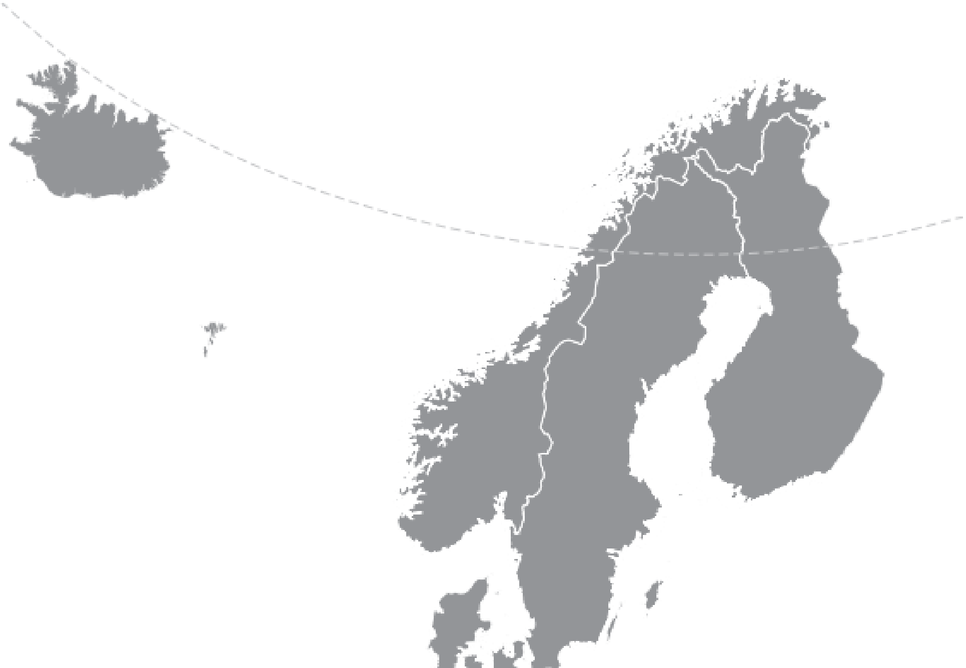
Nordic Concrete Research

Proceedings of the XXIII Nordic Concrete Research Symposium

Aalborg, Denmark 2017



Nordic
Concrete
Federation

NORDIC
CONCRETE
RESEARCH

Proceedings of

XXIII Nordic Concrete Research Symposium

Aalborg, Denmark

21-23 August, 2017

Edited by:
MARIANNE TANGE HASHOLT

Publisher:
NORSK BETONGFORENING
Postboks 2312, Solli
N-0201 Oslo
Norway

Preface

Every third year the Nordic Concrete Federation organises a research symposium, where on-going and new research projects in the five Nordic countries – Denmark, Finland, Iceland, Norway and Sweden – within the broad field of concrete technology and concrete construction are presented. The research symposium held this year in the Danish city Aalborg is the 23rd symposium in this succession of research symposia.

The continuous row of research symposia is a cornerstone in the work of the Nordic Concrete Federation. A Nordic Concrete Research Symposium is more than an event, where research conducted in the Nordic countries is presented. It is a forum, where researchers meet; they have face-to-face discussions, they extend their network, new ideas arise and working relationships between Nordic colleagues emerge. This year, we have invited our concrete colleagues from the Baltic countries, hopefully this will make the event even more fruitful for all of us.

This year's Symposium is organised by the board of the Danish Concrete Association. When the planning of the Symposium started, it was with Dr. Dirch H. Bager as the driving force in the organising committee. Unfortunately, Dirch H. Bager suddenly passed away February 3rd, 2016.

Dr. Dirch H. Bager was very well-known in the Nordic concrete community. He joined the Research Committee of the Nordic Concrete Federation in year 2000, and for more than 15 years, he was a very active member. For many years, he edited the bi-annual publication "Nordic Concrete Research". In the prefaces of the proceedings of the research symposia, there was always a special thank to Dirch. H. Bager, because he assisted the national organising committees with all sorts of tasks, great and small. In 2008, Dirch H. Bager received the NCF medal for his extraordinary contribution to make the Nordic cooperation prosper.

