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INFLUENCE OF CRUSHED STONE AGGREGATE TYPE ON CONCRETE CONSISTENCY

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Abstract. *The main reason for usage of crushed stone mineral aggregate is need for concrete construction building with care about environmental protection, water resources, etc. Influence of crushed stone mineral aggregate on concrete consistency is considered in this paper. River aggregate is used as a benchmark, and from crushed aggregates: limestone, andesite, diabase and basalt.*
The drawn conclusion is that fine crushed aggregate has an important influence on concrete consistency because it decreases concrete's workability and placing. Replacement with river aggregate improves concrete consistency. Coarse aggregate type also has an influence on consistency. Further investigations should be based on possibility of fine crushed aggregate usage for SCC production.

Key words: *consistency, crushed stone aggregate, river aggregate, limestone, andesite, diabase, basalt.*

INTRODUCTION

Fresh concrete consistency should facilitate its easy transportation and placing without segregation. Internal friction is one of the most important properties of fresh concrete mix. Because of that, concrete workability may be defined as a quantity of effective internal work which is required for complete fresh concrete compaction.

There are three factors having a huge effect on concrete workability: a water – cement ratio, aggregate – cement ratio and water quantity [1, 2], which are inter-related. Research showed that for cement content from 200 to 400 kg/m^3 of concrete, the fresh concrete mix mobility depends only on the water quantity, a not on the cement paste quantity. The water quantity depends on aggregate type, particle size distribution, shape and texture of grains and quantity of fines.

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Aggregate absorption increases with its surface [3]. When all other conditions are the same, finer aggregate requires more water [4, 5, 6].

Shape and texture of fine aggregates affects the required water quantity for concrete mixing [7]. If fine aggregate properties are expressed by void percentage in looseness condition, its influence on water quantity will be as in figure 1.

Shape of rough aggregate has a significant influence on concrete mix workability, particularly the slab – like grains.

Connection between coarse aggregate angularity which is expressed by angularity number, and potential for concrete (which is made with that aggregate) compaction is shown in figure 2. The increase angularity from minimum (0) to maximum (10) value decreases compaction factor for about 9%. Angularity number is determined in relation to BS812: Part 1.

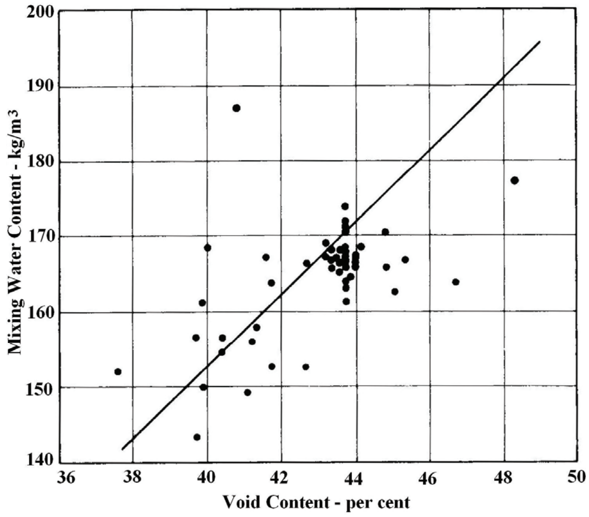

Fig. 1 Ratio between fine aggregate voids in looseness and water requrement for concrete made with that aggregate

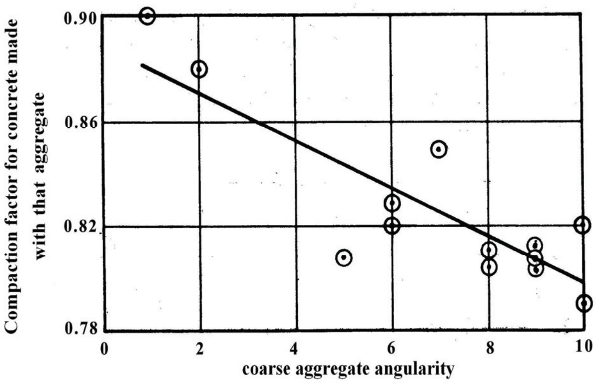

Fig. 2 Ratio between coarse aggregate angularity number and packing factor for concrete made with that aggregate

Influence of aggregate properties on concrete mix consistency decreases with the cement quantity increase, and becomes almost negligible for a small ratio aggregate – cement, about 2.5 or even 2 [8, 9].

