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Report

Rheology of concrete with crushed aggregate

Influence of volume and composition of matrix, and of sand-stone ratio

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SINTEF Community
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NTNU – MIKS-project

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ABSTRACT

The work is a part of the joint industry project "MIKS – Microproportioning of concrete with crushed sand". The overall aim of the work reported here was to provide experimental data as input to the work on the Particle-Matrix-Model (PMM) to predict workability in terms slump-flow, of self-compacting concrete with crushed aggregate and fines. The results confirm that concrete with crushed fines and aggregate follow the principle of the model originally developed for natural aggregates, and thus that PMM can be adapted to concrete with crushed aggregate.

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APPENDICES

1. The Norbetong method
2. Compressive strength
3. Pictures of slump-flow

1 Introduction and objective

The work reported here is a part of the joint industry project supported by the Research Council of Norway (RCN); "MIKS – Microproportioning of concrete with crushed sand" (RCN-project no 247619). One part of the project was to adopt the "particle-matrix-model (PMM)" as defined by Mørtsell [1, 2] to the use of crushed aggregate. PMM considers workability, in terms of slump or slump-flow, from the volumetric ratio between the matrix phase (fluids and all solid materials ≤ 0.125 mm), and the solid particle phase (> 0.125 mm). The workability is then determined numerically from a rheological parameter for the matrix, a voids ratio parameter for the aggregate phase and the volumetric ratio between the two. **The overall aim of the work reported here was to provide experimental data as input to the work on the numerical model to predict slump and slump-flow of concrete with crushed aggregate.** It includes measurement of workability of concretes with various matrix and aggregate compositions and matrix-aggregate ratios. The idea was to test the three main model parameters: matrix rheology, aggregate voids ratio and the matrix-aggregate volume ratio on both regular concrete (vibrated concrete) and self-compacting concrete. The original program included three matrix compositions, two sand/stone ratios and five matrix volumes, i.e., a total of 30 concrete mixes.

2 Initial tests - 1

Initial tests were conducted in order to conclude on the matrix compositions and sand-stone ratio that could give adequate workability, of the SCCs in particular in terms of slump-flow and stability, i.e. at least 650 mm slump-flow without segregation, with reasonable matrix content.

2.1 Aggregate formulation

PMM considers aggregate as all particles greater than 0.125 mm. Hence, a splitting of the aggregate on 0.125 mm was needed and done. The aggregate, crushed granite, was delivered by the aggregate and ready-mix concrete manufacturer "Velde", in the following fractions: 0-2 mm, 2-5 mm, 5-8 mm and 8-16 mm, of which the 8-16 mm was considered as the "stone fraction". The 0-2 mm fraction was split in 0.125-0.5 mm, 0.5-1.0 mm and 1.0-2.0 mm. Then, these fractions were recombined together with the 2-5 mm and 5-8 mm fractions to give the "sand" fraction. All fractions were practically oven dry when used (< 0.1 % water content).

The sand (0.125-8 mm) to stone (8-16 mm) ratio investigated was 55/45 and 65/35, respectively. The corresponding voids ratios were 31.4 and 34.0 %, respectively. It was measured according to the "Norbetong (a Norwegian concrete producer) internal procedure for determination of packing of aggregates" (APPENDIX 1), which in principle considers loose packing and according to [3] gives result in accordance with "EN 1097-3 Part 3 Determination of loose bulk density and voids". Particle size distributions for the two aggregate compositions are given in Fig. 1.

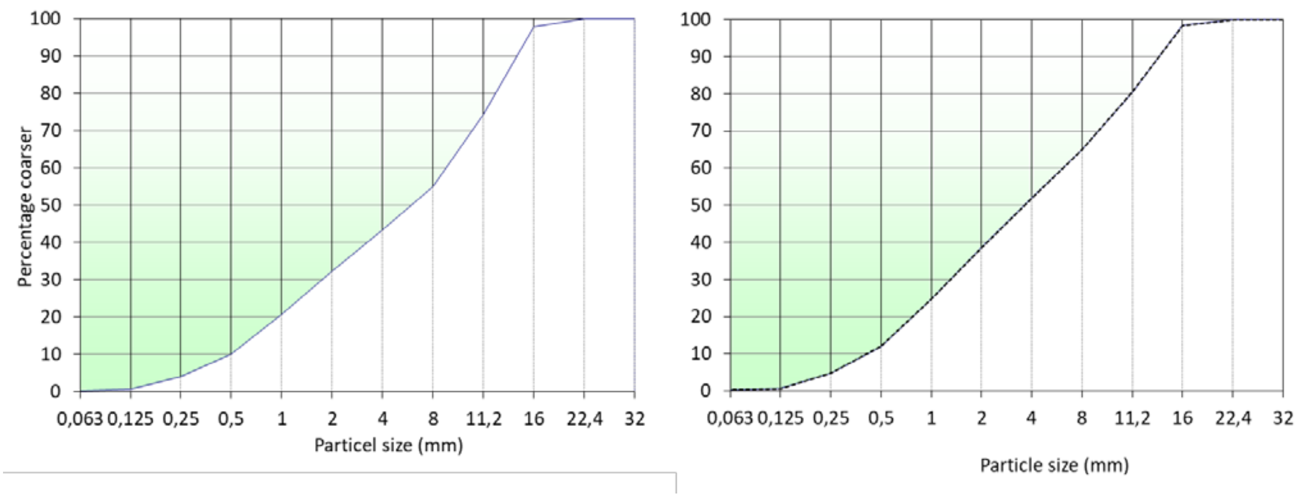


Figure 1. PSD of the aggregate with sand-stone ratio 55/45 (left) and 65/35 (right).

