IOP Conference Series: Materials Science and Engineering

PAPER • OPEN ACCESS

The influence of aggregate gradation on the fresh and hardened concrete properties

To cite this article: R Figmig and M Kovac 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **566** 012007

IOP Conf. Series: Materials Science and Engineering **566** (2019) 012007 doi:10.1088/1757-899X/566/1/012007

The influence of aggregate gradation on the fresh and hardened concrete properties

R Figmig[1] and M Kovac[1]

[1] Technical university of Kosice, Faculty of Civil Engineering, Institute of Environmental Engineering, Department of Material Engineering, Slovakia

Abstract. This experimental study is focused on the aggregate gradation impact on the properties of fresh and hardened concrete. For the experiment, 9 mix design were prepared with the constant content of cement, effective water, plasticizer and aggregate. The variable factor is represented by different proportions of 4 fraction (0/0.7, 0/4, 4/8, 8/16). Consistency by slump and flow table in time, compressive strength, water absorption and density were measured. Some significant differences were observed. Consistency by the slump test varied from 0 to 170 mm after 5 minutes and from 0 to 50 mm after 30 minutes of concrete mixing. Consistency by flow table varied from 340 to 530 mm after 5 minutes and 320 to 460 mm after 30 minutes. Standard compressive strength varied from 50.8 to 61.6 MPa. Water absorption varied between 4.7 and 5.9 mass % and density from 2380 to 2440 kg.m^{-3}.

1. Introduction

The properties of the aggregate, as dimension, shape as well as the texture of the grains, have crucial impact on consistency as well as on the other rheologic properties and properties in hardened state of concrete [1]. This influence is based on mutual interactions between the aggregate grains (i. e. mutual wedging, frictional forces between grains etc.) and particle movement in liquid state of fresh concrete [2]. The knowledge about aggregate influence on the properties of fresh and hardened concrete connected with this study can be presented as follows [3-8]:

1. viscosity of the fresh concrete increases with increasing quantity of fine particles (higher viscosity protects fresh concrete against stability loss, but decreases the flow velocity),
2. the need of mixing water for reaching the required consistency decreases with increasing the volume of coarse particles,
3. fine aggregate as well as fine particles needs higher volume of mixing water to achieve the required consistency of fresh concrete,
4. optimal aggregate granularity provides denser arrangement of the aggregate grains and need less cement paste to achieve required consistency; it is based on the fact, that volume of gaps is lower in the concrete with denser arrangement of aggregate,
5. fractional forces between the aggregate grains have significant impact on the overall rheology of fresh concrete,
6. the grains with rounded shape and smooth surface are optimal from the achieving fluid consistency point of view,
7. as the result of above points can be predicted, that using round shape, well grading aggregate with minimum content of powder particles from the crushing, provides denser microstructure

with lower content of voids, lower need of mixing water to achieve higher consistency, what can result in higher compressive strength and lower water absorption.

The aim of this experimental study is the observation and measuring the selected properties of fresh and hardened concrete in connection to various proportions of aggregate fractions.

2. Material and methods

2.1. Input materials

Cement CEM I 42.5 R from Ladce production factory, tap water, superplasticizer on PCE base and natural pre-crushed aggregate, were used for the experiment.
The mineralogical composition of aggregate fraction 0/4, 4/8 and 8/16 was as follows:

- biotic granodiorite up to granite – 36%
- limestones – 12%
- dolomites – 12%
- limy sandstones – 8%
- arkose quartzite – 8%

Size fractions 0/4, 4/8 and 8/16 from locality Sučany were used. Size fraction 0/0.7 was natural quartzite with almost rounded grain from locality Šajdikové Humence (Figure 1a). This fraction was used to make the overall gradation finer due to relatively coarse and angular fraction 0/4. In the figure 1b is shown the shape of the grains 1,4 – 2,0 mm from the fraction 0/4 as comparation to fraction 0/0.7.