EXPERIMENT

The main aim in concrete mix design was to obtain a variety of mixes with crushed stone aggregate. All concrete mixes were made in the same way: type of mixer, order of components dosage, mixing time, managing fresh concrete were the same. Thermohygrometrical conditions during mixing of fresh concrete measuring occurred at allowed intervals. All fresh concrete measurings were done by the same apparatuses [10]. Two different variants of mixes were made.

Variant A is concrete mix with just one type of aggregate.

Variant B is concrete mix with fine river aggregate and coarse crushed stone aggregate. Maximum grain was d_{max} = 16 mm. Experiment was conducted in the Laboratory for Building Materials at the Faculty of Civil Engineering and Architecture of Niš. The cement quantity was constant: 380 kg per a mix.

River aggregate from The South Morava river has been used in all mixes, separated in three fractions 0 – 4 , 4 – 8, 8 – 16 mm. Four sorts of crushed stone aggregates were used in experiment: limestone from stone – pit ″Koreni″ from Nišor near Pirot, andesite from stone – pit ″Velika Bisina″ near Raška, diabase from stone – pit ″Tavani″ near Ruma, basalt from stone – pit ″Zebrnik″ near Kumanovo, Macedonia. In all, there was 1850 kg of aggregate per 1m^3 of concrete.

Particle size distribution for all concrete mixes was the same (figure 3).

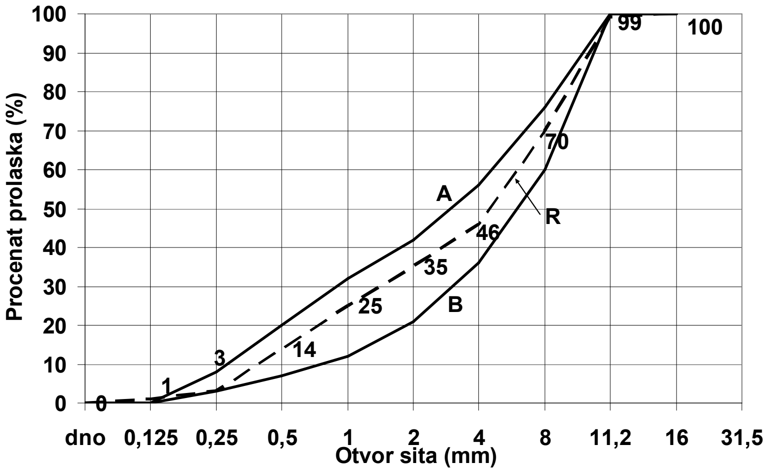

Fig. 3 Limite curves A and B and assimilated granulometric curve for benchmark concrete mixes

Three water – cement ratios were varied for every sort of aggregate: 0.45, 0.55, 0.65 to satisfy requirements for all consistencies: from liquid to stiff.

Table 1 contains data about grain density, water absorption and fines content for every sort of aggregates.

It is clear from table 1 that for concretes made from only one sort of aggregate limestone has the highest fines content, and river aggregate has the lowest fines content.

Water absorption is the highest for andesite and the lowest for limestone aggregate. For mixes, which are made from fine river aggregate and coarse crushed aggregate, the mix with diabase has the highest fines content and water absorption.

