničku mehaniku i teoriju konstrukcija Građevinskog fakulteta, bio je biran, za asistenta pripravnika (1975), asistenta (1981), docenta (1989), vanrednog profesora (1994) i redovnog profesora (2001). Na osnovnim studijama je predavao Statiku konstrukcija, na master studijama Elastoplastičnu analizu konstrukcija, a na doktorskim studijama, predmete Teorija kompozitnih nosača i Numeričko modeliranje nelinearnog ponašanja betona. Nastavu iz Statike konstrukcija držao je, takođe, i na Fakultetu tehničkih nauka u Novom Sadu i građevinskom fakultetu u Kosovskoj Mitrovici, kao i na građevinskom fakultetu u Podgorici od 1986. do 2006. Bio je mentor pri izradi deset magistarskih teza i osam doktorskih disertacija.

Na Građevinskom fakultetu u Beogradu bio je prodekan za nastavu (1991–1996), dekan (2004–2012), predsednik komisije za naučno-istraživački rad, a na Univerzitetu u Beogradu bio je član Skupštine, član Zadužbinskog saveta, potpredsednik Veća grupacije fakulteta tehničkih nauka i član Stručnog veća za arhitekturu, urbanizam, građevinarstvo i geodeziju. Bio je i potpredsednik Matičnog naučnog odbora za saobraćaj, građevinarstvo i urbanizam Ministarstva nauke Republike Srbije.

Bio je član Predsedništva Društva građevinskih konstruktera Srbije i član ICCE (International Community for Composite Engineering). Od 2009. godine bio je redovni član Akademije inženjerskih nauka Srbije.

Prof. Vuksanović bio je član Redakcionog odbora i Redakcije monografije „Građevinski fakultet Univerziteta u Beogradu 1846–1996" i član Izdavačkog Saveta časopisa G-magazin, te recenzent većeg broja naučnih radova i knjiga. Boravio je na studijskim putovanjima u Velikoj Britaniji (University College of Swansea, Imperial College of Science and Technology, London) i gostovanjima u SAD (Massachusetts Institute of Technology, Cambridge, University of California, Berkeley) i Kanadi (Concordia University, Montreal). Učestvovao je s referatima na brojnim svetskim naučnim skupovima i bio je član naučnih i organizacionih odbora domaćih naučnih skupova.

Naučnoistraživački radovi profesora Vuksanovića pripadaju oblasti primene numeričkih metoda i postupaka u linearnoj i nelinearnoj analizi inženjerskih konstrukcija, primene metode konačnih elemenata u statičkoj i dinamičkoj analizi ploča i ljuski, modeliranja armiranobetonskih konstrukcija konačnim elementima, statičke i dinamičke analize, stabilnosti i delaminacije ploča izrađenih od savremenih kompozitnih materijala.

Objavio je kao autor ili koautor preko sto naučnih radova i pet knjiga, i imao citiranost - 145 (Science Citation Index i Web of Science).

Radovi profesora Vuksanovića mogu se podeliti u tri grupe. Prvu grupu čine radovi koji se odnose na probleme primene metode konačnih elemenata u statičkoj i dinamičkoj analizi ploča i ljuski kao elemenata građevinskih konstrukcija. U tim radovima razmatrani su, pored linearne analize, i problemi geometrijske i materijalne nelinearnosti kao i problemi stabilnosti. Poseban doprinos dao je u oblasti numeričkog modeliranja ploča konačnim elementima, formulaciji novih elemenata i aspektima njihove primene. Iz ove grupe radova izdvajaju se istraživanja publikovana u poznatim svetskim časopisima *Computers and Structures* (1985) i *Engineering Computations* (1989). Druga grupa radova u vezi je s problemima modeliranja armiranobetonskih konstrukcija konačnim elementima. Ovi radovi su imali veliki uticaj na naša savremena istraživanja iz ove oblasti i bili su osnova za istraživanja drugih autora. Treća grupa radova se odnosi na probleme statičke i dinamičke analize, stabilnosti i delaminacije ploča izrađenih od savremenih kompozitnih materijala (laminatne ploče, sendvič i olakšane ploče) koje u zadnje vreme imaju sve veću primenu u građevinarstvu. Iz ove grupe radova izdvajaju se istraživanja publikovana u referentnom svetskom časopisu *Composite Structures* (2000 i 2008).

Koautor je monografije nacionalnog značaja „Teorija savijanja ploča: numeričke metode i računarski programi" i koautor praktikuma iz Statike konstrukcija.

Profesor Vuksanović bio je vrlo aktivan na polju građevinskog konstrukterstva u statičkoj i dinamičkoj analizi konstrukcija, kao i problemima stabilnosti složenih konstruktivnih sistema različitih građevinskih objekata. Uradio je preko 80 idejnih i glavnih projekata, studija, ekspertiza, sanacija i revizija. Među objektima u čijoj je realizaciji učestvovao posebno se ističu: Vojnomedicinska akademija u Beogradu, hotel Kosmos u Moskvi, hangar za avione u Surčinu, čelične konstrukcije parnih kotlova u Kragujevcu, tipski rešetkasti čelični mostovi ugrađeni u montažno-demontažni most na Dunavu u Novom Sadu i tako dalje.

