31
Research paper
Doi 10.61892/stp202401100V
ISSN 2566-4484

Jovan Volaš, University of Banja Luka, jovan.volas@aggf.unibl.org
Gordana Broćeta, University of Banja Luka, gordana.broceta@aggf.unibl.org
Marina Latinović Krndija, University of Banja Luka, marina.latinovic@aggf.unibl.org
Slobodan Šupić, University of Novi Sad, ssupic@uns.ac.rs
Vladan Pantić, University of Novi Sad, pantic_vladan@uns.ac.rs
Mirjana Malešev, University of Novi Sad, miram@uns.ac.rs
Vlastimir Radonjanin, University of Novi Sad, radonjanin.vlastimir@gmail.com
Anđelko Cumbo, University of Banja Luka, andjelko.cumbo@aggf.unibl.org
Aleksandar Savić, University of Beograd, sasha@imk.grf.bg.ac.rs
Žarko Lazić, University of Banja Luka, zarko.lazic@aggf.unibl.org
Draženka Lozo, University of Banja Luka, drazenka.radic@aggf.unibl.org

EFFECT OF THE HRWRA QUANTITY ON DURABILITY PROPERTIES OF SELF-COMPACTING CONCRETE

Abstract

The paper presents the results of our own experimental research on the effect of the high range water reducing admixture content – HRWRA (applied in the range from 0.8 to 1.2% by mass of cement – m_c) on the properties of self-compacting concrete in the fresh and hardened state.

The research showed that increasing the HRWRA content leads to the entrapped porosity reduction – up to 44%, increase of flowability – up to 13%, reduction of viscosity – up to 31%, improvement of passing ability – up to 15% and degradation of sieve segregation resistance of concrete in fresh state – up to 60%. The beneficial effect of the increase in HRWRA was shown on the analysed properties in the hardened state: compressive strength at the age of 28 days – up to 13%, water absorption – up to 61% and freeze/thaw resistance – up to 10%. The difference in the participation of HRWRA from 0.8 to 1.2% m_c does not have a statistically significant effect on the density and freeze/thaw resistance with a de-icing agent.

Keywords: high range water reducing admixture, self-compacting concrete, durability, experimental research.

УТИЦАЈ КОЛИЧИНЕ СУПЕРПЛАСТИФИКАТОРА НА ТРАЈНОСТ САМОУГРАЂУЈУЋЕГ БЕТОНА

Сажетак

У раду су приказани резултати сопственог експерименталног истраживања утицаја количине суперпластификатора високе моћи редукције воде – *HRWRA* (примијењеног у интервалу од 0,8 до 1,2% масе цемента – m_c) на својства самоуграђујућег бетона у свјежем и очврслом стању.

Истраживањем се показало да повећање учешћа *HRWRA* утиче на смањење заостале порозности – до 44%, повећање флуидности – до 13%, снижење вискозности – до 31%, побољшање способности проласка – до 15% и деградацију отпорности према сегрегацији бетона у свјежем стању – до 60%. Повољан утицај повећања учешћа *HRWRA* показао се на анализираним својствима у очврслом стању: чврстоћи при притиску при старости од 28 дана – до 13%, упијању – до 61% и отпорности према дејству мраза – до 10%. Разлика у учешћу *HRWRA* од 0,8 до 1,2% m_c нема статистички значајан утицај на запреминску масу и отпорност бетона према симултаном дејству мраза и соли.

Кључне ријечи:суперпластификатор високе моћи редукције воде, самоуграђујући бетон, трајност, експериментално истраживање.

1. INTRODUCTION

As self-compacting concrete technology is relatively new in our region, concrete manufacturers mostly rely on the production of conventional concrete based on established mix designs that have been tested multiple times. However, experience has shown that these concretes often lack satisfactory durability characteristics suitable for the environmental conditions of the elements in which they will be placed. As a consequence, the degradation and destruction of concrete structures are frequent occurrences, not only in domestic practice but also in many developed countries around the world [1, 2]. The durability of concrete is currently considered a significant topic, both within professional and scientific communities. The relevance of this issue is particularly emphasized by the fact that concrete serves as the fundamental material in the construction industry, and no forecasts are indicating the emergence of a viable replacement material in the near future [3-7]. Considering the above stated, it is important to direct research efforts towards finding solutions that will enhance the durability properties of concrete composites. As one such solution, many researchers recommend the production of self-compacting concrete (SCC), which demonstrates superior durability properties compared to the conventional concrete technologies [8-14]. In this regard, the society in one country needs to find a way to produce self-compacting concrete using component materials from domestic resources, which can respond to high durability requirements [15, 16]. This way, in the long term, better durability of concrete structures is ensured, enhancing their resistance and serviceability, leading to economic savings in maintenance, repair, rehabilitation, etc., as well as savings due to the reduced need for increasingly scarce qualified labour, etc. Given all the aforementioned needs to address the issue of concrete structure durability, the paper in question presents own experimental tests related to concrete used in traffic barriers, which have high durability requirements [1, 17, 18]. The presented research specifically focuses on determining the influence of high range water reducing admixture (HRWRA) content on the durability properties of self-compacting concrete for traffic barriers, manufactured using materials sourced from the domestic market.