2.2 Matrix formulation

Three matrix formulations were chosen, representing

- "M60" vibrated concrete,
- "M60" self-compacting concrete (SCC)
- "M40" vibrated/SCC

All are based on a CEM II A-V cement; "Norcem Standard FA" and additional inert filler (f); crushed granite from Velde; "Fine" in Fig. 2, and a polycarboxylate ether-based water reducing admixture (WRA) "Dynamon SR-N" from Mapei, with a dry solids content of 17.5 %.

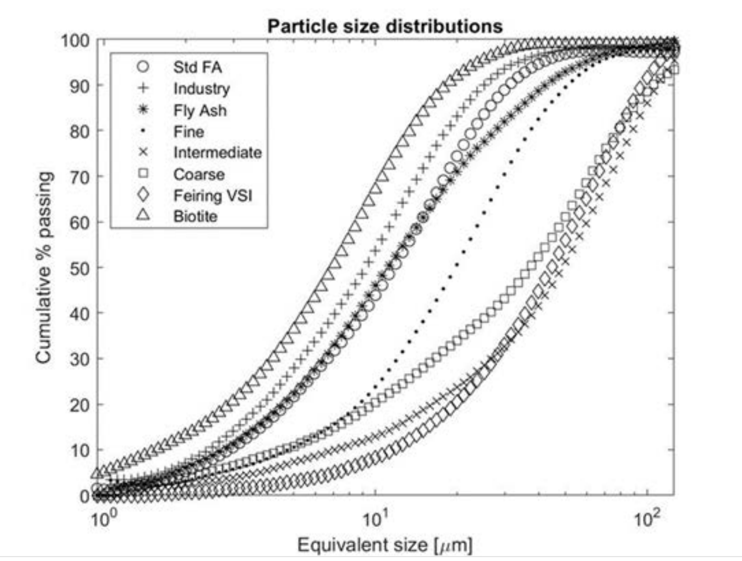


Figure 2. PSD of the cement ("Std FA") and "Velde" fillers named "Fine", "Intermediate" and "Coarse".

According to the current PMM the property of matrix is given by the term "flow resistance ratio", labelled λ_Q, that is determined using an apparatus called "FlowCyl" [4]. λ_Q is deduced from the relationship between mass flowing through the funnel of FlowCyl, and time and varies between 0 (no resistance) and 1 (no flow). The matrix composition parameters and measured λ_Q is shown in Table 1.

Table 1. Matrix composition parameters and measured flow resistance used in initial tests 1 and 2.

Matrix name	w/c	WRA (% of c)	f/c	Flow resistance ratio, λ_Q
M60 - 1	0.55	0.75	0.20	0.39
M60 SCC – 1	0.55	1.5	0.45	0.55
M40 – 1	0.40	1.5	0.15	0.67

2.3 Concretes

The two SCC matrices chosen (Table 1) were combined with the two sand-aggregate ratios chosen (section 2.1). Two different matrix volumes were tested for each combination (i.e., a total of 4 concretes), see Table 2.

Table 2. Matrix-aggregate combinations for the concretes and result, initial tests - 1

Mix No.	Sand/ stone (vol-%)	Matrix type	Matrix volume	Slump	Slump-flow	Yield stress τ_0	Plastic visc. μ	Segg.	R^2	Density	Air cont.	Temp.	Visual observation
			[l/m^3]	[mm]	[mm]	[Pa]	[Pas]	[%]	[-]	[kg/m^3]	[%]	[^{o}C]	
1	55/45	M60SCC	330	220	385	3957	73,22	49	0,849	2381	1,3	21,7	Stone rich
2	65/35	M60SCC	350	240	480	-35	61,45	10	0,946	2364	1,0	19,2	Some separation
3	65/35	M40	360	225	410	20	65,43	10	0,973	2362	1,5	21,1	OK, homogenious
4	55/45	M40	350	215	355	3103	50,79	26	0,944	2387	1,6	19,9	Stone rich

2.4 Mixing and testing

2.4.1 Mixing

The concretes were mixed in batches of 27 l in a 50 l forced action mixer with horizontal vanes on a vertical shaft, and according to the following procedure:

- All dry materials were added and mixed for 1 min
- Addition of water and the fixed amount of WRA, mixing for 2 min
- 2 min rest
- 2 min final mixing

Three 100 mm cubes were cast for measurement of the 28 day strength.