Pored navedenog, bio je revident za statiku Mosta na Adi preko reke Save u Beogradu, rukovodilac revidentskog tima glavnih projekata većeg broja saobraćajnica i delova autoputa, zatim, glavnih projekata rehabilitacije 15 mostova na pruzi Vrbnica–Bar u Crnoj Gori, glavnog projekta vodosnabdevanja Kosovske Mitrovice, Zvečana i Zubinog potoka. Bio je predsednik Komisije za tehnički pregled brane „Prvonek" kod Vranja i tako dalje.

Bio je veliki poklonik putovanja, posetilac muzeja, galerija, koncerata, pozorišta i kafana, kozer, omiljen u svakom društvu.

Pamtiće se njegove priče. Govorio je istinski, ljudski, sa izvesnom dozom humora, ali uvek dostojanstveno.

Biće upamćen kao gospodin profesor, izuzetan naučnik, veliki i dobar čovek, sa visoko izgrađenim ljudskim i etičkim vrednostima, koje su danas prava retkost.

Marta 2016.

Prof. dr Boško Stevanović, dipl.inž.građ.

UPUTSTVO AUTORIMA*

Prihvatanje radova i vrste priloga

U časopisu Materijli i konstrukcije štampaće se neobjavljeni radovi ili članci i konferencijska saopštenja sa određenim dopunama ili bez dopuna. prema odluci Redakcionog odbora. a samo izuzetno uz dozvolu prethodnog izdavača prihvatiće se i objavljeni rad. Vrste priloga autora i saradnika koji će se štampati su: originalni naučni radovi. prethodna saopštenja. pregledni radovi. stručni radovi. konferencijska saopštenja (radovi sa naučno-stručnih skupova). kao i ostali prilozi kao što su: prikazi objekata i iskustava - primeri. diskusije povodom objavljenih radova i pisma uredništvu. prikazi knjiga i zbornika radova. kao i obaveštenja o naučno-stručnim skupovima.

Originalni naučni rad je primarni izvor naučnih informacija i novih ideja i saznanja kao rezultat izvornih istraživanja uz primenu adekvatnih naučnih metoda. Dobijeni rezultati se izlažu kratko. jasno i objektivno. ali tako da poznavalac problema može proceniti rezultate eksperimentalnih ili teorijsko numeričkih analiza i tok razmišljanja. tako da se istraživanje može ponoviti i pri tome dobiti iste ili rezultate u okvirima dopuštenih odstupanja. kako se to u radu navodi.

Prethodno saopštenje sadrži prva kratka obaveštenja o rezultatima istraživanja ali bez podrobnih objašnjenja. tj. kraće je od originalnog naučnog rada. U ovu kategoriju spadaju i diskusije o objavljenim radovima ako one sadrže naučne doprinose.

Pregledni rad je naučni rad koji prikazuje stanje nauke u određenoj oblasti kao plod analize. kritike i komentara i zaključaka publikovanih radova o kojima se daju svi neophodni podaci pregledno i kritički uključujući i sopstvene radove. Navode se sve bibliografske jedinice korišćene u obradi tematike. kao i radovi koji mogu doprineti rezultatima daljih istraživanja. Ukoliko su bibliografski podaci metodski sistematizovani. ali ne i analizirani i raspravljeni. takvi pregledni radovi se klasifikuju kao stručni pregledni radovi.

Stručni rad predstavlja koristan prilog u kome se iznose poznate spoznaje koje doprinose širenju znanja i prilagođavanja rezultata izvornih istraživanja potrebama teorije i prakse. On sadrži i rezultate razvojnih istraživanja.

Konferencijsko saopštenje ili rad sopšten na naučnostručnom skupu koji mogu biti objavljeni u izvornom obliku ili ih autor. u dogovoru sa redakcijom. bitno preradi i proširi. To mogu biti naučni radovi. naročito ako su sopštenja po pozivu Organizatora skupa ili sadrže originalne rezultate prvi put objavljene. pa ih je korisno uz određene dopune učiniti dostupnim široj stručnoj javnosti. Štampaće se i stručni radovi za koje Redakcioni odbor oceni da su od šireg interesa.

Ostali prilozi su prikazi objekata. tj. njihove konstrukcije i iskustava-primeri u građenju i primeni različitih materijala. diskusije povodom objavljenih radova i pisma uredništvu. prikazi knjiga i zbornika radova. kao i obaveštenja o naučno-stručnim skupovima.

Autori uz rukopis predlažu kategorizaciju članka. Svi radovi pre objavljivanja se recenziraju. a o prihvatanju za publikovanje o njihovoj kategoriji konačnu odluku donosi Redakcioni odbor.

Da bi se ubrzao postupak prihvatanja radova za publikovanje. potrebno je da autori uvažavaju Uputstva za pripremu radova koja su navedena u daljem tekstu.