2. HIGH RANGE WATER REDUCING ADMIXTURE

Superplasticizing admixture (high range water reducing admixture) is added to fresh concrete to reduce the water content significantly (it reduces the amount of water by more than 12% compared to the control mix), without affecting the consistency, or to increase the slump-flow (an increase in slump ≥ 120 mm compared to the control mix (30±10) mm), i.e., flow (an increase in flow ≥ 160 mm compared to the control mix (350±20) mm), without affecting the water content, or to achieve both effects simultaneously, according to EN 934-2 [19]. Superplasticizing admixtures of the newer generation enable the reduction of water content by up to 40%. Table 1 [20-22] provides an overview of the evolution of admixtures from plasticizers to high range water reducing admixtures.

Table 1. Admixture basic substances and water reduction effects [20, 22]

Year	Product	Water reduction	Capillar porosity	Technical advantages
1930	Lignosulfonates	≤ 10%	20%	Improved concrete workability
1940	Gluconates	≤ 10%	20%	Improved concrete workability
1970	Naphthalene sulfonate	≤ 20%	20%	Concrete with a low water-cement ratio
1980	Melamine polycondensates	≤ 20%	10 – 20%	High properties; controlled binding time
1990	Vinyl copolymers	≤ 25%	10 – 20%	Increased concrete workability with a low water-cement ratio; high early strength; controlled binding time
2000	Modified polycarboxylates	≤ 40%	5 – 10%	Significantly improved concrete workability with a low water-cement ratio and without the segregation risk; increased concrete compactness; better appearance of the final surface

Most admixture manufacturers offer a range of superplasticizing admixtures customized to specific user requirements and their effects on other components in the concrete mix. In addition to ensuring the necessary fluidity of the fresh concrete and water reduction, these admixtures must also maintain the dispersion effect during the time required for transport and application. The retention of the required consistency depends on the concrete application – precast concrete requires a shorter retention time for the required consistency than concrete that needs to be transported and placed on-site [23].

The new generation of HRWRA, based on modified polycarboxylic-ether, differs significantly from traditional plasticizing admixtures, providing better workability and higher concrete strength. This is achieved through the constant release and absorption of polymer chains during cement hydration, thereby preventing early setting. The result is a superior compact microstructure of concrete with a low water-cement ratio and increased mechanical properties compared to concrete using traditional plasticizers [24, 25]. Therefore, this type of admixture is considered an indispensable component for the production of self-compacting concrete, high-strength concrete, and high-performance concrete [22, 26-28].

In Nadhim's experimental research [26], the effects of different dosages of HRWRA on the fresh properties of self-compacting lightweight concrete (SCLCs) were studied using various percentages of HRWRA – 1, 1.3, 1.5, 1.7, and 2% by mass of binder. The results of this research show that increasing the dosage of HRWRA increases flowability. Both the time required to reach a 500 mm slump-flow (t_{500}) and the time required to flow through the V-funnel (t_v), which defines viscosity, decreased as the dosage of HRWRA increased up to 8.25 kg/m^3 (1.5% by mass of binder). After reaching this dosage, both of these parameters (t_{500} and t_v) decreased with further increases in HRWRA dosage. It was observed that increasing the HRWRA content resulted in a gradual increase in the L-box height ratio (H_2/H_1) of SCLC mixture up to a content of 8.25 kg/m^3, which reached 0.97, after which it decreased with further increases in HRWRA content.

It is important to note that the application of these admixtures, due to their significant reduction in the required amount of water, substantially alters the arrangement of pores in the microstructure of concrete, namely in the cement stone. Experimental tests have indicated a decrease in the percentage of larger pores (pores larger than 10^{-4} mm), that negatively impact concrete strength and increase its water permeability, vapour permeability, etc., while there is an increase in the percentage of smaller pores (pores smaller than 10^{-4} mm). These effects result in a denser cement stone structure, significantly enhancing durability and strength [11, 22, 29, 30]. However, an excessive amount of HRWRA can have a negative effect on concrete properties. Previously mentioned research [26] has shown that HRWRA participation up to 1.5% by mass of binder improves the compressive strength of concrete, but a dosage higher than that percentage diminishes strength. Therefore, it is crucial to determine the optimal amount of HRWRA in concrete mixes to ensure the enhancement of concrete properties.

In the present research, the impact of HRWRA is investigated within the optimal interval recommended by admixture manufacturers, based on own research and that of the scientific community. Additionally, the water content is kept constant for all mixtures designed in the experiment to establish the effects of HRWRA on the properties of self-compacting concrete in both fresh and hardened states.

3. EXPERIMENTAL STUDY

In this chapter, the results of own experimental research conducted in the Quality Control Department Laboratory of the Binis Concrete Factory in Banja Luka and the Laboratory of Center for Materials and Structures at the Faculty of Architecture, Civil Engineering and Geodesy, University of Banja Luka, is presented.

The research includes laboratory tests on 3 types of self-compacting concrete for the production of traffic barriers, for which the amount of admixture – HRWRA based on polycarboxylic-ether polymers varied in amounts of 0.8, 1.0, and 1.2%, by the applied mass of cement. Other quantities of component materials – cement, addition type I – limestone filler, aggregate and water were constant for all designed concrete mixtures.