2.4.2 Testing

The following was measured for each mix:

- Concrete temperature (while in the mixer)
- Slump and slump-flow, immediately after mixing, in accordance with EN 12350-8
- Fresh concrete density and air content, immediately after mixing, according to EN 12350-6 and EN 12350-7
- Rheology in terms of yield stress and plastic viscosity found from testing in the BML-viscometer [5]
- Compressive strength at 28 days of age (water curing)

Slump/slump-flow measurements and BML-viscometer measurements were done at the same time and immediately after end mixing.

2.5 Results

The results (Table 2) revealed that the chosen matrix-aggregate combinations do not fulfil the requirement of a stable SCC, as the concretes appeared stone rich and showed tendency of segregation already at a slump-flow of less than 500 mm. Therefore, it was decided to proceed with a higher sand-stone ratios; 60/40 and 70/30 (section 3).

3 Initial tests – 2

3.1 Concretes

The four concretes already tested (section 2) were repeated, but with the sand-stone ratios of 60/40 and 70/30. Also, more matrix volumes were tested with the aim to reach at least 650 mm slump-flow. Since M40 concretes appeared more stable than M60 concretes, as expected, the M40 matrix was chosen as basis for this work.

3.2 Results

The results, shown in Table 3 and Fig. 3, confirm that the sand/stone increase improved the homogeneity and to an acceptable level, but indicate also that a slump-flow of at least 650 mm is not within reach given the present matrix formulations (for M60 separation occurred already at 500 mm, while for M40 even the rather high matrix content of 390 l was apparently too low to give more than 505 mm). Therefore, three concretes with altered matrix formulations were tested (section 4).

Table 3. Matrix-aggregate combinations for the concretes and result, initial tests - 2.

Mix No.	Sand/ stone (vol-%)	Matrix type	Matrix volume	Slump	Slump-flow	Yield stress τ_0	Plastic visc. μ	Segg.	R^2	Density	Air cont.	Temp.	Visual observation
			[l/m³]	[mm]	[mm]	[Pa]	[Pas]	[%]	[-]	[kg/m³]	[%]	[°C]	
5	60/40	M60SCC	330	225	410	4181,0	68,8	46	0,89	2360	1,4	20,3	OK, homogenious
6	70/30	M60SCC	350	240	500	-28,3	63,5	16	0,94	2350	1,5	20,0	Some separation
7	70/30	M40	360	220	390	49,5	80,6	15	0,97	2350	1,9	20,8	OK, homogenious
8	60/40	M40	340	195	350	83,1	109,8	13	0,98	2390	1,6	20,3	OK, homogenious
9	70/30	M40	370	240	435	35,6	67,6	13	0,97	2360	1,7	21,3	OK, homogenious
10	60/40	M40	350	220	355	73,8	106,3	17	0,98	2370	1,6	21,1	OK, homogenious
11	70/30	M40	380	245	475	28,1	56,7	15	0,97	2350	1,4	19,7	OK, homogenious.
12	60/40	M40	360	235	425	60,4	75,4	11	0,98	2360	1,3	20,6	OK, homogenious
13	70/30	M40	390	240	505	16,7	49,5	13	0,98	2350	1,5	20,0	OK, homogenious
14	60/40	M40	370	225	425	36,0	62,8	12	0,99	2380	1,2	18,9	OK, homogenious

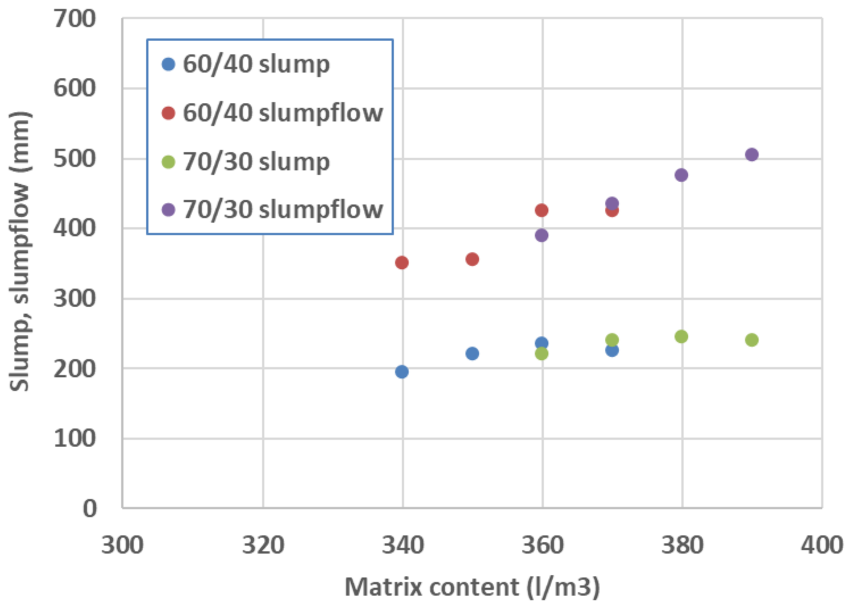


Figure 3. Slump and slump-flow versus matrix content of concretes with sand-stone ratio of 60/40 and 70/30, respectively, and with the M40 matrix (Table 1).

4 Initial test – 3

4.1 Concretes

The three new matrices were designed with increased WRA content and 4 % silica fume (of c+s+f), and one of them, M40, also with reduced filler content, see Table 4.