Uputstva za pripremu rukopisa

Rukopis otkucati jednostrano na listovima A-4 sa marginama od 31 mm (gore i dole) a 20 mm (levo i desno). u Wordu fontom Arial sa 12 pt. Potrebno je uz jednu kopiju svih delova rada i priloga. dostaviti i elektronsku verziju na navedene E-mail adrese. ili na CD-u. Autor je obavezan da čuva jednu kopiju rukopisa kod sebe zbog eventualnog oštećenja ili gubitka rukopisa.

Od broja 1/2010. prema odluci Upravnog odbora Društva i Redakcionog odbora. radovi sa pozitivnim recenzijama i prihvaćeni za štampu. publikovaće se na srpskom i engleskom jeziku.

Svaka stranica treba da bude numerisana. a optimalni obim članka na jednom jeziku. je oko 16 stranica (30000 slovnih mesta) uključujući slike. fotografije. tabele i popis literature. Za radove većeg obima potrebna je saglasnost Redakcionog odbora.

Naslov rada treba sa što manje reči (poželjno osam. a najviše do jedanaeset) da opiše sadržaj članka. U naslovu ne koristiti skraćenice ni formule. U radu se iza naslova daju ime i prezime autora. a titule i zvanja. kao iime institucije u podnožnoj napomeni. Autor za kontakt daje telefone. faks i adresu elektronske pošte. a za ostale autore poštansku adresu.

Uz sažetak (rezime) od oko 150 do 200 reči. na srpskom i engleskom jeziku daju se ključne reči (do deset). To je jezgrovit prikaz celog članka i čitaocima omogućuje uvid u njegove bitne elemente.

Rukopis se deli na poglavlja i potpoglovlja uz numeraciju. po hijerarhiji. arapskim brojevima. Svaki rad ima uvod. sadržinu rada sa rezultatima. analizom i zaključcima. Na kraju rada se daje popis literature.

Kod svih dimenzionalnih veličina obavezna je primena međunarodnih SI mernih jedinica.

Formule i jednačine treba pisati pažljivo vodeći računa o indeksima i eksponentima. Autori uz izraze u tekstu definšu simbole redom kako se pojavljuju. ali se može dati i posebna lista simbola u prilogu.

Prilozi (tabele. grafikoni. sheme i fotografije) rade se u crno-beloj tehnici. u formatu koji obezbeđuje da pri smanjenju na razmere za štampu. po širini jedan do dva stupca (8cm ili 16.5cm). a po visini najviše 24.5cm. ostanu jasni i čitljivi. tj. da veličine slova i brojeva budu najmanje 1.5mm. Originalni crteži treba da budu kvalitetni i u potpunosti pripremljeni za presnimavanje. Mogu biti i dobre. oštre i kontrastne fotokopije. Koristiti fotogrfije. u crno-beloj tehnici. na kvalitetnoj hartiji sa oštrim konturama. koje omogućuju jasnu reprodukciju. Skraćenice u prilozima koristiti samo izuzetno uz obaveznu legendu. Prilozi se posebno označavaju arapskim brojevima. prema redosledu navođenja u tekstu. Objašnjenje tabela daje se u tekstu.

Potrebno je dati spisak svih skraćenica korišćenih u tekstu.

U popisu literature na kraju rada daju se samo oni radovi koji se pominju u tekstu. Citirane radove treba prikazati po azbučnom redu prezimena prvog autora. Literaturu u tekstu označiti arapskim brojevima u uglastim zagradama. kako se navodi i u Popisu citirane literature. napr [1]. Svaki citat u tekstu mora se naći u Popisu citirane literature i obrnuto svaki podatak iz Popisa se mora navesti u tekstu.

U Popisu literature se navode prezime i inicijali imena autora. zatim potpuni naslov citiranog članka. iza toga sledi ime časopisa. godina izdavanja i početna i završna stranica (od - do). Za knjige iza naslova upisuje se ime urednika (ako ih ima). broj izdanja. prva i poslednja stranicapoglavlja ili dela knjige. ime izdavača i mesto objavljivanja. ako je navedeno više gradova navodi se samo prvi po redu. Kada autor citirane podatke ne uzima iz izvornog rada. već ih je pronašao u drugom delu. uz citat se dodaje «citirano prema...». Neobjavljeni članci mogu se pominjati u tekstu kao «usmeno saopštenje»

Autori su odgovorni za izneseni sadržaj i moraju sami obezbediti eventualno potrebne saglasnosti za objavljivanje nekih podataka i priloga koji se koriste u radu.

Ukoliko rad bude prihvaćen za štampu. autori su dužni da. po uputstvu Redakcije. unesu sve ispravke i dopune u tekstu i prilozima.

Za detaljnija tehnička uputstva za pripremu rukopisa autori se mogu obratiti Redakcionom odboru časopisa.

Rukopisi i prilozi objavljenih radova se ne vraćaju. Sva eventualna objašnjenja i uputstva mogu se dobiti od Redakcionog odbora.

Radovi se mogu slati i na e-mail: folic@uns.ac.rs ili miram@uns.ac.rs i dimk@ptt.rs

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* **Uputstvo autorima je modifikovano i treba ga u pripremi radova slediti.**

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