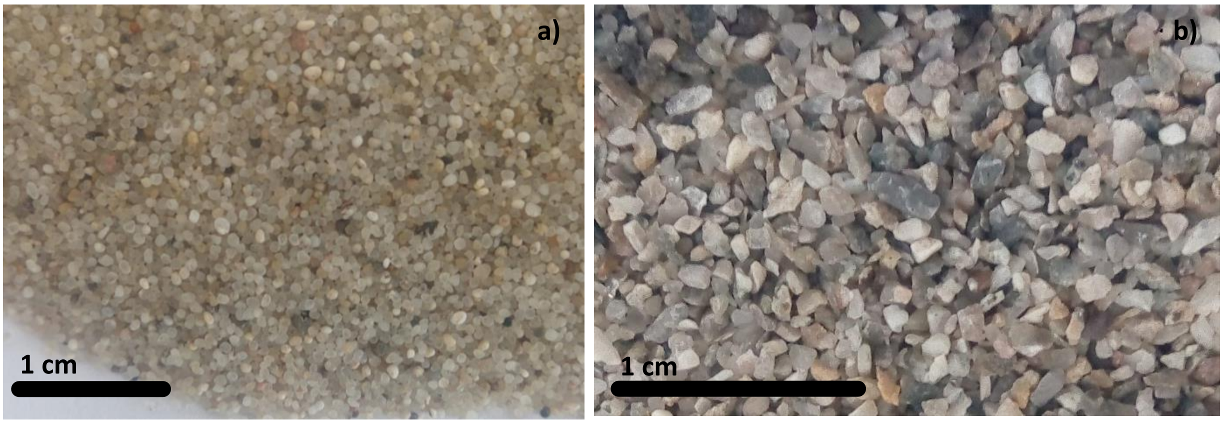

Figure 1. The shape features of used fine fractions: **a)** Siliceous sand fraction 0/0.7, **b)** Grains 1,4 - 2,0 mm from the fraction 0/4. [author]

2.2. Mix design

For the experimental study, 9 mix designs were prescribed (R1-9) with different proportion of aggregate fractions as noted in the Table 1. The amount of cement, effective water, plasticizer and overall aggregate amount were constant (Table 2) for each of the batches. According to practise, coarser granularity was chosen for the first batch. The reason for that was the experience, that for covering of finer aggregate of fraction 0/4 used in experiment is high need of cement paste (created either by cement or water or indirectly by plasticizer), what is subsequently reflected on the costs of mix design. R8 was designed as concrete with gap grading aggregate in according to prediction of better arrangement grains in microstructure to improve properties of fresh as well as hardened concrete. R9 had solely trial character. The amount of mixing water and plasticizer stayed the same for each of batches despite the fact, that the two first batches evinced the tough consistency.

Table 1. Proportion of aggregate fractions in the batches.

Fraction [%]	R1	R2	R3	R4	R5	R6	R7	R8	R9
0/0.7	0	0	10	10	10	15	15	30	25
0/4	50	55	40	40	50	55	40	0	25
4/8	0	0	0	10	0	0	0	30	25
8/16	50	45	50	40	40	30	45	40	25

Table 2. General mix design.

Material	Cement	$Water_{eff}$	Plasticizer	Aggregate	w/c [-]
Content [kg/m^3]	350	140	2.1	1915	0.4

2.3. Methods

At first, aggregate properties as water absorption (WA_{24}), apparent density (ρ_{ad}), proportion of crushed (C_c) and rounded grain (C_r), shape index (SI) and voidage V and grain-size distribution were found out. Subsequently, the amount of the fine particles under 0.25 mm was calculated. Grain-size distributions of each batch design were rendered in graph as percentage of passing materials through the sieve with specific size and compared in connection with the standard curves. The experimental study resided in the observation of changing the consistency (measured by slump (S_5 and S_{30}) and flow on the table with 15 impacts (F_5 and F_{30})) depending on the aggregate granularity of the batch in 2 time intervals (5 and 30 minutes after mixing). After measuring of consistency, specimens for testing the uniaxial compressive strength ($f_{c,150}$) (cubes, a = 150 mm^3) and for water absorption (WA) test (cubes, a = 100 mm^3) were prepared. The all samples were cured under water till the tests - 28 days. The apparent density in saturated state was calculated based on weight and dimensions. The samples for WA test were dried first at the temperature of 105±5°C till the time of fixed dried weight within the 24 hours. After cooling down they underwent the compressive strength ($f_{c,100,dried}$) test as well. This was performed as additional test for comparation with standard uniaxial compressive strength procedure.