Table 4. Matrix composition parameters and measured flow resistance used in initial tests 3.

Matrix name	w/(c+s)	WRA (% of c+s+f)	WRA (% of c)	f/c	s/(c+s)	Flow resistance, λ_Q
M60 SCC - 2	0.55	1.5	2.3	0.477	0.058	na
M40 - 2	0.40	1.6	1.9	0.157	0.046	na
M40 - 3	0.40	1.8	2.0	0.067	0.042	na

Also, in order to establish a better basis for the choice of suitable WRA amount for the final test program (section 6), three concretes (Mix 15, 16 and 17) were added extra WRA (after measuring slump and slump-flow) in several steps. The concrete was mixed for 2 minutes after each extra WRA addition before the measurements. One concrete (Mix no. 15) was mixed for an extra 5 minutes after the first measurements to confirm any delayed response of the WRA.

4.2 Results

The results (Table 5) show:

- Still not acceptable workability, at least when using a reasonable amount of matrix and WRA
- No significant influence of mixing time
- WRA content to reach 650 mm slump-flow for the M40 concrete appears to be higher than 2 % of (c+s+f)

- The combined effect of silica fume addition and increased WRA content did not influence slump and slump-flow of the M40 concrete significantly; comparing mixes 13 (Table 3) and 15: slump/slump-flow = 240/505 and 245/485 mm, respectively)
- Lower filler content (M40 matrix) contributed to higher slump and slump-flow and indicatively equal or even improved stability (comparing mixes 15 and 16)

Table 5. Influence of mixing time and WRA content (delayed addition in one and the same concrete).

Mix No.	Sand/ stone [vol-%]	Matrix type	Matrix volume [l/m^3]	Time of measure Min. after water. add.	WRA cont. [% of c+s+f]	Slump [mm]	Slump-flow [mm]	Yield stress τ_0 [Pa]	Plastic visc. μ [Pas]	Segg. [%]	R^2 [-]	Comments
15	70/30	M40 - 2	390	10	1,6	245	485					Homogenous
				20	1,6	250	485					5 min extra mixing
				30	1,7	255	500					Homogenous
				38	1,8	255	525					Homogenous
				46	1,9	255	535					Tendency of "boiling" in the mixer, but appears stable on the slumpflowboard
				54	2,0	255	575					
				61	2,1	260	585					
				69	2,3	270	630	-6,4	24,0	10,5	0,98	"On the edge" of separation
16	70/30	M40 - 3	390	10	1,8	265	605					Homogenous
				16	2,0	270	635					Homogenous
				23	2,2	270	655	-10,6	20,2	-1,7	0,95	Homogenous
17	70/30	M60SCC - 2	350	10	1,5	245	555					Tendency of "boiling"
				20	1,7	255	640	-16,8	37,9	10,1	0,95	"On the edge" of separation

Further steps:
It appears that the present WRA type is not sufficiently effective and that the water demand of the present filler is too large to give SCC with reasonable matrix contents. Therefore, it was decided to test this hypothesis by repeating the "M60" concrete (Mix 17) but with another filler, one with the present WRA and one with another WRA, see next section.

5 Initial test – 4

5.1 Concretes

The recipes are modified from Mix 17. Because a "clean" (0-0.125 mm) alternative filler was not available another sand (including filler) was used to get an indication of the influence of filler type. The sand was "Årdal 0-8 mm" (60/40 % blend of natural and crushed sand grains) containing 8.4 % filler (< 0.125 mm), se Fig. 4. The stone was "Årdal 8-16 mm". The sand-stone ratio was 72/28, giving a f/(c + f) of 0.34. The WRA chosen was "Mapei Dynamon SX-23".

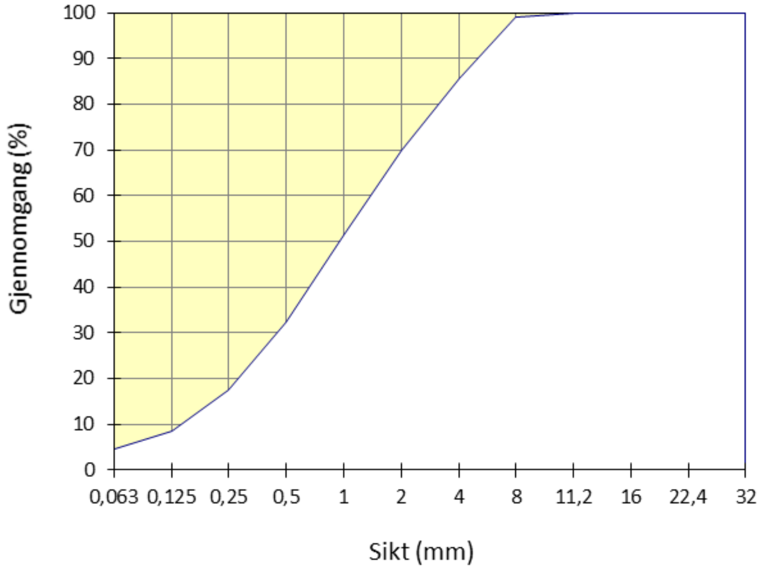


Figure 4. PSD of the "Årdal 0-8 mm" sand.

