Science of Sintering, **48** (2016) 87-99

doi: 10.2298/SOS1601087T

UDK 666.982.7; 622.785

Impact of Crushed Mineral Aggregate on the Pumpability of Concrete during Transport and Placement

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Abstract:

In the spirit of the sustainable buildings, and with the goal of protection of river courses, in the near future an already announced directive ordering closing down of a large number of river aggregate dredging operations will be adopted. For that reason, usage of crushed mineral aggregate in concrete mixes is increasing. Irrespective of downsides of the fined crushed mineral aggregate, such as the presence of fine particles bordering the upper permissible limit and the unfavorable shape of the grain of the course aggregate for obtaining liquid consistency required for the pumpable concrete, the demanded pumpability of concrete during transport and placement has been achieved.

By adding admixtures to concrete, the required concrete properties, such as: frost resistance, simultaneous frost and salt resistance and water tightness have been achieved.
Keywords: Aggregate, Concrete, Pumpability, Transport, Placement

1. Introduction

Concrete has a high degree of heterogeneity, and it may be assumed to be a multiphase material consisting of coarse aggregate embedded in mortar matrix and an interfacial zone between the particles of coarse aggregate and the hydrated cement paste.

Since approximately 75% of the concrete volume is occupied by the aggregates for which around 45% are coarse aggregate, it is assumed that the aggregate properties greatly affect the durability and the structural performance of concrete material. The transition zone is about 10–50 μm thick and it is generally the weaker component of concrete, consequently it has a major influence on the mechanical behavior of concrete compared to its volumetric

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importance [1,2].

In the earlier times, aggregate was considered an inert material, incorporated in the cement paste, for the economizing purposes. Nowadays, aggregate is considered a primary building material, which is bound by the cement paste into a cohesive unity. In fact, aggregate is not inert in terms of its physical and thermal, and sometimes of its chemical properties, so it has an impact on the concrete performance [3].

Aggregate is less costly then cement, so it is cost-effective to use as much aggregate, and as little cement as possible. However, economy is not the only reason for which aggregate is used. It helps in achieving considerable technical advantages in concrete, providing much more enhanced stability of volume and much better durability than the cement paste alone[4,5].

The previous statements suggest that when designing concrete mixes of required properties, it is very important to select an aggregate adequate for the required properties of concrete [6].

River aggregate is prevalently used in concrete mix design in Serbia. However, in terms of sustainable construction and with a goal to preserve the river courses, in the recent period it has been attempted to close down a large number of dredging operations. The law, prohibiting dredging of river aggregate has not been enacted yet, but it has been in force in many surrounding EU countries.

As for the crushed mineral aggregate, the following should be emphasized:

All the aggregate grains once belonged to a large rock mass, which disintegrated under the weathering and erosion effects, or it was crushed using machinery. For that reason, many aggregate properties depend on the original rock properties: on its chemical and mineral composition, petrographic description, specific gravity, toughness, strength, physical and chemical stability, porosity, color. On the other hand, aggregate possesses some properties which were not present in the original rock, such as the size and form of grains, surface texture, water absorption, etc. all those properties can have an important impact on concrete quality – both in fresh and hardened states [7,8].

Even though all these properties can be examined separately, it is extremely difficult to provide a precise definition of a good aggregate; it can only be said that it is the aggregate which allows making good concrete under given circumstances and for a specific purpose [9].

There are cases, when aggregate is not suitable for some of its properties but it can still be used for making good concrete. For instance, a sample of a rock can disintegrate under the frost action, but it does not mean that aggregate made of that rock will disintegrate in concrete, regarding that grains are enveloped and protected by the cement paste which has a poor thermal conductivity. However if an aggregate proves to be dissatisfactory in terms of several criteria, there is a low probability it would help constitute good concrete. Accordingly, testing of stone aggregate helps us evaluate how suitable or unsuitable it is for making concrete [10,11].

1.1. Physical properties of aggregates

The physical properties of aggregates are those that refer to the physical structure of the particles that make up the aggregate, and those are: absorption, porosity and permeability.

The internal pore characteristics are very important properties of aggregates. The size, the number, and the continuity of the pores through an aggregate particle may affect the strength of the aggregate, abrasion resistance, surface texture, specific gravity, bonding capabilities, and resistance to freezing and thawing action.

Absorption relates to the particle's ability to take in a liquid.

Porosity is a ratio of the volume of the pores to the total volume of the particle.

Characteristics controlled by porosity are: Density: a) Apparent specific density: Density of the material including the internal pores. b) Bulk density Bulk density (dry-rodded unit weight) weight of the aggregate that would fill a unit volume: affects the following concrete behavior: mix design, workability, and unit weight. Permeability refers to the particle's ability to allow liquids to pass through. If the rock pores are not connected, a rock may have high porosity and low permeability [12].