The experimental research aims to determine the impact of the amount of the subject admixture on the characteristics of the concrete in the fresh and hardened state, with an emphasis on durability properties, crucial for concretes used for traffic barriers.

The concrete mixtures labels and corresponding HRWRA percentage are listed below:

C1 – self-compacting concrete produced with 1.2% HRWRA by mass of cement,

C2 – self-compacting concrete produced with 1.0% HRWRA by mass of cement and

C3 – self-compacting concrete produced with 0.8% HRWRA by mass of cement.

Preparation of concrete, molding and curing the samples for all 3 mixtures was carried out in the same manner and under equal thermo-hygrometric conditions, namely at a temperature of 23±0.5°C, with a relative humidity of 65±5%. The samples were kept in molds for the first 24 hours, covered with foil, and then up to 28 days in a chamber with constant spraying.

3.1. EXPERIMENTAL PLAN AND PROGRAMME

Following the regulations of the Republic of Srpska, the testing of the designed concretes was carried out according to SRPS standards, except for the properties of self-compacting concretes in the fresh state, for which EN standards were applied.

3.1.1. EXPERIMENTAL TESTING ON FRESH CONCRETE

The following characteristics were tested on fresh concrete:

- temperature, according to SRPS U.M1.032 [31],
- entrapped air content, according to SRPS U.M1.032 [32],
- density, according to SRPS U.M1.009 [33],
- flowability using the slump-flow test, according to EN 12350-8 [34],
- viscosity by measuring time t_{500}, according to EN 12350-8 [34] and V-funnel test, according to EN 12350-9 [35],
- passing ability using the L-box test, according to EN 12350-10 [36],
- segregation resistance using the sieve segregation test, according to EN 12350-11 [37].

In Figures 1-3, the tests conducted on the fresh concrete are presented.

Figure 1. Measuring of temperature (left), entrapped air content (middle) and density of fresh concrete (right)

Figure 2. Flowability measurements using the slump-flow test (left), fresh concrete during V-funnel test (right)

Figure 3. Passing ability testing, using the L-box (left), segregation resistance testing (right)

3.1.2. EXPERIMENTAL TESTING ON HARDENED CONCRETE

On hardened concrete, the following characteristics were tested:

- density, according to SRPS U.M1.009 [33],
- compressive strength at the age of 28 days, according to SRPS U.M1.020 [38],
- water absorption by gradual immersion test, according to SRPS B.B8.010:1981 [39] (in the absence of a suitable standard for testing SCC water absorption, stone material water absorption regulations were used),
- freeze/thaw resistance (100, 150 and 200 cycles) according to SRPS U.M1.016[40],
- freeze/thaw resistance with a de-icing agent (f/t) according to SRPS U.M1.055 [41].

Concrete cores used for water absorption by gradual immersion test and freeze/thaw resistance test, and prisms used for freeze/thaw resistance with a de-icing agent test are subsequently extracted from hardened concrete at the age of 28 days.

In Figure 4, the tests conducted on the hardened concrete are shown.

Figure 4. Compressive strength test (left), freeze/thaw surface resistance with a de-icing agent (middle), samples for freeze/thaw resistance (right)

3.2. COMPONENT MATERIALS

For the subject experimental research, component materials available on the domestic market were used, specifically:

- cement CEM II/B-M(S-LL) 42,5 N, manufacturer CEMEX d. d. Split, Republic of Croatia,
- addition type I – limestone filler, manufacturer "Herc gradnja", quarry site "Drakuljica", Bileća, Republic of Srpska, Republic of Bosnia and Herzegovina,
- crushed aggregate "Dobrnja", manufacturer BINIS d. o. o. Banja Luka, Republic of Srpska, Republic of Bosnia and Herzegovina,
- admixture – superplasticizer "Dynamon PC 25 ES", manufacturer MAPEI, Austria,
- tap water.

The applied crushed three-fraction aggregate has a nominal maximum grain size of 16 mm, where two fractions of a fine aggregate of different sizes were used – fraction 0/4 mm and mid-size fraction 0/2 mm, and coarse fractions 4/8 and 8/16 mm. The granulometric curve of the mixture is continuous (Figure 5).

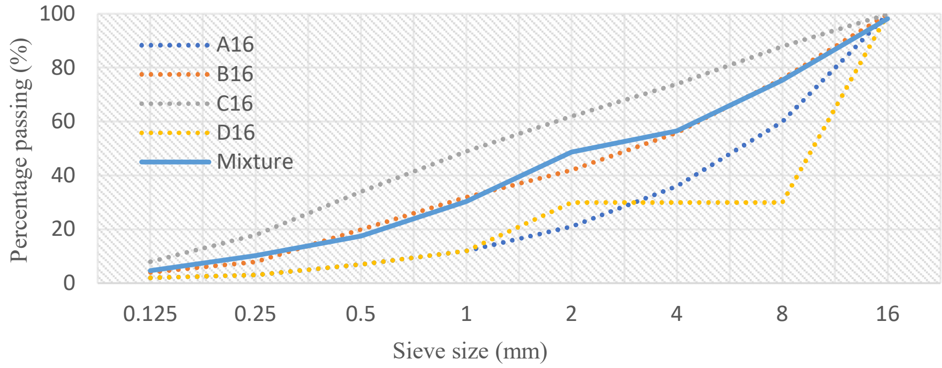

Figure 5. Granulometric curve for mix design

The properties of the subject admixture, taken from the manufacturer's technical sheet, are listed in Table 2.