Table 1. Grain density, water absorption, fines content

River aggregate "MORAVAC"			
Fraction [mm]	Grain density [kg/m^3]	Water absorption [%]	Fines content [%]
0 – 4	2539	2,100	1,598
4 – 8	2577	1,479	0,378
8 – 16	2576	1,268	0,242
Mix R	2562	1,647	0,798
LIMESTONE, crushed			
0 – 4	2524	2,805	13,582
4 – 8	2708	0,584	0,380
8 – 11,2	2710	0,583	0,186
11,2 – 16	2837	0,435	0,264
Mix K	2647	1,579	6,389
Mix KR	2653	1,254	0,878
ANDESITE, crushed			
0 - 2	2541	2,672	7,730
2 - 4	2565	2,344	1,528
4 - 8	2742	2,897	1,492
8 – 11,2	2698	1,565	0,453
11,2 - 16	2757	2,655	0,292
Mix A	2650	2,527	3,343
Mix RA	2646	2,302	1,203
BASALT, crushed			
0 - 4	2720	2,299	12,727
4 - 8	2862	2,134	1,174
8 – 11,2	2806	2,433	0,678
11,2 - 16	2830	1,912	0,464
Mix B	2782	2,235	6,167
Mix BR	2700	2,145	1,159
DIABASE, crushed			
0 - 2	2636	2,298	4,085
2 - 4	2633	2,353	0,502
4 - 8	2636	1,455	0,635
8 – 11,2	2808	0,580	0,270
11,2 - 16	2833	0,594	0,364
Mix DR	2664	2,411	2,092

Tables 2 and 3 contain consistency values measured by slump and Vebe methods.

Table 2. Consistency values measured by slump and Vebe methods for concrete mixes A

Aggregate	Mixture	w_c	Slump value [cm]	Vebe [sec]	Consistency
river – R	R/0.45	0.45	0	18.0	Stiff
	R/0.55	0.55	4	4.4	Semi - plastic
	R/0.65	0.65	23	1.0	Liquid
limestone – K	K/0.45	0.45	0	32.3	Stiff
	K/0.55	0.55	2.5	9.2	Semi - plastic
	K/0.65	0.65	17	1.0	Liquid
andesite – A	A/0.45	0.45	0	51.8	Stiff
	A/0.55	0.55	2	7.8	Semi - plastic
	A/0.65	0.65	18	1.0	Liquid
basalt – B	B/0.45	0.45	0	57.7	Stiff
	B/0.55	0.55	1	16.4	Stiff
	B/0.65	0.65	5	7.1	Semi - plastic

Table 3. Consistency values measured by slump and Vebe methods for concrete mixes B

Aggregate	Mixture	w_c	Slump value [cm]	Vebe [sec]	Consistency
river – R	R/0.45	0.45	0	18.0	Stiff
	R/0.55	0.55	4	4.4	Semi – plastic
	R/0.65	0.65	23	1.0	Liquid
R + limestone – KR	KR/0.45	0.45	0	18.9	Stiff
	KR/0.55	0.55	7	4.3	Semi – plastic
	KR/0.65	0.65	23	1.0	Liquid
R + andesite – AR	AR/0.45	0.45	0	14.4	Stiff
	AR/0.55	0.55	5.5	5.1	Semi – plastic
	AR/0.65	0.65	24	1.0	Liquid
R + basalt – BR	BR/0.45	0.45	0	16.0	Stiff
	BR/0.55	0.55	3	8.1	Semi – plastic
	BR/0.65	0.65	19	1.0	Liquid
R + diabase DR	DR/0.45	0.45	0	13.7	Stiff
	DR/0.55	0.55	10	2.0	Plastic
	DR/0.65	0.65	25	1.0	Liquid

ANALYSIS OF CONSISTENCY RESULTS MEASURED BY SLUMP METHOD – VARIANT A

Consistency measured by Abrams' cone in function of water – cement ratio shows that for $w_c = 0.45$ consistency was stiff, figure 4.

For $w_c = 0.55$ concrete with basalt (B) had the stiffest consistency, slump value was 1 cm, and the concrete with river aggregate (R) had the least stiff consistency, slump value was 4 cm. There was no significant deviation in results for this water – cement ratio and different aggregate sorts.

For $w_c = 0.65$ the concrete with basalt (B) had the lowest slump, slump value was 5cm. This was the most significant deviation (slump value was from 17 to 23 cm).