Surface texture

Surface texture is the pattern and the relative roughness or smoothness of the aggregate particle.

Surface texture plays a big role in developing the bond between an aggregate particle and a cementing material. A rough surface texture gives the cementing material something to grip, producing a stronger bond, and thus creating a stronger portland cement concrete. Surface texture also affects the workability and the water requirements of portland cement concrete [13].

Strength and elasticity

Strength is a measure of the ability of an aggregate particle to stand up to pulling or crushing forces.

Elasticity measures the "stretch" in a particle. High strength and elasticity are desirable in aggregate base and surface courses. These qualities minimize the rate of disintegration and maximize the stability of the compacted material. The best results for portland cement concrete may be obtained by compromising between high and low strength, and elasticity. This permits volumetric changes to take place more uniformly throughout the concrete [14].

Density and specific gravity

Density is the weight per unit of volume of a substance. Specific gravity is the ratio of the density of the substance to the density of water.

Aggregates voids

There are aggregate particle voids, and there are voids between aggregate particles. As solid as aggregate may be to the naked eye, most aggregate particles have voids, which are natural pores that are filled with air or water. These voids or pores influence the specific gravity and absorption of the aggregate materials.

The voids within an aggregate particle should not be confused with the void system which makes up the space between particles in an aggregate mass. The voids between the particles influence the design of hot mix asphalt or portland cement concrete [15].

Particle shape

The shape of the aggregate particles affects such things as the workability and the strength of portland cement concrete. Crushed aggregate have irregular, angular particles that tend to interlock when compacted or consolidated. The crushed stone or crushed gravel aggregate concrete mix is somewhat difficult to place. To improve the workability, many mixes contain both angular and round particles. The coarse aggregate particles are usually crushed stone or crushed gravel, and the fine aggregate particles are usually natural sand [15].

Fig. 1. show aggregate characteristics that affect concrete properties [16].

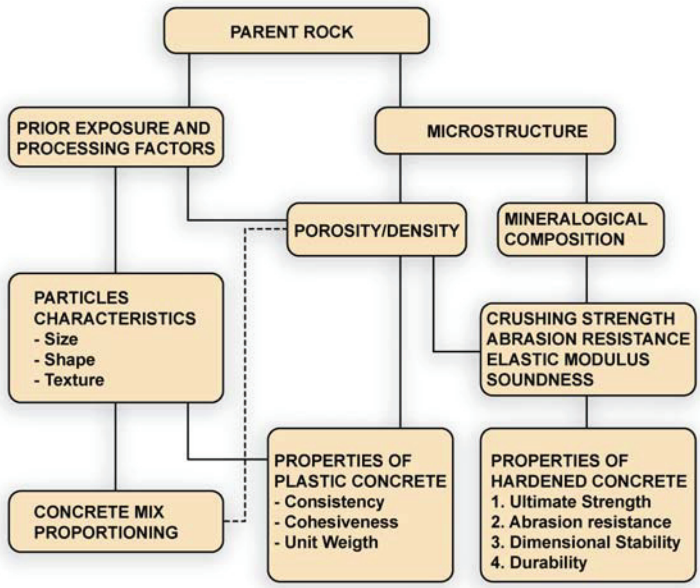


Fig. 1. Aggregate characteristics that affect concrete properties [16].

1.2. Slump loss of concrete

Loss of workability of concrete with time, often referred to as slump loss, is very important in construction practice, particularly with ready-mixed concrete where long haul times and delays on site are common. Slump loss occurs due to the effects of cement hydration, evaporation, and absorption of water in the case of dry aggregate; its rate is influenced mainly by cement characteristics, cement content, water/cement ratio, ambient and concrete temperature, initial slump and presence of admixture [17–20].

The coarse and fine aggregates generally occupy 70–80% of the concrete volume and have an important influence on its fresh and hardened properties. Most normal-weight aggregates (fine and coarse) have absorption capacities in the range of 1–2% by weight of aggregate [21,22].

The water absorption rate of typical limestone aggregates is high when the aggregates are first wetted but rapidly decreases with time [23,24]. Slump loss, affected by the moisture condition of aggregates, is expected to be greater with dry aggregates because of the absorption of water by aggregates [25,26]. The use of aggregates in dry condition is common in arid regions.