Table 2. Admixture technical data

State of aggregation	Colour	Density [g/cm^3]	pH value	Chloride content [%]	Alkali content [%]
Liquid	Brown	1.04 – 1.08	5.5 – 7.5	< 0.10	< 2.5

3.3. MIX DESIGN

For the experimental research, three types of self-compacting concrete with component materials of domestic origin were designed. High requirements were set for the properties of the fresh concrete mixture in terms of placeability, workability and resistance to segregation, and also for the high quality of the concrete surface and durability properties of the hardened concrete.

3.3.1. DESIGN CRITERIA

The initial criteria for designing the subject mixtures, from the perspective of achieving the required characteristics of concrete in its fresh state, were related to:

- achieving compactness without the use of mechanical means for placing, i.e. the entrapped air content is limited to a value of 3%,
- achieving consistency class SF2 and/or SF3, i.e. to provide the requisite slump-flow greater than 660 mm,
- achieving passing ability class PL2, where passing ability ratio is ≥ 0.80 with three rods,
- achieving segregation resistance class SR2, where segregated portion is ≤ 15 %.

Additional common characteristics of the subject concrete mixtures were:

- the amount of cement 420 kg/m^3,
- the amount of addition type I – limestone filler 160 kg/m^3,
- the amount of powder (cement, addition type I and aggregate with grains less than 0,125 mm) 630 ± 5 kg/m^3 and
- the amount of water 180 kg/m^3.

Considering the significant amount of applied addition type I – limestone filler, of 160 kg/m^3, a viscosity modifying agent was not applied.

The requirements for the properties of the designed concretes in the hardened state were as follows:

- achieving a freeze/thaw resistance class of M_{200}*,
- achieving a class "resistant" after the freeze/thaw resistance test with a de-icing agent.

* Considering that for concrete traffic barriers used on roads, according to the SRPS U.N2.060 [42] standard, the M_{200} class is required in terms of freeze/thaw resistance, the same requirement has been adopted for this property of concrete that will be used in the production of traffic barriers.

3.3.2. MIX PROPORTION

Table 3 shows the component materials contents in 1 m^3 of the designed concrete mixtures, as well as the calculated values of concrete density in the fresh state.

Table 3. Mixture compositions, water-cement ratio and density of designed SCC

Mix identity			C1	C2	C3
Cement		[kg/m³]	420	420	420
Limestone filler		[kg/m³]	160	160	160
Aggregate	0/2	[kg/m³]	635	635	636
	0/4	[kg/m³]	260	260	260
	4/8	[kg/m³]	276	276	276
	8/16	[kg/m³]	454	454	455
Admixture – HRWRA		[kg/m³]	5.04	4.20	3.36
Water		[kg/m³]	180	180	180
Water-cement ratio		[%]	0.43	0.43	0.43
Admixture-cement ratio		[%]	1.20	1.00	0.80
Density		[kg/m³]	2401	2402	2403

3.4. TEST RESULTS AND DISCUSSION

3.4.1. CONCRETE IN FRESH STATE

Table 4 shows the findings of testing concrete in fresh state – temperature (T), density (D), entrapped air content (A_c), the slump-flow (SF), t_{500} time, V-funnel flow time (t_v and $t_{v,5min}$), L-box test results – the ratio of concrete heights at the horizontal and the vertical section of the L-box (H_2/H_1) and segregated portion SR.

Table 4. Test results of fresh concrete properties

Mix identity	T	D	A_c	SF	t_{500}	V		H_2/H_1	SR
						t_v	$t_{v,5\ min}$		
	[°C]	[kg/m³]	[%]	[mm]	[s]	[s]	[s]	[-]	[%]
C1	23.5	2400	1.8	852.50	2.60	10.10	11.94	1	11.72
C2	22.5	2390	2.1	775.00	2.85	10.03	10.55	1	10.78
C3	23.5	2370	2.6	740.00	3.42	11.52	12.60	0.85	4.66

All designed self-compacting concretes are of normal-weight concrete, with a high level of compactness, i.e. with an amount of entrapped air of less than 3%. However, the applied amount of superplasticizer affects the entrapped air content in fresh concrete. Concrete made with 1% HRWRA by mass of cement, compared to concrete made with 1.2% HRWRA by mass of cement, exhibits a 17% higher entrapped air content. Also, concrete made with 0.8% HRWRA by mass of cement, compared to concrete made with 1.2% HRWRA by mass of cement, has a 44% higher entrapped air content.