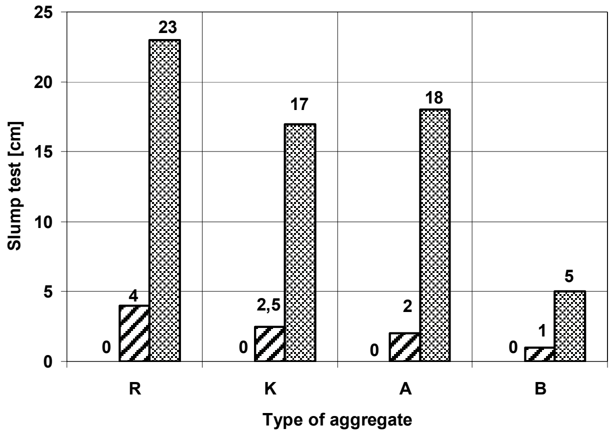

Fig. 4 Aggregate influence on concrete consistency measured by Slump method in function of water – cement ratio (Variant A)

As it is shown in figure 5, when water – cement ratio increases, differences between slump values for different concretes increase too. The concrete mixes with river aggregate (R) have the highest slump values. Concrete mixes with limestone (K) and andesite (A) have almost same regression curves and concretes made with basalt (B) have the lowest slump values.

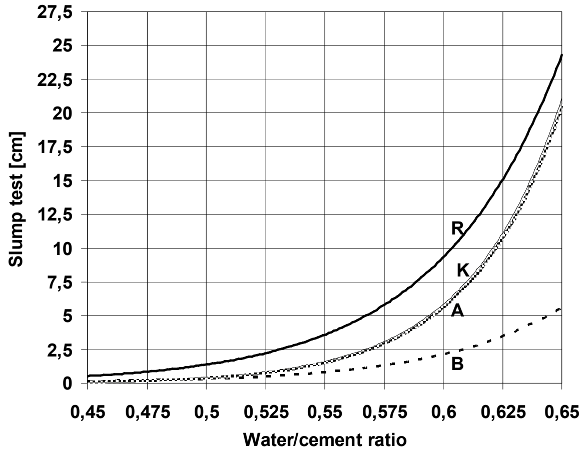

Fig. 5 Water-cement ratio influence on concrete consistency depending on aggregate measured by slump method – variant A

Analysis of Consistency Results Measured by Slump Method - Variant B

For water-cement ratio 0.45 consistency was stiff for all concrete mixes, regardless of aggregates (figure 6).

For water- cement ratio 0.55 concrete mix DR/0.55 (mix of river aggregate and diabase) had the highest slump value 10 cm; concrete mix BR /0.55 (mix of river aggregate and basalt) had the lowest slump value 3 cm. Aggregate influence dominates for this water- cement ratio [11].

For water-cement ratio 0.65 slump values are almost the same. For high water-cement ratio water quantity dominates the aggregate [12].

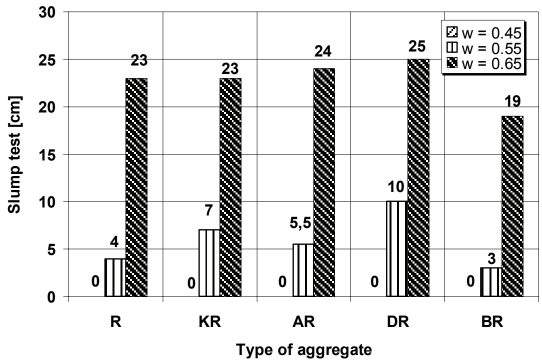

Fig. 6 Aggregate influence on concrete consistency measured by slump method depending on water-cement ratio (variant B)

As it is shown in figure 7, concrete mixes DR (river aggregate + diabase) for all water-cement ratios have the highest slump values, and concrete mixes BR(river aggregate + basalt) have the lowest slump values. Diagrams for other mixes are the same. It should be noticed that different aggregates can have same slump values for concretes with different workability. For mixes with semi – plastic and stiff consistency better results for further analyses gives Vebe method [13].