1.3. Concrete for pumping

The concrete mix design must be correctly proportioned so that the concrete will flow easily and uniformly through the pipe-line. The pipe diameter should be 3.5 to 4 times greater than the maximum aggregate size in the concrete. This helps ensure that the pipeline will not become blocked. Another factor in mix design is the consistency (slump or flow test) of the concrete. A higher consistency will allow the concrete to move more readily within the pump and pipe-line. However, an excessively high slump can cause the concrete to segregate resulting in plugs of coarse dry material in the pump or pipe-line, the paste being squeezed out.

What makes concrete pumpable? Pumpable concrete must be capable of being pushed under pressure through a pipe-line as a cylinder, separated from the pipe wall by a lubricating layer of mortar (water, cement, and sand). A concrete mix must be such that the concrete can pass through reducers in the pipeline system, and can go around bends in the line. In order to obtain this type of pumpability, the mix must be dense, cohesive, and have a sufficient paste and mortar fraction to minimize voidage. The mortar volume required depends on the line size, efficiency of concrete pump, and pressure available for pumping the concrete [27,28].

Viscosity Modifying Admixtures for Pumping Concrete: for both economic and technical reasons pumped concrete has gained increasing importance over recent years but as a result of developments in construction practice, the requirements on pumped concrete have become more demanding and have approached the limits of normal concrete technology. Viscosity Modifying Admixtures are used to meet these demands and to reduce fluctuations in concrete performance. The most common problem with pumping concrete occurs when the coarse aggregate particles start to lock together, usually at a bend or other slight constriction. The pump pressure forces the lubricating mortar fraction to separate from the mix, leaving a plug of coarse aggregate which eventually blocks the line. Traditionally this has been solved by increasing the fines content of the mix but is not always technically and economically acceptable and may not be effective in the most demanding applications. The Viscosity Modifying Admixtures is a more effective solution, preventing this segregating effect by making the concrete more cohesive without the need to change the mix design [29].

The benefits of using a VMA include:

• Prevent blockages by allowing the concrete to remain fluid, homogeneous and resistant to segregation, even under high pumping pressures
• Increased output when used in combination with a superplasticizer to give optimal pumping pressure.
• Reduced wear due to lubrication effect of the admixture
• Assists pump restart by preventing segregation in static lines [30].

2. Materials and Experimental Studies

In the Laboratory of building materials of the Faculty of Civil Engineering and Architecture of Niš, nine concrete mixes where made, the requirements being the liquid consistency by slump test (Abrams's cone) S4 on the placing location, for the duration of transport of 30 minutes. Concrete is placed by a pump. The hardened concrete properties required are compressive strength and some special properties such as: frost action resistance, simultaneous frost and salt action resistance and water tightness of concrete. Within the mentioned mixes, two concrete mixes satisfying conditions for making piles were made.

The mix designs for infrastructural structures such as bridges are regulated by the codes, i.e. maximum allowed total water/cement ratio is 0.50. This condition was met. Maximum grain size diameter was 16 mm. In order to provide frost action resistance according to the national standard BAB 87, the required percentage of entrained air was 5 to 7 %. In order to achieve liquid consistency S4, minimal water/cement ratio 0.50, required previously mentioned special properties of concrete, as well as the pumpability of concrete for the transport time of 30 minutes, two admixtures were used. One was a hyperplasticizer type, while the other was air-entraining agent. It should be emphasized that making of concrete mixes went on at the air temperature of 20 ^{0}C+- 2^{0}C and relative humidity of 65 % + 5 %.

The following concrete mixes were made: MB20/III M100 V6 MS“0”; MB25/III M100 V8 MS“0”; MB30/III M150 V8 MS“0”;MB30/III M100 V6 MS“0” for piles; MB35/III M100 V8 MS“0” for piles; MB35/III M200 V8 MS“0”; MB40/III M150 V8 MS“0”;MB45/III M200 V8 MS“0”; MB50/III M200 V6 MS“0”.

For making of concrete mixes was used the cement “Holcim” Novi Popovac designated CEM II A-L 42,5R and Holcim CEM I 52.5 R (for concrete classes 45 and 50).

Two types of aggregate were used: crushed stone fractionated aggregate, fractions 0/4, 4/8 and 8/16 mm, manufacturer „Budućnost“ a.d. Preševo and river separated aggregate, fraction 0/4 mm, manufacturer „5D“.

Admixtures used were: Sika Viscocrete 3070 and Sika Aer. Sika Viscocrete 3070 is a hyperplasticizer made on the basis of modified polycarboxylates for medium concrete transport and summer placing conditions. It is used for: classical, pumped and SCC concretes, workability and placing capability of concrete are improved, and provides higher ultimate strengths. The water used was from the city water supply network. Prior to making of concrete mixes, particle size distribution of fractions of crushed limestone aggregate and fine river aggregate was tested. Maximum grain size was 16 mm. Particle size distribution of fraction 0/4 mm, 4/8 mm and 8/16 mm crushed limestone aggregate as well as of fraction 0/4 mm of the river aggregate is shown in Fig. 2.