Flowability test showed that concretes C1 and C2 have a consistency class of SF3, while the concrete with the least HRWRA participation – concrete C3 has a consistency class of SF2. Specifically, concrete made with 1% HRWRA by mass of cement, compared to concrete made with 1.2% HRWRA by mass of cement, has a 9% smaller diameter of the flow spread. Also, concrete made with 0.8% HRWRA by mass of cement, compared to concrete made with 1.2% HRWRA by mass of cement, shows a 13% smaller diameter of the flow spread.

Viscosity testing showed that all designed concretes are class VS2, determined by measuring time t_{500}, or class VF2, determined by measuring the V-funnel flow time. The flow rate of fresh concrete does not significantly differ between concretes C1 and C2. However, in comparison to concrete C1, concrete C3 exhibits a 32% longer time t_{500} and a 14% longer time t_v. Moreover, all designed concretes demonstrate viscosity stability, with the difference in discharge speed from the V-funnel t_v and $t_{v,5min}$ being less than 3 seconds. Concrete containing 1% HRWRA by mass of cement exhibits the best viscosity stability.

The passing ability results, tested using L-box with three bars, showed that all designed concrete mixtures meets the requirements for class PL2. In this regard, concretes C1 and C2 have the ideal passing ability ratio, while concrete C3 exhibits a 15% higher mean depth of fresh concrete in the vertical section of the box, than the mean depth of fresh concrete in the horizontal section of the box. By testing the segregation resistance, it was shown that all designed concretes meet the requirements for class SR2. Additionally, increasing the superplasticizing admixture content in concrete affects the increase of the segregated portion. The best segregation resistance test result was obtained for concrete C1. In this regard, concrete made with 1% HRWRA by mass of cement, compared to concrete made with 1.2% HRWRA by mass of cement, has a 0.94% larger segregated portion, i.e. 8% more favourable result in terms of segregation resistance. Also, concrete made with 0.8% HRWRA by mass of cement, compared to concrete made with 1.2% HRWRA by mass of cement, has a 7.06% larger segregated portion, i.e. 60% more favourable result in terms of segregation resistance.

3.4.2. CONCRETE IN HARDENED STATE

Table 5 presents the results of the compressive strength at 28 days of age ($f_{c,cube,28}$), density (D), absorption by the gradual immersion method (A_b) after 12 days, the frost resistance coefficient (r_{FTR}), and freeze/thaw resistance with de-icing salt, expressed in mass loss (L), depth of scaling (H) and scaling degree, after 25 cycles (surface scaling degree is presented in Figure 6).
Frost resistance coefficient is calculated as the ratio of the mean value of the compressive strength of the specimens subjected to f/t cycles and the mean value of the compressive strength of the reference samples tested at the equivalent age, after 100, 150 and 200 cycles of freeze/thaw (M_{100}, M_{150}, M_{200}). For all the mentioned f/t cycles, 6 concrete samples were tested.

Table 5. Test results of hardened concrete properties

Mix identity	$f_{c,cube,28}$	D	A_b	Freeze-thaw			Freeze/thaw with de-icing salt		
				M_{100}	M_{150}	M_{200}	L	H	scaling degree*
	[MPa]	[kg/m³]	[%]	[%]	[%]	[%]	[mg/mm²]	[mm]	
C1	57.93	2404	1.52	0.98	0.91	0.89	0	0	0
C2	55.77	2376	2.39	0.93	0.88	0.87	0	0	0
C3	50.40	2393	2.45	0.88	0.85	0.80	0	0	0

** Note: 0 – without scaling (L≈0mg/mm², HFTR-S≈0 mm), 1 – a little scaling (L≈0.2 mg/mm², HFTR-S≈1.0 mm), 2 – medium scaling (L≈0.5 mg/mm², HFTR-S≈4.0 mm), 3 – severe scaling (L≈1.0 mg/mm², HFTR-S≈10.0 mm).*

Figure 6. Surfaces appearance after 25 f/t cycles with de-icing salt

Characteristic changes of impact parameters in relation to the varied property are shown graphically in Figure 7.

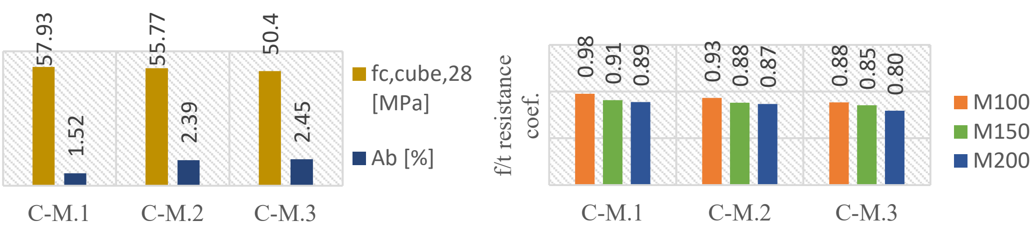

Figure 7. Test results of hardened concrete properties

Compressive strength test results showed that the application of HRWRA has a beneficial effect – by increasing the amount of admixture, higher values of compressive strength at the age of 28 days are obtained.

In that sense, it was shown that concrete C1 has a higher compressive strength value by 2.16 MPa, i.e., 4% at the age of 28 days compared to concrete C2, and by 7.53 MPa, i.e., 13%, at the age of 28 days compared to concrete C3.