5.2 Results

The results show:

- SX-23 appears to be approx. 20 % "more effective" than SR/N (1.14 % of (c+s+f) corresponds to 1.5 % of (c+s))
- The results indicate strongly that "Velde fine" exhibits a higher water demand: Mix 18 (Årdal-filler) gave SF of **680 mm with 1.44 % SR/N**, while Mix 17 (Velde filler) gave **640 mm with 1.7 % SR/N**. Note however that f/(c+s+f) was somewhat lower in Mix 18; 0.25 vs 0.31.

Table 6. Influence of WRA type and amount on slump and slump-flow

Mix No.	Sand/ stone [vol-%]	Matrix type	Matrix volume	Time of measure	WRA cont.	Slump	Slump-flow	Visual observation
			[l/m³]	Min. after water add.	[% of c+s+f]	[mm]	[mm]	
18	72/28 Årdal	M60 Årdal SR/N	350	10	1,14	255	605	Homogenous
				16	1,29	270	665	Homogenous
				22	1,44	270	680	"Boiling" in the mixer, but appears quite stable on the slump-flow board
19	72/28 Årdal	M60 Årdal SX-23	350	10	1,14	270	675	Boiling in the mixer, but appears quite stable on the slump-flow board

6 Main test program

Based on the initial tests reported in chapter 2-5, the following main test program was decided, comprising a total of 20 mixes. For each of the four mixes the matrix content was altered in five steps of 10 l/m^3. Mixing and testing (including test methods) were performed as described in section 2.4.

6.1 Matrix formulation

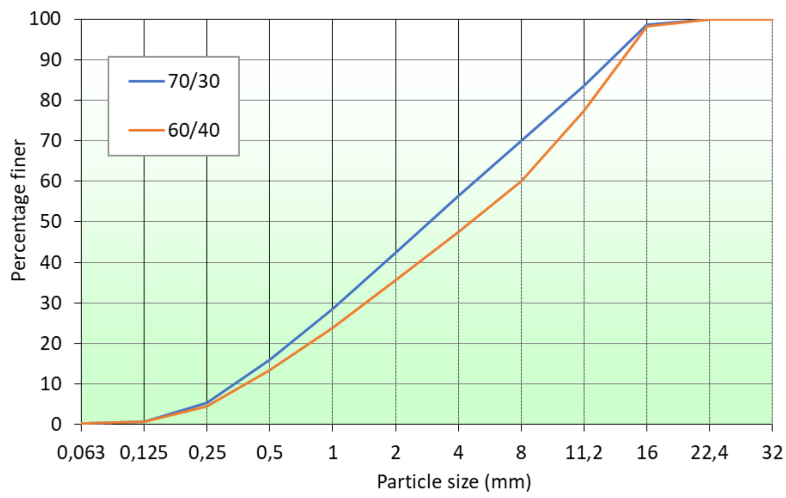
Materials: Norcem Std FA (as before), Dynamon SX-23, Elkem microsilica (D940) and Velde Intermediate filler (see Figure 2). As the initial tests consumed much more of the pre-processed aggregate phase than estimated, it was not enough left for the full program as intended. It was therefore decided to exclude the "M60 vibrated concrete" from the program. Also, it was decided to exclude the M60 SCC 60/40 sand/stone because of the uncertain stability ("stone rich" appearance), and rather include another matrix design with more fines to improve stability (Table 7).

Table 7. Matrix composition parameters and measured flow resistance used in the main test program (mp).

Matrix name	w/(c+s)	WRA (% of c+s+f)	WRA (% of c+s)	f/(c+s+f)	f/(c+s)	s/(c+s)	Flow resistance, λ_Q
M60 SCC (mp-1)	0.55	1.14	1.6	0.30	0.43	0.04	0.33
M60 SCC (mp-2)	0.55	1.0	1.5	0.335	0.50	0.04	0.38
M40 (mp)	0.40	1.35	1.5	0.10	0.11	0.04	0.51

6.2 Aggregate formulation

PSD was composed as described in section 2.1, but the sand/aggregate ratio used was 60/40 and 70/30, respectively, see Fig. 5.



Size [mm]	60/40 vol.[%]	70/30 vol. [%]
16	98,2	98,6
11,2	77,4	83,5
8	60,0	70,0
4	47,6	56,5
2	35,8	42,4
1	23,9	28,5
0,5	13,4	16,0
0,25	4,6	5,5
0,125	0,7	0,7
0,063	0,3	0,3

Figure 5. PSD of the two aggregate compositions.

6.3 Results

Summary of results are given in Tables 8 and 9, and in Figs. 6 and 7. The influence of the three model parameters (matrix rheology, aggregate voids ration and matrix volume) are consistent and as expected: Matrix volume needed to give a certain slump-flow decreases with decreasing λ_Q and aggregate voids ratio (60/40 lower voids ratio than 70/30). The tendency seems to be the same for t_{500}, although not as consistent. Note that these results are from one measurement and on one batch, only. Still, the reliability is considered to be good, supported by the consistent/expected results and the fact that the difference in compressive strength, given as mean value of three parallels, within each series is quite low (APPENDIX 2).