Fine aggregate was made as a mixture of crushed limestone and fine river aggregate in a 50% : 50% ratio, Fig. 3.a. Prior to adopting this ratio, several test mixes were made, where fine limestone and river aggregate were mixed in 40%:60% ratio. However, the required pumpability of concrete could not be achieved. Afterwards, the available fractions of graded aggregate were used to make the most favorable particle size distribution of aggregate mixture in accordance with the EMPA curves, Fig. 3.b.

Particle size distribution of the mix is: 0/4 mm 50% - crushed limestone aggregate 50% and river aggregate 50% ; 4/8 mm 15% - crushed limestone aggregate and 8/16 mm 35% - crushed limestone aggregate.

Methods of examinations were: Making and curing of test specimens for strength tests: SRPS ISO 2736-2:1997;Determination of compressive strength of test specimens:SRPS ISO 4012:2000;Slump test: SRPS ISO 4109:1997; Determination of air content of freshly mixed concrete – SRPS ISO 4848:1999.

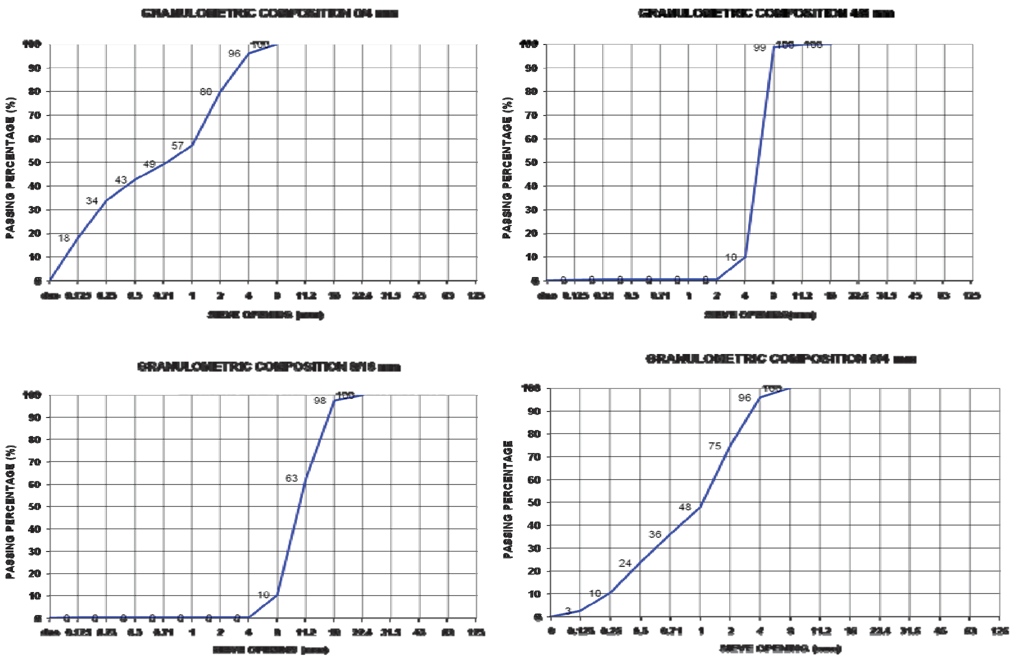
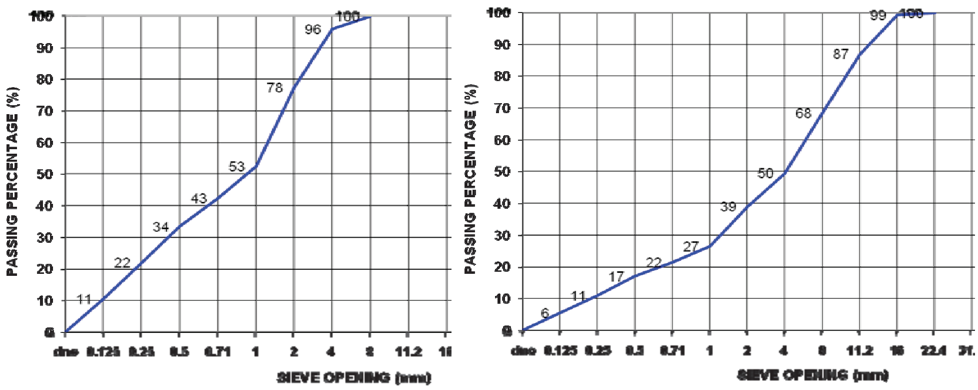


Fig. 2. Particle size distribution of fractions 0/4 mm, 4/8 mm and 8/16 mm of the crushed limestone aggregate as well as of fraction 0/4 mm of the river aggregate.