3. Results and discussion

3.1. Aggregate properties

The results of water absorption, apparent density, proportion of crushed and rounded grain, shape index and voidage are given in the Table 3 and of sieve analysis in the Table 4.

Table 3. The properties of aggregate.

	0/0,7	0/4	4/8	8/16
WA_{24} [%]	0.5	2.0	1.0	1.0
ρ_{ad} [kg/m^3]	2650	2580	2660	2650
C_c [%]	0	83	51	75
C_r [%]	100	17	49	25
SI [%]	0	0	8	6
V [%]	-	28	38	37

Table 4. Gradation of used aggregate.

Sieve size [mm]	Overall passing material [%]			
	0/0.7	0/4	4/8	8/16
0	0	0	0	0

0.063	0.4	1.7	0.5	1.3
0.125	1.6	3.1	0.6	1.5
0.25	20.4	6.8	0.7	1.6
0.5	77.3	16.2	0.8	1.7
1	100	31.0	0.9	1.7
1,4	-	39.5	1.3	1.7
2	-	50.9	2.1	1.8
2,8	-	65.4	4.2	2
4	-	81.6	30.4	2.6
5.6	-	98.4	93.0	5
8	-	100	100	17.4
11.2	-	-	-	59.5
16	-	-	-	99.2
22.4	-	-	-	100
32	-	-	-	-

In the Figure 2, resulting grading curves of aggregate mixtures R1-R9, along with the standard curves as recommended by the technical standard for concrete [9], are given. In the figure 3, grains proportional content within each aggregate curve design is given.

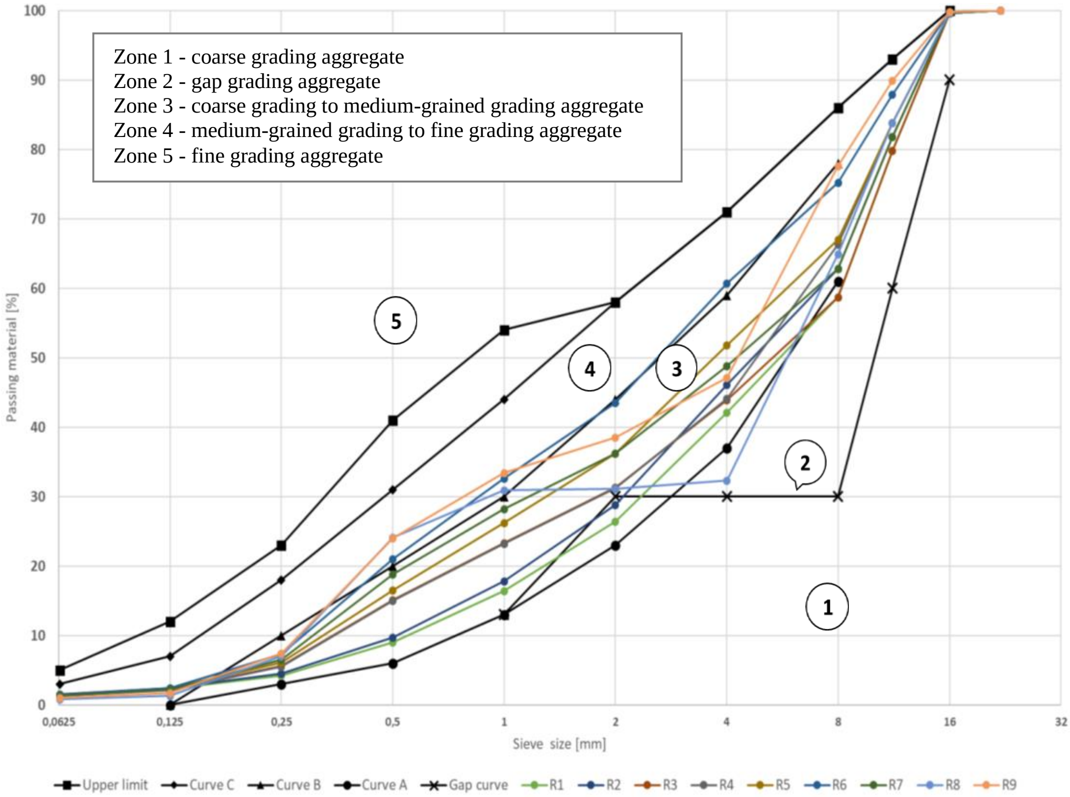

Figure 2. The aggregate grading curves of mix designs R1-9 along with the standard curves.