The results from testing of rheological parameters; yield shear stress and plastic viscosity, are not that consistent. In fact, yield stress results make partly no sense since values within series vary apparently randomly between positive and negative values, for M60 concretes in particular. The reason is most likely, based on experience, that the present viscometer is unfortunately not adapted to concretes that can be classified as "stone rich", as here, meaning that the measurements are considerably affected by particle migration / segregation. The pictures taken confirm the "stone rich appearance (APPENDIX 3). Viscosity is usually less affected than yield shear stress, and in that respect a fair correlation between viscosity and t_{500} can be seen (Figs. 7 and 8), as expected.

Table 8. Overview of results M60.

Mix				Slump-flow	t500	Rheological parameters				Air	Concrete temp.
No.	Matrix	Sand/stone	Volume l/m3	mm	sec.	τ Pa	µ Pas	Segg. %	R2 -	%	°C
24	M60 mp-1	70/30	320	445	-	-51	115	28	0,9	1,7	21,1
23			330	540	-	2	73	24	0,91	1,4	19,7
22			340	620	7,0	-30	44	4	0,91	1,3	20,7
21			350	645	4,3	-1	34	5	0,9	0,7	20,4
20			360	670	3,6	22	31	7	0,91	0,6	20,3
39	M60 mp-2	70/30	330	450	-	-77	100	27	0,89	1,5	22,3
37			340	490	-	337	31	33	0,84	1,3	23,2
36			350	565	5,7	-36	51	25	0,89	1,1	21,1
35			360	645	3,4	-21	49	25	0,87	1,1	21,0
38			370	690	2,6	-19	31	33	0,84	0,7	22,4

Table 9. Overview of results M40.

Mix				Slump-flow	t500	Rheological parameters				Air	Concrete temp.
No.	Matrix	Sand/stone	Volume l/m3	mm	sec.	τ Pa	µ Pas	Segg. %	R2 -	%	°C
34	M40 mp	60/40	340	520	10,1	1594	16	-2	0,93	0,6	21,6
33			350	615	3,2	275	16	-68	0,97	0,7	20,6
32			360	650	3,1	4	28	-4	0,96	0,5	21,7
31			370	655	2,5	9	30	-2	0,96	0,5	21,3
30			380	665	2,1	5	24	-7	0,96	0,6	22,3
29		70/30	340	500	11,2	18	57	10	0,94	1,7	21,0
28			350	555	9,0	6	46	8	0,95	1,6	20,7
27			360	630	3,9	2	40	7	0,96	1,5	20,6
26			370	640	3,2	-8	35	6	0,96	1,2	21,0
25			380	665	2,4	-9	28	3	0,96	1,1	20,6

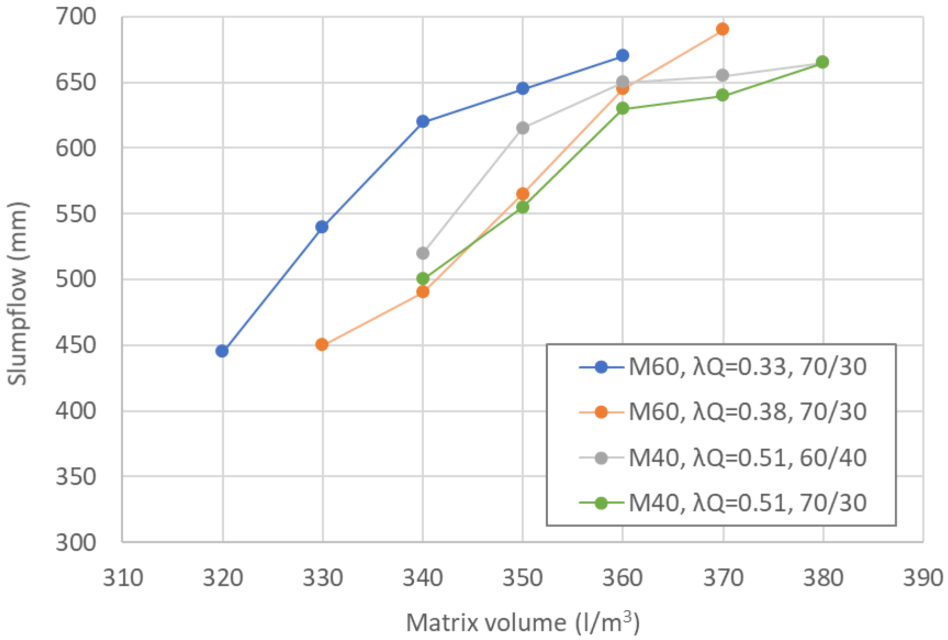


Figure 6. Slump-flow vs. matrix volume.