Pressure method were: Concrete, hardened: Determination of density: SRPS ISO 6275:1997; Concrete, compacted fresh:Determination of density:SRPS ISO 6276:1997;

Measuring temperature of concrete:SRPS U.M1.032:1981.

Used standards and codes were: Design of concrete mixtures category B.II: Code for concrete and reinforced concrete (PBAB 87); Dimensions, tolerances and applicability of test specimens:SRPS ISO 1920:1997; Classification by compressive strength: SRPSU.M1.021:1997; Classification of consistency: SRPS ISO 4103:1997.



3.a. 3.b.

Fig. 3. a) Particle size distribution of the mix of crushed and river ggregate fraction 0/4 mm (50% crushed and 50% river aggregate), **b)** Granulometric composition of the mix.

3. Results and discussion

In Tab. I. were provided data on the composition of concrete mixes, and in Tab. II, data on the fresh concrete.

Compressive strengths of hardened concrete were measured after 2,7 and 28 days. In Tab. III and Fig. 4 were presented the obtained values of compressive strengths of the made concrete mixes.

On the basis of the obtained results of fresh and hardened concrete, the following can be concluded:

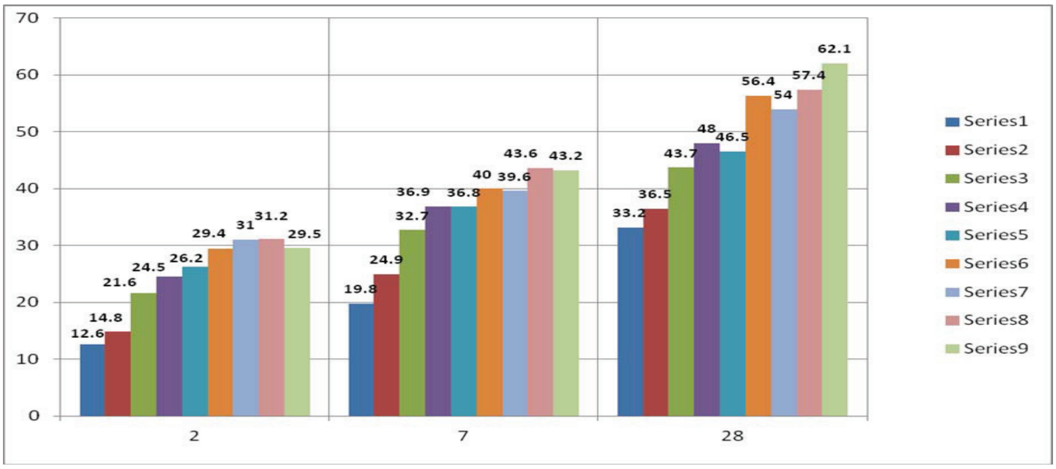
- In order fulfill the liquid consistency condition in design of concrete mixes, it was necessary to mix the fine crushed river or limestone aggregate in 50%: 50% ratio. This reduced the percentage of passage of particles smaller than 0,125 from 18% to 11%.
- Particle size distribution of the curve was adopted between the bordering curves A and B (Empa curves) for the maximum grain size of the aggregate of 16 mm. It was intended to increase the share of fine aggregate in order to achieve liquid consistency and pumpability of concrete, without risking obtaining of required compressive strengths.
- For making of concrete mixes, cement designated CEM II A-L 42.5R was used. For mixtures MB 45 and MB 50, cement CEM I 52.5 R was used. The necessary condition for concrete mix MB 45 was stated, because it was intended for making a concrete mix for pre-stressed elements. As for concrete mix MB 50, the condition was given in order to achieve the required strength, so cement of the class 52.5 was adopted.

It was required that w/c factor was 0.50 maximum. In order to observe this and the liquid consistency requirements, Sika Viscocrete 3070 hyperplasticiser on the basis of modified polycarboxylates for medium concrete transport duration and summer conditions of placing was used. Since it is used for classic, pumped and SCC concretes, improving workability and placing capacity of concrete and provides higher ultimate strengths, the required conditions were achieved. It is important to point out that hyperplasticizers which are used for SCC as well make it possible to obtain the required pumpability for design of concrete mixes with a high percentage of fine particles of 0.125.

Tab. I Data on composition of concrete mixes.