Dirch H. Bager left a gap, which it has not been easy to fill out. However, we have done our utmost to follow in his footsteps, and we very much look forward to welcoming you in Aalborg for the XXIII Nordic Concrete Research Symposium!

Kgs. Lyngby, July 2017

Anette Berrig,
Chairman of the Danish Concrete Association

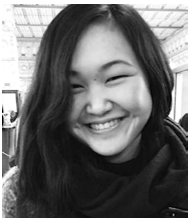
Marianne Tange Hasholt
Chairman of the Research Council of the Nordic Concrete Federation

Scientific committee

(The Research Council of the Nordic Concrete Federation as per August 2017)

Ass. professor Marianne Tange Hasholt, Technical University of Denmark (DK) - chairman
Senior consultant Gitte Normann Munch-Petersen, Danish Technological Institute (DK)
Professor Jouni Punkki, Aalto University (FI)
Professor Jukka Lahdensivu, Tampere University of Technology (FI)
Dr. Jón E. Wallevik, Innovation Center Iceland (IS)
Dr. Olafur H. Wallevik, Innovation Center Iceland (IS)
Dr. Terje F. Rønning, Heidelberg Cement (NO)
Professor Mette Rica Geiker, NTNU (NO)
Tekn. Dr. Peter Utgenannt, CBI Swedish Cement and Concrete Research Institute (SE)
Section manager Mårten Janz, ÅF (SE)

Excavated rock materials from tunnels for sprayed concrete



Judy Luong
MSc student
Norwegian University of Science and Technology
Department of Structural Engineering
Richard Birkelandsvei 1a, NO-7491 Trondheim
yuenwl@stud.ntnu.no

Kari Aarstad
Siv. Ing., Dr. ing., Senior scientist
SINTEF Building, Infrastructure and Architecture
Richard Birkelandsvei 3, NO-7465 Trondheim
kari.aarstad@sintef.no

Klaartje De Weerdt
MSc, PhD, Associate professor
Norwegian University of Science and Technology
Department of Structural Engineering
Richard Birkelandsvei 1a, NO-7491 Trondheim
klaartje.d.weerdt@ntnu.no

Øyvind Bjøntegaard
MSc, PhD, Senior Principal Engineer
Norwegian Public Roads Administration
Tunnel and Concrete section
Abels gate 5, 7030 Trondheim
oyvind.bjontegaard@vegvesen.no

ABSTRACT

Sand extracted from natural resources is widely used in concrete production nowadays. The increase in demand for concrete production has resulted in shortage of natural sand resources, especially in terms of suitable materials for concrete production. At the same time, large amounts of excavated rock materials are and have been generated from tunnelling projects and discarded. Hence, there is an opportunity to use these excavated rock materials as aggregates for concrete production. The challenge lays in the production of suitable aggregates. The focus of the study presented in this paper is on the use of processed excavated rock materials from tunnelling projects as aggregates in sprayed concrete production. Five sand materials, both natural and excavated, have been characterized. The effect of three of these materials' properties on the workability properties of the resulting spray concrete will be investigated. The study is not completed yet and a final conclusion remains to be drawn.

Key words: Aggregate, Mix Design, Reuse and Recycling, Rheology, Sustainability

1 INTRODUCTION

High amounts of excavated rock materials are produced in infrastructure projects in Norway, especially when tunnelling is involved. In 2015, 7 million m^3 rock material was excavated from Norwegian mountains [1]. Most of this material has traditionally been used as landfill or placed in deposits in lakes or fjords. However, this practice is becoming more and more controversial, and the project *Local Materials* (Kortreist stein) was established to accommodate extended use of this material. Four areas of possible utilization have been identified in this project: Asphalt, concrete, road construction and ballast, sub- and super structures in railway. This paper is limited to the study of the utilization of excavated rock materials in sprayed concrete production as tunneling projects often require high volumes of sprayed concrete. Utilizing the excavated rock materials in this manner may be both economically, logistically and environmentally beneficial.