From the Figure 2 can be observed, that major aggregate mix design curves (R 1, 2, 3, 4, 5, 7) are located in Zone 3 what is in accordance with design stated in part 2.2. Curve R6 almost copy standardised curve B what can be considered to be optimal grain-size curve by technical standard. Curve R8 has gap-curve character. Curve R9 particularly extends to the Zone 4.

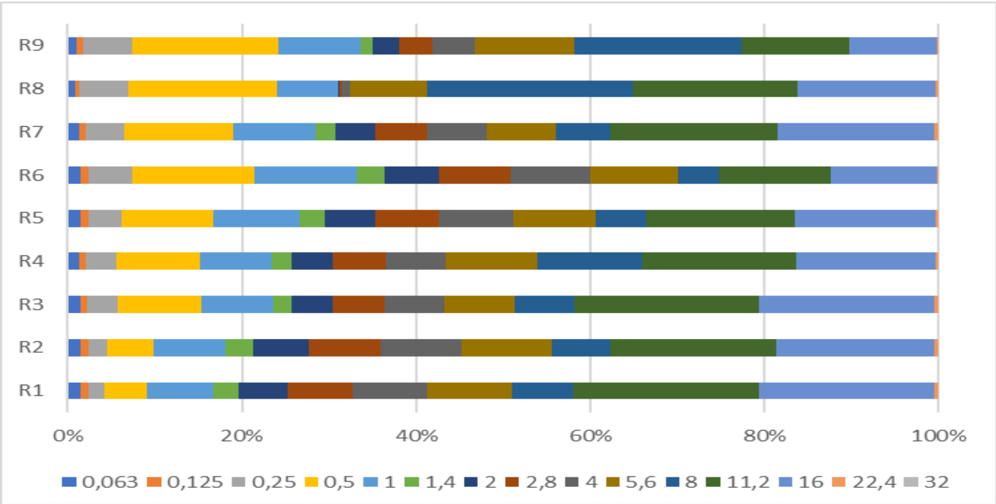

Figure 3. The particle [mm] (passing material) content distributions within the overall aggregate content.

The amount of the fine particles under 0.25 mm (including aggregate as well as cement particles) in individual aggregate designs R1 - R9 was found by calculation (Table 5) and it was confirmed that it met the recommended limit of the technical standard [9] for the concretes of standard composition (max. 530 kg.m^{-3} for D_{max}16).

Table 5. The amount of the fine particles for each aggregate mix design.

Aggregate Mix design	R1	R2	R3	R4	R5	R6	R7	R8	R9
Fine particles (<0.25 mm) [kg/m^3]	417	423	442	442	455	482	462	465	480

3.2. The fresh and hardened concrete properties

The results of measuring the consistency in time by slump (S_5 and S_{30}) and by flow table (F_5 and F_{30}) are given in the Figures 4 and 5.

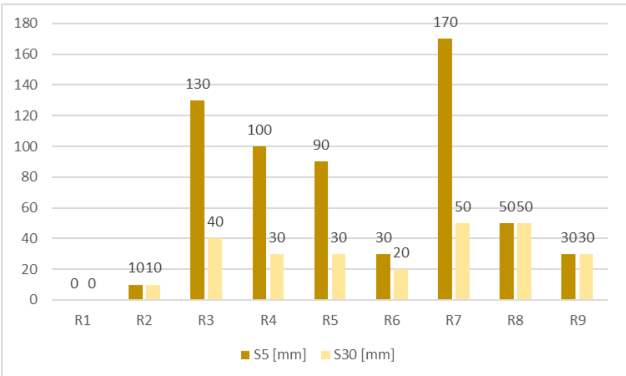

Figure 4. Results of slump test [mm] 5 and 30 minutes (S5, S30) after mixing.