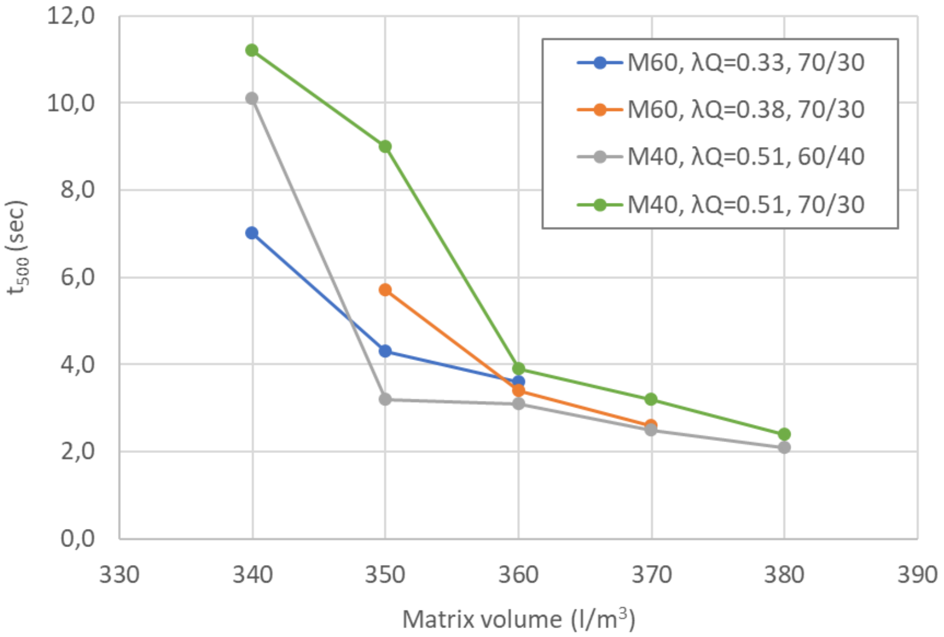


Figure 7. t_{500} versus matrix volume.

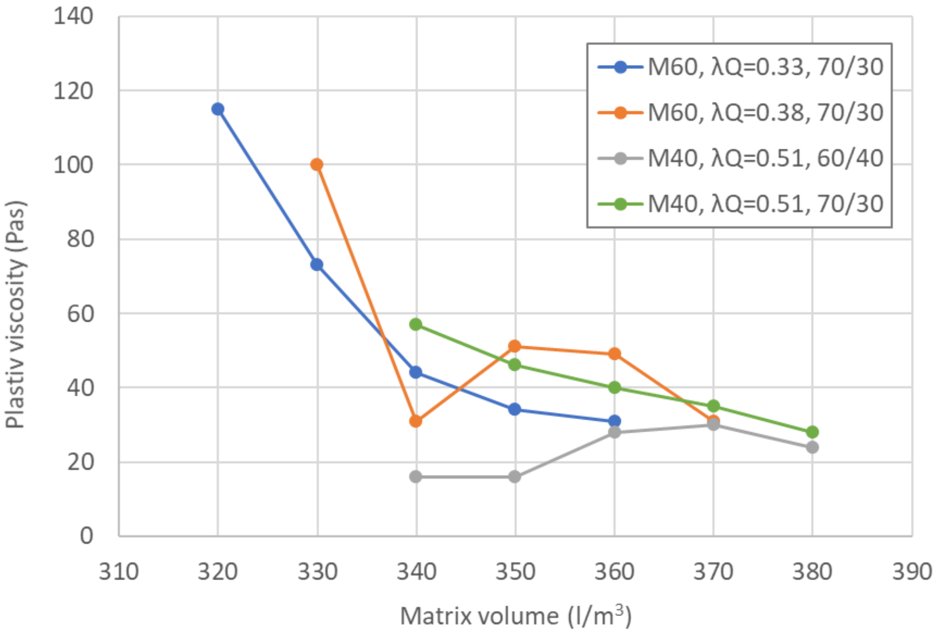


Figure 8. Plastic viscosity vs matrix volume.

7 Conclusion

The results confirm that concrete with crushed fines and crushed sand follows the principle of the particle-matrix-model (PMM) originally developed for natural aggregates, and thus that PMM can be adapted to concrete with crushed aggregate.

8 References

1. Mørtsell E. (1996), Modellering av delmaterialenes betydning for betongs konsistens. PhD-thesis, NTNU Trondheim.
2. Mørtsell, E., Maage, M. and Smeplass, S. (1995). A Particle -Matrix Model for Prediction of Workability of Concrete, Proceedings of the International Conference on Production Methods and Workability of Fresh Concrete", Glasgow, Scotland.
3. Martius-Hammer, TA., Skjølsvold, O. and Cepuritis, R. (2020). Rheology of mortars with manufactured sand. Influence of grain size distribution and shape. SINTEF-report 2020:00967.
4. http://www.contec.is/viscometer2.htm#BML-Viscometer

APPENDIX 1. Procedure for testing of voids ratio according to the "Norbetong method"

Dokumentnavn	Prosedyre for testing av pakningsgrad tilslag
Utgave	2
Forfatter	Skjeggerud, Magnus Gade (Laksevåg) NOR
Gjelder f.o.m.	06.06.2018
Godkjenner	Skjeggerud, Magnus Gade (Laksevåg) NOR
Identitet	PD4694

Formål:

Pakningsgraden av tilslag vil direkte påvirke betongens behov for matriks. Matriksinnholdet i en betong skal være tilstrekkelig til å fylle hulrommet i tilslagssammensetningen samt gi et lite overskudd for å dytte tilslagskornene fra hverandre slik at massen som en helhet flyter.