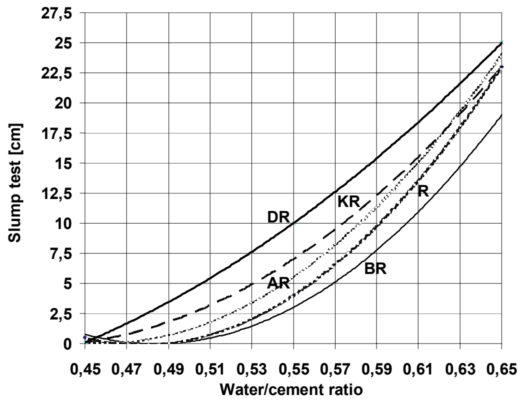

Fig. 7 Water-cement ratio influence on concrete consistency depending on aggregate measured by slump method (variant B)

ANALYSIS OF CONSISTENCY RESULTS MEASURED BY VEBE METHOD – VARIANT A

Concrete consistency, measured by Vebe method depending on aggregate and water – cement ratio (figure 8), for water – cement ratio 0.45 was stiff for all mixes. Concrete B/0.45 – basalt (57.7 Vebe's seconds) had the highest stiffness. As it is expected, the benchmark concrete R/0.45 had the lowest stiffness value (18 Vebe's seconds).

For water-cement ratio 0.55, the mix with basalt had the highest stiffness (16,4 Vebe's seconds), and concrete with river aggregate R/0.55 had the lowest stiffness value (4,4 Vebe's seconds). For water-cement ratio 0.65, concrete with basalt B/0.65 had the highest stiffness B/0.65 (7,1 Vebe's seconds), significantly different than other three mixes (R/0.65, K/0.65 i A/0.65).

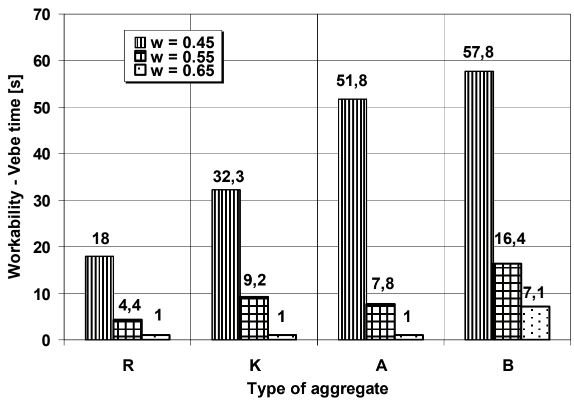

Fig. 8 Aggregate influence on concrete consistency measured by Vebe method depending on water-cement ratio (variant A)

From diagrams in figure 9 it can be noticed that concrete mixes with basalt (B) had the highest stiffness values, and the benchmark concrete R (with river aggregate) had the lowest stiffness values.

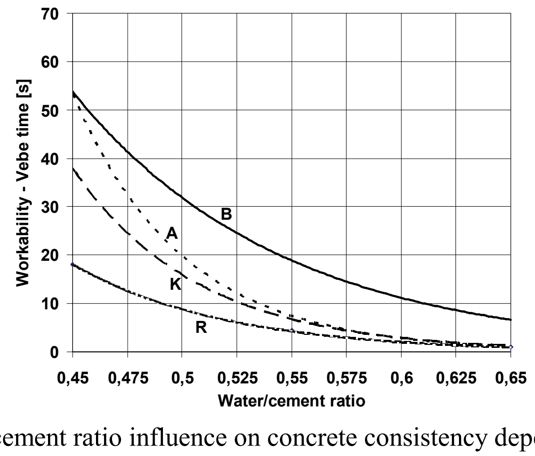

Fig. 9 Water-cement ratio influence on concrete consistency depending on aggregate measured by Vebe method (variant A)

ANALYSIS OF CONSISTENCY RESULTS
MEASURED BY VEBE METHOD – VARIANT B

In this variant (figure 10) for different water – cement ratios (0.45 and 0.55) consistency values were different. The benchmark concrete had the highest stiffness for water – cement ratio 0.45 (20.6 Vebe's seconds) and the lowest stiffness had the mix DR (13.7 Vebe's seconds). The mix BR (river aggregate + basalt) had the highest stiffness for water – cement ratio 0,55, and the lowest stiffness had the mix with fine river aggregate and coarse diabase aggregate DR (2 Vebe's seconds). For water – cement ratio 0.65 all values were the same. The concrete mixes with fine river aggregate and coarse diabase aggregate DR than all other mixes (figure 11) had lowest stiffness value.