The results for S_5 vary from 0mm (R1) to 170mm (R7) and for S_{30} from 0mm (R1) to 50mm (R7, R8). Generally, mix designs with replacement of the angular fraction 0/4 by the rounded fraction 0/0.7 achieved higher initial consistencies. The loss of consistency (evaluable) is the lowest (0%) at designs R8 and R9 and the highest (approx. 70%) at designs R3, R4 and R7

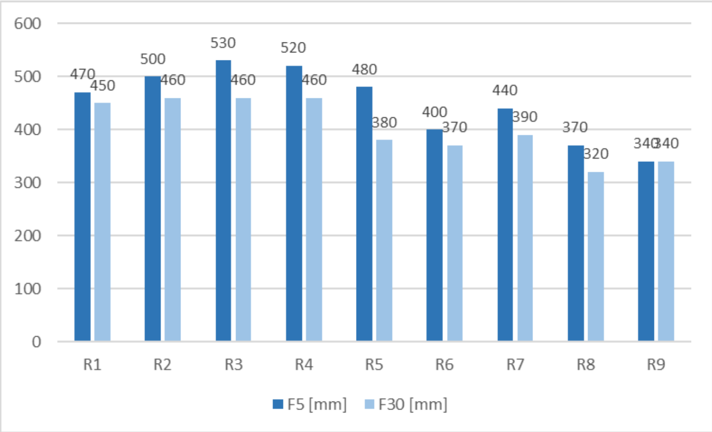

Figure 5. Results of table flow test [mm] 5 and 30 minutes (S_5, S_{30}) after mixing.

The results for F_5 vary from 340mm (R9) to 530mm (R3) and for F_{30} from 320mm (R8) to 460mm (R2, R3, R4). Lower flow can be observed at mix design with high content of 0/0.7 (25% and 30%), what could cause increasing viscosity. The highest values achieved mix designs with proportional content (50:50) of fine and coarse aggregate with 10% replacement of fraction 0/4 by fraction 0/0.7. Based on comparation of results from the slump test and from the flow on table test can be observed higher consistency loss at the slump test.

The results of compressive strength ($f_{c,150}$) and compressive strength after drying the samples for WA test ($f_{c,100,dried}$) are given in the Figures 6.

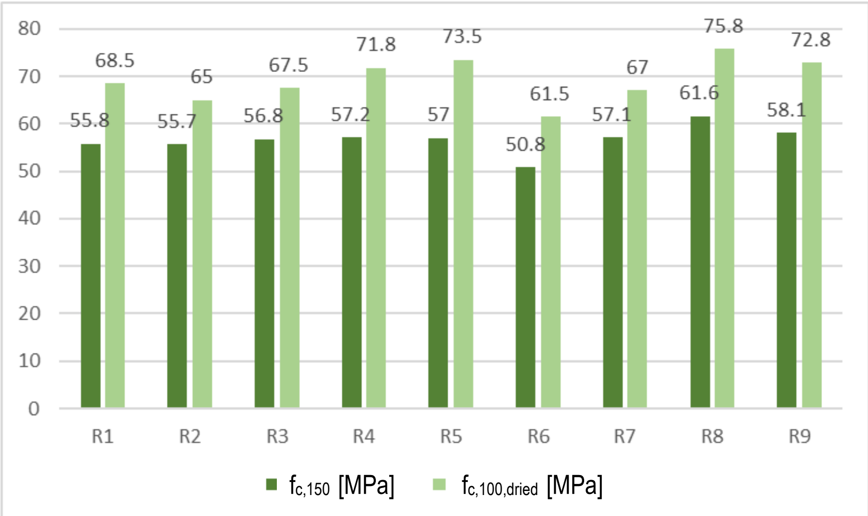

Figure 6. Results of compressive strength test.

The results of standard compressive strength ($f_{c,150}$) vary from 50.8MPa (R6) to 61.6MPa (R8). Compressive strengths of second set (dried samples – $f_{,100,dried}$) approximately (with taking the measurement and method errors into account) fit the standard test results. The lowest result is achieved with optimal grading curve (R6) by standard, the highest with gap grading curve (R8).

The results of water absorption test (WA) as well as density in saturated state (D_{sat}) are given in the Figure 7.