Concrete mix number	Qunatity of cement per 1 m^3 of concrete	Quantity of water	Quantity of aggregate per 1m^3 by fractions: 0 -4mm river% i [kg]	0-4 mm crushed % i [kg]	4-8 mm crushed % i [kg]	8-16 mm crushed % i [kg]	Sika Viscocrete 3070 admixture quantity added on making of concrete mixes	Sika Viscocrete 3070 admixture quantity added on the location of placing
	kg	kg	50%		15%	35%	kg	kg
CEM II A-L 42,5 R								
1	300	150	50% 475	50% 475	286	665	1,2% + 0,2% or 3,60 kg + 0,60 kg	0,01% or 0,03 kg
2	320	160	462	462	278	648	1,2% + 0,2% or 3,84 kg + 0,64 kg	0,01% or 0,032 kg
3	340	196	460	460	276	644	1,2% or 4,08 kg	0,01% or 0,034 kg
4	400	196	437	437	263	613	0,6% + 0,1% or 2,40 kg + 0,40 kg	0,01% or 0,040 kg
5	450	202,5	425	425	255	595	0,5% or 2,25 kg	0,01% or 0,045 kg
6	380	190	440	440	264	616	0,01% or 0,040 kg	0,01% or 0,038 kg
7	400	180	442	442	266	620	1,2% or 4,80 kg	0,01% or 0,040 kg
CEM I 52,5 R								
8	420	176,4	442	442	266	720	1,0% or 4,20 kg	0,01% or 0,042 kg
9	440	171,6	440	440	264	616	1,1% + 0,1% or 4,84 kg + 0,44 kg	0,01% or 0,044 kg

In order to make concrete resistant to frost action and simultaneous action of frost and salt, air-entraining agent Sika Aer was added. This provided the conditions of air entrainment in fresh concrete from 5% do 7%. The entrained air reduces compressive strengths of concrete. However, the required values were obtained.



Time [days]

Fig. 4. Compressive strength [N/mm^2] after 2, 7 and 28 days for the made concrete mixes.

- In designing concrete mixes for the piles, mixtures 4 and 5, the condition according to BAB 87 was that the minimum amount of cement for MB 30 was 400 kg of cement, and for MB 35

for piles 450 kg.
- It was observable that in those two mixes, there were no considerable differences in the obtained compressive strengths. The reason for this is that the used amount of cement of 450 kg per 1 m^3 of concrete exceeded the maximum amount of cement for that concrete mix. After maximum amount of cement is used for making of concrete mix, the strength values remain the same or start to decrease [3].

Tab. II Fresh concrete data.

No. of mix designs	Air temperature in the laboratory °C	Air temperature in the laboratory °C	Air temperature in the laboratory °C	Classification of consistency by slump	Air content of fresh mixed concrete %	Density kg/m^3
1	20,9	19,1	21,5	S4 (180 mm) after 10 min S4 (150 mm) after 30 min	5,0	22358
2	20,4	18,2	21,9	S4 (180 mm) after 10 min S4 (150 mm) after 30 min	5,1	2238
3	20,1	20,7	22,4	S4 (190 mm) after 10 min S4 (190 mm) after 30 min	5,7	2350
4	18,7	17,8	20,7	S4 (170 mm) after 10 min S4 (190 mm) after 30 min	6,1	2324
5	17,5	16,7	19,1	S4 (160 mm) after 10 min S4 (170 mm) after 30 min	5,2	2332
6	17,1	16,5	20,8	S4 (180 mm) after 10 min S4 (160 mm) after 30 min	5,0	2350
7	18,0	17,3	21,3	S4 (180 mm) after 10 min S4 (210 mm) after 30 min	6,1	2360
8	20,2	19,5	22,7	S4 (190 mm) after 10 min S4 (160 mm) after 30 min	5,3	2367
9	19,6	22,4	20,0	S4 (190 mm) after 10 min S4 (170 mm) after 30 min	5,2	2380

- The amount of added hyperplasticizer was added during making of concrete mixes. Regarding that during the mixing time of 30 minutes (simulated transport time), there was a drop in consistency, for mixes was defined a necessary subsequent amount of hyperplasticizer to be added on the location of placing.
- All the compressive strengths obtained at 28 days, according to the BAB 87 requirements, Code for concrete and reinforced concrete had to be higher for 8 N/mm^2 than the required concrete class. This condition was observed, and for some mixtures, even higher values of compressive strength were achieved.
- All concrete mixes met the required special properties, frost resistance – there was no onset of flaking or cracks, resistance to simultaneous action of frost and salt MS „0“ and when it concerns water tightness of concrete, the water penetration was maximum 10 mm.
- All concrete mixes were made in laboratory conditions:: temperature 20 + 2^0 C, relative air humidity was 65 + 5 %. It should be pointed out that the construction site conditions of concrete factories, during transport and placement of concrete are different. According to that the correction of admixture dosage should be made.