Also, it has been shown that an increase in the proportion of HRWRA has a favourable effect on the value of water absorption by the test of gradual immersion at atmospheric pressure. The lowest value of water absorption has concrete with the highest proportion of HRWRA. Specifically, concrete C1 has 0.87% less absorption than concrete C2, or a 57% more favourable value. Additionally, concrete C1 has 0.93% less absorption than concrete C3, or a 61% more favourable value.

The results of testing the frost resistance revealed that the frost resistance coefficient is not below 75% for all of the concretes tested. According to the criterion [40], all tested types of concrete meet the quality requirements after 100, 150 and 200 f/t cycles. However, the results indicate that the proportion of HRWRA impacts freeze/thaw resistance. Specifically, after 200 freeze/thaw cycles, concrete C1 decreases strength by less than 0.02% than concrete C2, meaning it has a 2% more favourable value. Additionally, concrete C1 shows a decrease in strength of less than 0.09% than concrete C3 or a 10% more favourable value.

Testing for resistance to the simultaneous action of frost and de-icing salt revealed that none of the designed concretes exhibited surface spalling after 25 f/t cycles in the presence of a 3% salt solution. Consequently, all the mentioned concretes are classified as "resistant" after the freeze/thaw resistance test with a de-icing agent, in accordance with [41]. However, it is noted that concretes C2 and C3 exhibit visually noticeable less smooth surface (these concretes have a matte colour, as seen in Figure 7). Based on this, it can be assumed that concretes C2 and C3 may have lower resistance after a greater number of freeze/thaw cycles in the presence of a salt solution.

4. CONCLUSION

The conducted tests show that the applied amount of admixture, a superplasticizer based on polycarboxylate, influences the properties of both fresh and hardened self-compacting concrete. Considering that the focus of this research is concrete intended for use in traffic barriers, durability properties regarding freeze/thaw resistance and freeze/thaw resistance with a de-icing agent are of particular importance.

Tests on fresh concrete have shown that a higher quantity of HRWRA contributes to a reduction in the entrapped air content. For the application of superplasticizers ranging from 0.8 to 1.2% by mass of cement, every 0.1% of superplasticizer on average reduces entrapped porosity by 0.2% in the fresh concrete. Additionally, every 0.1% increase in superplasticizer content on average increases the diameter of the flow spread by 28 mm. Moreover, increasing the proportion of HRWRA accelerates the flow rate of fresh concrete, which describes viscosity. It has been demonstrated that the best viscosity stability is achieved for concrete produced with 1% HRWRA by mass of cement. Ideal passing ability is obtained for concretes with a 1% or more HRWRA participation by mass of cement. Such concretes can be applied in elements with congested reinforcement without loss of uniformity or blocking. In the case where the participation of HRWRA is less than 1%, occurrences of blocking and accumulation of coarse aggregate particles in narrow gaps between reinforcement bars are possible (although an acceptable passing ability ratio is achieved for the participation of 0.8% HRWRA by mass of cement).

The quantity of HRWRA ranging from 0.8 to 1.2% ensures satisfactory resistance to segregation, where an increase in the content of this admixture degrades the aforementioned resistance.

Considering the impact of HRWRA on the properties of fresh self-compacting concrete, in terms of improving fluidity and passing ability, reducing viscosity, and decreasing segregation resistance, it is concluded that for the designed types of self-compacting concrete with limestone filler, the optimal quantity of HRWRA is 1% by mass of cement.

The quantities of HRWRA do not have a statistically significant impact on the density, both in the fresh and hardened states.

Increasing the quantity of HRWRA has a positive impact on the increase in compressive strength of SCC at the age of 28 days. However, the function of the influence of increased strength due to the increase in the quantity of HRWRA is non-linear – concrete with 1.2% HRWRA has a higher compressive strength value of 4% compared to concrete with 1% HRWRA and of 13% compared to concrete with 0.8% HRWRA by mass of cement.

The greatest impact of HRWRA application on the properties in the hardened state is observed during testing water absorption using the gradual immersion method. Significantly lower amounts of absorbed water are obtained for SCC with the highest proportion of HRWRA. Similar to the influence of the quantity of HRWRA on compressive strength, the dependence function of the absorption reduction and quantity of HRWRA is non-linear. Concrete with 1.2% HRWRA is, in terms of absorption, 57% more favourable compared to concrete with 1% HRWRA, and 61% more favourable compared to concrete with 0.8% HRWRA.

Although SCC, with all analysed quantities of HRWRA, meets the frost resistance criterion for M_{200}, it has been shown that the applied quantity of HRWRA has an impact on the frost resistance coefficient. After 200 f/t cycles, concrete with 1.2% HRWRA is 2% more favourable than concrete with 1% HRWRA, and 10% more favourable than concrete with 0.8% HRWRA. Considering the importance of this property for concretes used in traffic barriers and similar exposure conditions during exploitation, it is recommended that the participation of HRWRA in such cases is a minimum of 1% by mass of cement.