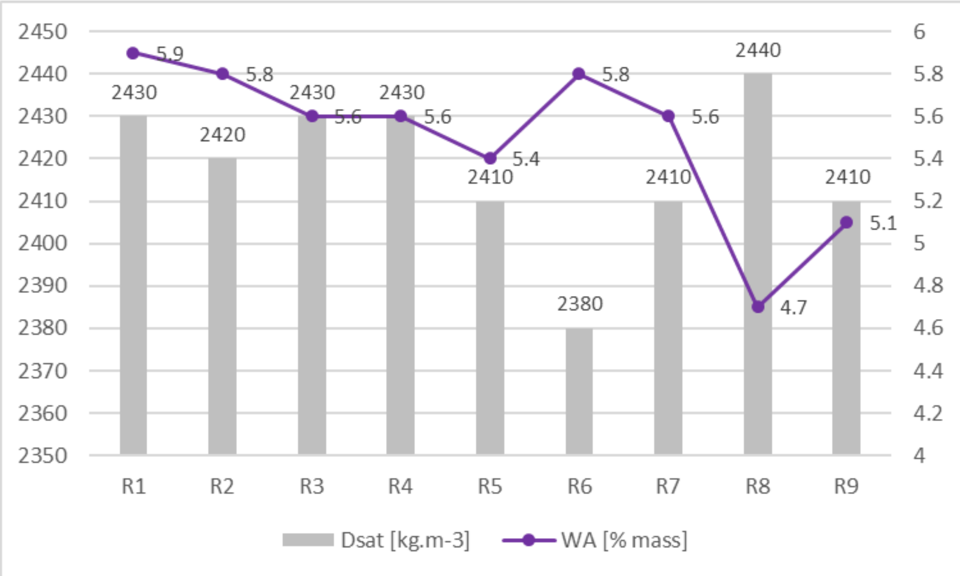

Figure 7. Results of water absorption and density.

Water absorption (WA) of tested samples vary from 4.7% (R8) to 5.9% (R1) and density in saturated state (D_{sat}) from 2380 kg.m-3 (R6) to 2440 kg.m-3 (R8). The mix design with optimal grading curve (R6) achieved the lowest density and high water absorption. The mix design with gap grading curve and with content 30% of fraction 0/0.7 (R8) achieved the highest value of density and the lowest value of water absorption what is in accordance with prediction in Introduction.

4. Conclusion

In this experimental study, various grading curves of aggregate in concrete were tested with the aim to observe the changes in fresh and hardened concrete. Based on results, following can be stated:

- properties of aggregate, especially the shape and surface of the grains as well as aggregate proportions, significantly impacted properties of fresh (consistency) and hardened concrete (compressive strength and water absorption),
- gap grading curve for aggregate into concrete can improve strength as well as durability of hardened concrete,
- optimal standardised grading curve did not provide proper values nor for fresh nor for hardened concrete properties, what can be consequence of not taking the grains properties into account.

5. References

[1] Mehta P K, Monteiro P J M 2006 *Concrete – structure, properties and materials* (New York: McGraw-Hill)
[2] Ferraris C F 1999 Measurement of the rheological properties of high-performance concrete: state of the art report *J. Res. Natl. Inst. Stand. Technol.* **104** 461–477
[3] Alexander M, Mindess S 2005 *Aggregates in Concrete* (London: CRC Press)
[4] Roussel N 2012 *Understanding the rheology of concrete* (Cambridge: Woodhead Publishing)
[5] Geiker M, Brandl M, Thrane L, Nielsen L 2002 On the Effect of Coarse Aggregate Fraction and Shape on the Rheological Properties of Self-Compacting Concrete *Cem. Concr. Aggreg.* **24** 3-6
[6] Jamkar S S, Rao C B K 2004 Index of aggregate particle shape and texture of coarse aggregate as a parameter for concrete mix proportioning *Cem. Concr. Res.* **34** 2021-2027
[7] Kurokawa Y, Tanigawa Y, Mori H, Nishinosono K 1996 Analytical study on effect of volume fraction of coarse aggregate on Bingham´s constants of fresh concrete *Trans. Japan Concr. Inst.* **18** 37-44
[8] Jiong H, Wang K 2011 Effect of coarse aggregate characteristics on concrete rheology *Constr. Build. Mater.* **25** 1196-1204
[9] STN EN 206/NA: 2015 *Concrete. Specification, performance, production and conformity. National Annex*

Acknowledgements
This paper has been prepared within the Grant No. 1/0648/17 of the Slovak Grant Agency for Science.