Tab. III Data on the hardened concrete, density of hardened concrete and obtained values of compressive strengths after 2, 7 and 28 days for the made concrete mixes.

Concrete mix	Age [Days]	Density [kg/m^3]	Compressive strength [N/mm^2]
1	2	2344	12,6
	7	2343	19,8
	28	2346	33,2
2	2	2335	14,8
	7	2333	24,9
	28	2329	36,5
3	2	2344	21,6
	7	2339	32,7
	28	2334	43,7
4	2	2327	24,5
	7	2323	36,9
	28	2314	48,0
5	2	2320	26,2
	7	2317	36,8
	28	2307	46,5
6	2	2340	29,4
	7	2341	40,0
	28	2338	56,4
7	2	2350	31,0
	7	2349	39,6
	28	2347	54,0
8	2	2364	31,2
	7	2365	43,6
	28	2361	57,4
9	2	2362	29,5
	7	2370	43,2
	28	2369	62,1

4. Conclusion

It is best to mix the crushed fine limestone aggregate in the composition of concrete adapted for required conditions of liquid consistency, pumpability and transport time with the fine river aggregate in (50% : 50%) ratio. This reduces the share of the particles smaller than 0.125 mm, and this accomplishes the required w/c factor, consistency, i.e. pumpability of concrete.

The maximum percentage of fine aggregate of 50 % was adopted when particles size composition of the mix was designed, in regard of the boundary Empa curves. The reason for this is the required liquid consistency of concrete at the location of placing and pumpability of concrete.

By implementing coarse limestone aggregate for obtaining of concrete mixtures of the required properties, the required compressive strengths were achieved such as 45 and 50 N/mm^2 with maximum grain size of 16 mm, which is difficult to achieve with the available river aggregate. This confirms the higher contribution of coarse limestone aggregate to the compressive strengths in comparison to the available coarse river aggregate.

The required liquid consistency of concrete, i.e. pumpability of concrete was achieved. However, it decreases in time, so this has to be considered in the real construction site conditions. It is necessary to add a certain dose of hyperplasticizer at the concreting location.

It should be emphasized that the technical conditions of the manufacturers which have a certain amount of hyperplasticizer which should be added to the concrete mix are provisional, and different for each concrete mix. This should be corroborated making of preliminary concrete mixes.

5. Acknowledgements

The work reported in this paper is a part of investigation within the research project TR 36017 „Utilization of by – products and recycled waste materials in concrete composites in the scope of sustainable construction development in Serbia: investigation and environmental assessment of possible applications“supported by Ministry for Science and Technology, Republic of Serbia. This support is gratefully acknowledged.

6. Reference

1. J. Zhang, P. C. Taylor and C. Shi, "Investigation of Approaches for Improving Interfacial Transition Zone-Related Freezing-and-Thawing Resistance in Concrete Pavements", Materials Journal, Vol. 112(5) (2015), pp. 613-618.
2. K. Lijuan, D. Yuanbo, "Interfacial Interaction of Aggregate-Cement Paste in Concrete", Journal of Wuhan University of Technology-Mater. Sci. Ed., Vol. 30(1) (2015), pp. 117-121.
3. A. M. Neville, and J. J. Brooks, Concrete technology, Longman Group Ltd., Essex CM20 2JE, 1990. (in England)
4. O. Sengul, C. Tasdemir, and M. A. Tasdemir; „Influence of aggregate type on mechanical behaviour of normal and high-strength concretes". Materials Journal, 99(6) (2002), pp. 528–533.
5. C.F. Goble and M.D. Cohen, " Influence of aggregate surface area on mechanical properties of mortar". Materials Journal, 96(6) (1999), pp. 657–662.
6. P.C. Aitcin and P.K.Mehta,"Effect of coarse aggregate characteristics on mechanical properties of high-strength concrete", Materials Journal, 87(2) (1990), pp. 103–7.
7. A. Cetin and R. L. Carrasquillo, "High-performance concrete: influence of coarse aggregates on mechanical properties", Materials Journal, 95(3) (1998) pp.252–261.
8. M.S.Meddah, S.Zitouni and S. Belâabes, "Effect of content and particle size distribution of coarse aggregate on the compressive strength of concrete", Construction and Building Materials, Vol. 24(4) (2010), pp. 505–512.
9. F.J. Luo,L.He,Z.Pan,W. H. Duan, X. L. Zhao and F.Collins,"Effect of very fine particles on workability and strength of concrete made with dune sand", Construction and Building Materials, Vol.47 (2013), pp.131–137.
10. http://www.in.gov/indot/files/chapter_03.pdf
11. X. Chen, S. Wu, and J. Zhou, " Pore Size Distribution of Cement Mortar Prepared with Crushed Limestone Sand", KSCE Journal of Civil Engineering, Vol. 20(2) (2015), pp. 762-767
12. G. Topličić-Ćurčić, Z. Grdić, N. Ristić, I. Despotović, D. Đorđević, M. Đorđević:„Aggregate Type Impact on Water Permeability of Concrete“, Romanian Journal of Materials, Vol. 42 (2) (2012), p.p. 134 – 142.