The quantity of the applied admixture ranging from 0.8 to 1.2% for the analysed types of self-compacting concrete does not have a significant impact on the concrete's freeze-thaw resistance with a de-icing agent. Namely, all experimentally implemented types of self-compacting concrete exhibit a high level of quality of the final surface after the f/t cycles in the presence of de-icing salts. However, the optimal quantity of HRWRA concerning the high demand for the visible (final) surface of the concrete traffic barrier is 1.2%, with a 180 kg/m^3 of addition type I – limestone filler.

From the aforementioned conclusions regarding freeze-thaw resistance with and without de-icing agents, it is observed that the participation of HRWRA does not have an equal impact intensity. This is particularly emphasized due to the frequent misinterpretation of domestic practices suggesting that the impact intensity of certain admixture on these two properties is equal. Although the application of this specific admixture has the "same sign" of impact on both mentioned properties, research [5], [9] shows that some other admixture may even have a "different sign" of impact on these properties (favourable impact for one property and unfavourable impact for the other property).

In conclusion, it is determined that the application of self-compacting concrete technology, in which HRWRA is an essential component, enables the production of concrete elements with high durability requirements. Therefore, the importance of promoting this concrete technology, as well as analysing the properties of different types of self-compacting concrete prepared with domestically sourced component materials, is of utmost significance. This aims to increase the presence of these concretes in the domestic market compared to previous practices.

ACKNOWLEDGEMENT

The paper presents the part of research realized within the project "Development of new binders based on agricultural and industrial waste from the area of Vojvodina for the production of eco-friendly mortars" financed by the Provincial Secretariat for Higher Education and Scientific Research in Vojvodina. The authors gratefully acknowledge the resources and expertise provided within the experimental program by "The Institute for testing, assessment, and repair of structures doo" in Novi Sad, Serbia.

LITERATURE

[1] G. Broćeta, M. Malešev, V. Radonjanin, S. Šupić, A. Savić, I. Lukić, A. Cumbo, M. Latinović Krndija, "Effect of aggregate origin on freeze/thaw resistance of self-compacting concrete with and without a de-icing agent," *Building Materials and Structures*, vol. 66, no. 4, pp. 11–11, 2023, doi: 10.5937/grmk2300013b.

[2] A. Radević, D. Zakić, A. Savić, M. Aškrabić, D. Jevtić, "Primena in-situ metoda ispitivanja u cilju sanacije betonskih konstrukcija," *Proceedings of the 12th international conference Assessment, maintenance and rehabilitation of structures*, vol. 244, Vrnjačka Banja, The Union of Engineers and Technicians of Serbia, June 29. – July 1., pp. 244–253, 2022.

[3] C. R. Gagg, "Cement and Concrete as an engineering material: an historic appraisal and case study analysis," *Engineering Failure Analysis*, vol. 40, pp. 114–140, 2014, DOI:10.1016/j.engfailanal.2014.02.004

[4] A. Baikerikar, "A Review on Concept of Sustainable Concrete," *Conference: Recent Advances in Civil Engineering,* 2018. https://www.researchgate.net/publication /325177414_A_Review_on_Concept_of_Sustainable_Concrete

[5] G. Broćeta, M. Malešev, V. Radonjanin, "Trajnost samougrađujućeg betona u funkciji primijenjene vrste agregata", Scientific monograph of exceptional importance, University of Banja Luka, Faculty of Architecture, Civil Engineering and Geodesy, Banja Luka (2021).

[6] K. Moslemi, "Guide to Construction Materials and Latest Innovations in 2024," *Construction Magazine*, 2023.

[7] Market Growth Updates: Concrete Construction Materials Market Research Report 2024 Trends, Growth Opportunities, and Forecast Scenarios upto 2032. https://www.linkedin.com/pulse/2024-2032-concrete-construction-materials-ugz6e

[8] D. Jevtić, "Mogućnosti modeliranja svojstava betona u funkciji povećanja trajnosti," *Building Materials and Structures*, vol. 51, no. 1, pp. 18–31, 2008.

[9] D. Duh: "Samozgoščevalni in vibrirani betoni z apnenčevo moko", *Doktorska disertacija*, Fakultet za gradbeništvo in geodezijo, Univerze v Ljubljani, Ljubljana, avgust 2008.

[10] A. Hassan, M. Lachem, "Durability Characteristics of SCC Incorporating Metakaolin" *ACI Extreme Concrete Convention*, Chicago, 2010.

[11] D. Jevtić, A. Savić, G. Broćeta: "Fiber Reinforced Self-Compacting Concrete – Possibility of Modelling of Properties," *VI International Scientific Conference "Contemporary Materials", Book of proceedings*, Academy of Sciences and Arts of Republic of Srpska, B&H, July 4-6, 2013, Banjaluka, pp. 473–482, 2014.

[12] D. Jevtić, G. Broćeta, "Uticaj prelazne zone u betonu na trajnost betonskih konstrukcija," *X međunarodni naučno-stručni skup – "Savremena teorija i praksa u graditeljstvu," Zbornik radova*, Banjaluka, BiH, 15–16. maj 2014, str. 439–446, 2014.

[13] G. H. Ahmed, H. Ahmed, B. Ali, R. Alyousef, "Assessment of High Performance Self-Consolidating Concrete through an Experimental and Analytical Multi-Parameter Approach," *Materials*, vol. 14, no. 4, pp. 1–21, 2021.