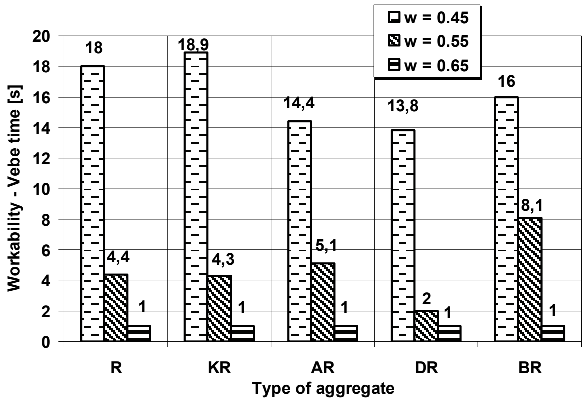

Fig. 10 Aggregate influence on concrete consistency measured by Vebe method depending on water-cement ratio (variant B)

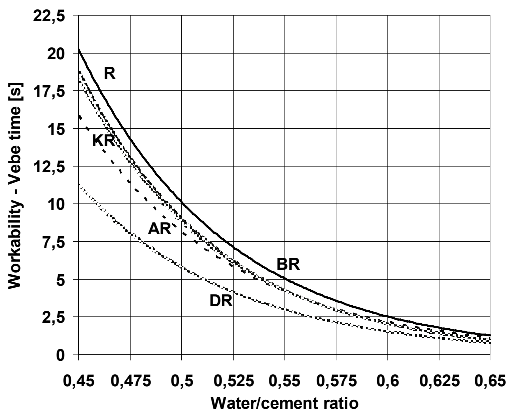

Fig. 11 Water-cement ratio influence on concrete consistency depending on aggregate measured by Vebe method (variant B)

CONCLUSION

The most important conclusions drawn from these results are:

The data of consistency, which either obtained by the Abrams' method or by Vebe method have an excellent accordance.

When water–cement ratio increases from 0.45 to 0.65, concrete consistency changes from stiff to liquid regardless of the aggregate.

In mixes with crushed stone aggregate, fine crushed stone aggregate had unfavorable influence on fresh concrete consistency.

Imperfections of fine crushed stone aggregate disappear after replacing it with first fraction of river aggregate.

In the analyzed mixes, for water–cement ratio 0.55, there is an important influence of aggregate sort on concrete consistency. Sort of aggregate had a small influence on consistency for water–cement ratio 0.65.

For concrete mixes made with fine river and coarse crushed stone aggregate, the influence of aggregate sort on concrete consistency decreases with the increase of the water–cement ratio.

For modern concrete production, usage of plasticizers is necessary. Introduction of this important parameter is aim for further investigations. The results from this research could show different influence of aggregate sort on concrete consistency. This investigation leads to further researches about possible use of fine crushed stone aggregate in Self – Compacting Concrete production [14, 15].

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UTICAJ VRSTE DROBLJENOG MINERALNOG AGREGATA NA KONZISTENCIJU SVEŽEG BETONA

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Osnovni razlog za eksploataciju drobljenog mineralnog agregata je potreba za građenjem konstrukcija od betona, ali se pri tome mora voditi računa o zaštiti životne stredine, vodenih resursa i sl. U radu je razmatran uticaj drobljenog mineranog agregata na konzistenciju betona. Korišćen je rečni agregat kao etalon, a od drobljenih agregata: krečnjak, andezit, diabaz i bazalt.

Došlo se do zaključka da sitan drobljeni agregat ima značajnog uticaja na konzisteniju betona tako što smanjuje njegovu obradljivost i ugadljivost. Zamenog istog rečnim, poboljšava se obradljivost betona. Vrsta krupnog agregata utiče na ostvarenu konzistenciju. Dalja istraživanja treba nastaviti u smeru iskorišćenja sitnog drobljenog agregata za projektovanje SCC betona.

Ključne reči: *konzistencija, drobljeni mineralni agregat, krečnjak, andezit, diabaz, bazalt, rečni agregat*