13. P. J. Tumidajski and B. Gong "Effect of coarse aggregate size on strength and workability of concrete" Canadian Journal of Civil Engineering, Vol. 33(2) (2006), p.p. 206 -213.
14. A. M. Alhozaimy ,"Effect of absorption of limestone aggregates on strength and slump loss of concrete|", Cement and Concrete Composites Vol. 31(7), (2009), p.p. 470–473.
15. C. Gonilho Pereira,J. Castro-Gomes, L. P. de Oliveira, Influence of natural coarse aggregate size, mineralogy and water content on the permeability of structural concrete, Construction and Building Materials, Vol. 23(2), (2009), p.p. 602–608.
16. http://www.ce.berkeley.edu/~paulmont/165/aggregate.pdf
17. R. W. Previte, "Concrete slump loss",. Journal Proceedings, Vol. 74 (8), p.p. 361–367.
18. P. K. Mehta, P. J. M. Monteiro, "Concrete structure, properties and materials". 2nd ed. New Jersey: Prentice-Hall; (1993). (in USA)
19. G.H. Tattersall, Workability and quality control of concrete,. E&FN Spon;.1991. (in England)
20. J.D. Dewar, R. Anderson, "Manual of ready mixed concrete", Taylor & Francis Group; 1992. (in England)
21. S. Mindess, J. F. Young, D. Darwin, "Concrete", Prentice-Hall, 2003. (in USA)
22. B. M. Arissoun , S.D. Hwang, K. H. Khayat, "Influence of aggregate characteristics on workability of superworkable concrete", Materials and Structures, Vol. 49(1),(2016), p.p. 597-609.
23. Portland Cement Association, "Principles of quality concrete"; John Wiley & Sons ,1975.(in USA)
24. M. L. K. Khouadjia, B. Mezghiche and M. Drissi, "Experimental evaluation of workability and compressive strength of concrete with several local sand and mineral additions", Construction and Building Materials Vol. 98 (2015), p.p. 194–203.
25. ACI committee 221, ACI 221R-96,"Guide for use of normal weight and heavyweight aggregates in concrete", American Concrete Institute , 1997. (in USA).
26. A. M. Neville, and J. J. Brooks, "Properties of concrete", 4th ed. Longman,1995. (in England)
27. http://www.concrete.org.uk/fingertips-nuggets.asp?cmd=display&id=554
28. M. S. Choi, Y. J. Kim, and J. K. Kim,"Prediction of Concrete Pumping Using Various Rheological Models", International Journal of Concrete Structures and Materials, Vol.8(4),(2014).pp. 269–278.
29. M. S. Choi, Y. J. Kim, K. P. Jang and S. H. Kwon, "Effect of the coarse aggregate size on pipe flow of pumped concrete", Construction and Building Materials, Vol. 66 (2014), p.p. 723–730.
30. In co-operation with EFCA The European Federation of Concrete Admixture Associations, "Guidelines for Viscosity Modifying Admixtures For Concrete", , (2006),http://www.efnarc.org/pdf/Guidelines%20for%20VMA%20(document%20180).pdf

Садржај: *У духу одрживе градње, а са циљем заштите речних токова у блиској будућности биће усвојена већ најављена директива о затварању великог броја сепарација речног агрегата. Из тог разлога, примена дробљеног минералног агрегата у саставу бетона је све више заступљена. Без обзира на неповољности које носи ситан дробљени минерални агрегат као што је присуство ситних честица на горњој дозвољеној граници и неповољан облик зрна који има крупан агрегат за добијање течне* *конзистенције која је потребна за пумпатибилни бетон, постигнут је услов захтеване пумпатибилности бетона за време транспорта и уградње.*

Додавањем адитива бетону постигнута су и посебна својсва бетона као што су: отпорност на мраз, отпорност на истовремено дејство мраза и соли и водонепропустљивост.

Кључне речи: *агрегат, бетон, пумпатибилност, транспорт, уградња*