Utstyrsliste:

- Luftbøtte, uten topp med manometer
- Stor bøtte, 10-20liter
- Tønne 50liter, med lokk
- Vekt, kapasitet opp til 25kg
- Gjennomsiktig plate, av glass/plast

Gjennomføring:

1. Luftbøttens tomvekt med glassplate og volum sjekkes og registreres.
2. Fukt i tilslagsfraksjonene måles.

3. Tilslagskombinasjonen veies opp og blandes i tønne.
    a. Tønnen fylles med oppveid tilslag (totalt typisk 15kg)
    b. Sett på lokk
    c. Rull/vend tønnen til tilslaget er tilstrekkelig blandet
4. Fyll luftbøtten med tilslag og stryk lett av toppen slik at luftbøtten er helt full av ukompaktert tilslag
5. Luftbøtten med glassplate og tilslag veies og registreres
6. Tøm ut tilslaget i den «store bøtten»
7. Fyll litt vann (~0,5liter) i bunn av luftbøtten
8. Fyll deretter noe av tilslaget fra den store bøtten forsiktig tilbake i luftbøtten
9. Vann og tilslag fylles om hverandre frem til alt tilslaget er fylt i bøtten og vannspeilet er på likt nivå med «tilslagsspeilet»
10. Luftbøtten med glassplate, tilslag og vann veies og registreres
11. Vann fylles videre til luftbøtten er helt full
12. Stryk av toppen med glassplaten
13. Luftbøtten med glassplaten, tilslag, vann og ekstra vann veies og registreres Registrering foregår i eget excel ark, Pakningsgrad tilslag.xlsx.

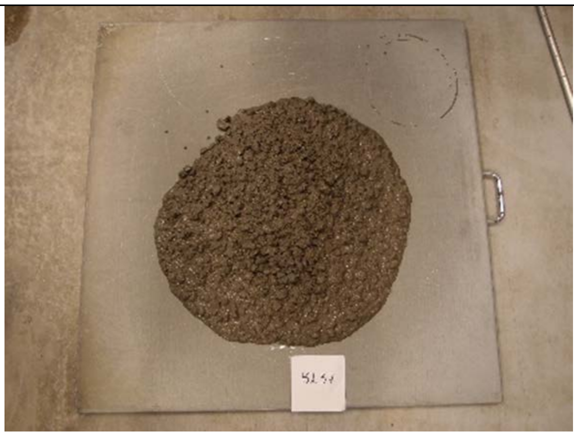
APPENDIX 2. Compressive strength (mean value of three)

Mix				Comp. cube strength, 28 d
No	Matrix	Sand/stone	Matrix volume l/m^3	MPa
1	M60 - 1	55/45	330	57,3
2		65/35	350	52,7
3	M40	65/35	360	74,5
4		55/45	350	77,4
5	M60 - 1	60/40	330	58,6
6		70/30	350	54,0
7	M40	70/30	360	74,1
8		60/40	340	77,1
9		70/30	370	75,2
10		60/40	350	75,1
11		70/30	380	75,0
12		60/40	360	74,6
13		70/30	390	71,1
14		60/40	370	72,8
15	M40 - 2	70/30	390	89,1
16	M40 - 3		390	82,8
17	M60 - 3		350	63,7
18	M60 Årdal SR/N	72/28 Årdal	350	na
19	M60 Årdal SX-23		350	na
20	M60 mp-1	70/30	360	61,8
21			350	62,5
22			340	60,1
23			330	62,6
24			320	62,1
25	M40 mp	70/30	380	86,5
26			370	85,5
27			360	83,8
28			350	83,7
29			340	81,4
30		60/40	380	86,0
31			370	86,8
32			360	87,5
33			350	84,1
34			340	81,4
35	M60 mp-2	70/30	370	61,7
36			360	61,7
37			350	59,2
38			340	62,2
39			330	61,0

APPENDIX 3. Pictures of slump-flow

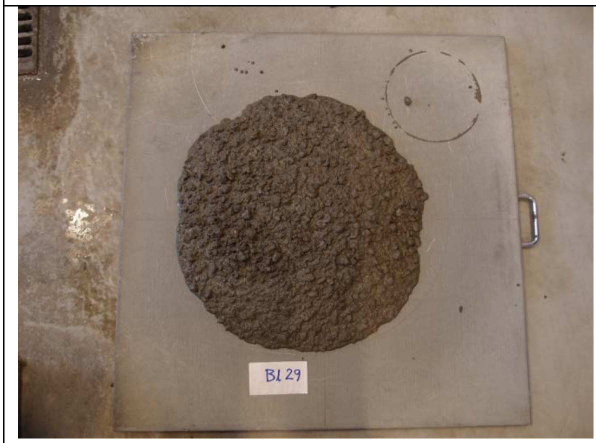
M60 70/30 mp-1

M60 70/30 mp-2



M40 60/40

M40 70/30

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