[14] P.R. Kalyana Chakravarth, K. Namratha, "Strength and durability properties of high strength self compacting concrete," *Materials Today: Proceedings*, Elsevier, 2022.

[15] T. Savić, A. Radević, M Vlahović, S. Martinović, N. Đorđević, G. Broćeta, T. Volkov-Husović, "Valorization of Fly Ash from a Thermal Power Plant for Producing High- Performance Self-Compacting Concrete," *Science of Sintering,* 2020.

[16] T. Vasić, M. Savić, A. Martinović, S. Vlahović, M. Volkov-Husovic, "Properties of Green Self-Compacting Concrete Designed by Particle Packing Density Method," *Association for Promotion of Holistic Approach to Environment,* 2023.

[17] A. Kurtović, N. Ademović, B. Strojil, "Trajnost betonskih ograda na cestama," *IV kongres o cestama*, 2014, DOI: 10.13140/2.1.4541.3127

[18] O. Đokić, A. Radević, D. Zakić, B. Đokić, "Potential of natural and recycled concrete aggregate mixtures for use in pavement structures," *Minerals*, vol. 10, no. 9, p. 744, 2020.

[19] EN 934-2:2009+A1:2012 Admixtures for concrete, mortar and grout – Part 2: Concrete admixtures – Definitions, requirements, conformity, marking and labelling.

[20] "www.isomat.co.rs"

[21] P. M. I. Papayianni, G. Tsohos, N. Oikonomou, "Influence of superplasticizer type and mix design parameters on the performance of them in concrete mixtures," *Cement and Concrete Composites*, vol. 27, no. 2, pp. 217–222, 2005.

[22] G. Broćeta, "Istraživanje komponentnih materijala samozbijajućeg betona sa metodama ispitivanja svježe betonske mase," *Magistarski rad,* Arhitektonsko-građevinski fakultet, Univerzitet u Banjaluci, 2014.

[23] EFNARC, The European Guidelines for self-compacting concrete – Specification, Production and Use, 2005.

[24] G. Broćeta, D. Đurić-Mijović, M. Škrbić, "Dejstvo hiperplastifikatora na beton," *Zaštita Materijala*, vol. 55, pp. 419–425, 2014.

[25] G. Broćeta, D. Đurić-Mijović, "Mehanizam djelovanja hemijskih dodataka visokog stepena umanjenja količine vode," *Treći međunarodni Kongres – "Inženjerstvo, Ekologija i Materijali u procesnoj Industriji Jahorina*, pp. 1006–1010, 2013.

[26] N. A. Hamah Sor, "The effect of superplasticizer dosage on fresh properties of self-compacting lightweight concrete produced with coarse pumice aggregate," *Journal of Garmian University*, 2018, doi: 10.24271/garmian.336.

[27] D. Zakić, D. Jevtić, A. Radević, M. Vidović, S. Ž. Mitrović, "Research, testing and application potential of steel fiber reinforced ultra-high performance concrete," *Slovenian colloquium on concrete: Multi-component fine-grained concretes and mortars,* Trzin, Slovenia, pp. 71-80, 2023.

[28] M. Jimena de Hita, M. Criado, "Influence of superplasticizers on the workability and mechanical development of binary and ternary blended cement and alkali-activated cement," *Construction and Building Materials*, vol. 366, 2023, doi: https://doi.org/10.1016/j.conbuildmat.2022.130272.

[29] D. Jevtić, "Dodaci betonu," Prvi zbornik radova Arhitektonsko-građevinskog fakulteta Univerziteta u Banjaluci, pp. 26–42, 2006.

[30] J. Volaš, "Uticaj količine hemijskog dodatka na trajnosna svojstva samougrađujućeg betona za saobraćajne barijere," *Diplomski rad,* Arhitektonsko-građevinsko-geodetski fakultet, Univerzitet u Banjaluci, 2019.

[31] SRPS U.M1.040/1994 Concrete – Compression test of concrete cores.

[32] SRPS U.M1.032/1981 Concrete – Measuring temperature of concrete.

[33] SRPS U.M1.009/1994 Concrete – Determination of bulk density of concrete.

[34] EN 12350-8:2019 Testing fresh concrete – Part 8: Self-compacting concrete – Slump-flow test.

[35] EN 12350-9:2010 Testing fresh concrete – Part 9: Self-compacting concrete – V funnel test.

[36] EN 12350-10:2010 Testing fresh concrete – Part 10: Self-compacting concrete – L box test.

[37] EN 12350-11:2010 Testing fresh concrete – Self-compacting concrete – Sieve segregation test.

[38] SRPS U.M1.020/1993 Concrete – Determination of compressive strenght of test specimens.

[39] SRPS B.B8.010:1981 Testing of natural stone – Determination of water absorption.

[40] SRPS U.M1.016:1992 Concrete – Method of test for resistance of concrete against freezing and thawing.

[41] SRPS U.M1.055:1984 Concrete – Method of test for resistance of concrete against freezing.

[42] SRPS U.N2.060:1990 – Prefabricated concrete units – Kerbs – Technical requirements.