2 MATERIALS AND METHODS

2.1 Materials

In total five different types of sand materials from three different sources have been included in the study. The most essential information about these materials is summarized in Table 1. Three of these sand materials are processed excavated rock materials from two ongoing tunnelling projects in Norway, the new Ulriken tunnel and the Follo Line tunnel. The Follo Line connects Oslo and Ski with a 20 km long double track railway tunnel, and the Ulriken tunnel is an 8 km long double track railway tunnel between Bergen and Arna. Both tunnels are mainly driven by Tunnel boring machines (TBM), but the method drill&blast (D&B) is also applied. Furthermore, the natural sand materials from Årdal (Norstone AS) have been included in the study as reference materials for comparison with the crushed sand materials.

Table 1 - Description of the sand materials used in the study.

Name	Source	Particle sizes	Type of aggregate	Production process Main process	 Secondary process	Rock types
MR1	Årdal	0 – 8 mm	Natural	Glaciofluvial and moraine deposit	Partly crushed Washed	Dark rocks Granite/gneiss Feldspathic rocks
MR2	Årdal	4 – 8 mm	Natural	Glaciofluvial and moraine deposit	Partly crushed Washed	Dark rocks Granite/gneiss Feldspathic rocks
MU1	Ulriken	0 – 4 mm	Crushed	Tunneling D&B	Crushed Washed	Dark rocks Granite/gneiss Feldspathic rocks
MU2	Ulriken	0 – 4 mm	Crushed	Tunneling D&B	Crushed	Dark rocks Granite/gneiss Feldspathic rocks
MF	Follo-banen	0 – 8 mm	Crushed	Tunneling TBM	Crushed Washed	Granite/gneiss

The natural sand materials from Årdal, MR1 and MR2, are partly processed in terms of crushing of particles greater than 22 mm and washing [2]. The sand materials from Ulriken, MU1 and MU2, are crushed from the larger rock fragments that are produced during the traditional tunnelling method drill&blast. The crushing process includes a jaw crusher, a gyratory crusher and a cone crusher [3]. The sand material from Follo Line is produced by crushing TBM muck into smaller particles [4]. The crushing includes a cone crusher and a Vertical Shaft Impacter (VSI).

2.2 Experimental program

Characterization
Only the properties that are considered as relevant have been declared and included in the study. These properties are grading, fines content, particle density and water adsorption, particle shape and free mica content.

Mix design
Sprayed concrete mix design from a commercial ready-mix concrete supplier has been used as basis for the proportioning part. Three mixes have been proportioned: one mix containing 50% MR1, 45 % MU1 and 5 % MR2, one mix containing 50 % MF and 50 % MR1 and finally one reference mix containing 100 % MR1. MU1 is MR2 combined to form one unit, containg particles with sizes in the entire range of interest (0 – 8 mm). MU2 is excluded in the study of fresh concrete properties due to its high content of fines (see Table 2), which is known to have a negative impact on workability properties.

FlowCyl test and void content measurement
The FlowCyl test and the void content measurements are based on the particle-matrix model [5]. In the particle-matrix model, fresh concrete is considered as a two-phase system, consisting of a flowable part, the *matrix phase*, and a friction part, the *particle phase*. The FlowCyl test and the void content measurements will and have been carried out in order to characterize the properties of the matrix phase and the particle phase, respectively. According to the particle-matrix model, the workability of fresh concrete is determined by the properties of the phases and the volume ratio between them. Hence, the results of these experiments can give an indication of the workability properties of the sprayed concrete mixes, such that any necessary adjustments and changes on the proportioning part can be made before conducting the remaining experiments.

Fresh concrete properties measurements
Testing of fresh concrete properties by means of slump test, flow-table test and 4SCC have not been performed yet. These experiments will be carried out during Spring 2017.

3 RESULTS AND DISCUSSION

The results of the characterization and the particle void content measurements are presented in Table 2 and Figure 1. The results confirm that the use of VSI in the crushing process provides higher particle shape quality and that the crushing process generally will generate a lot of fines and shall therefore be combined with a wet- or air classification step in order to keep the fines content within acceptable limits.

In general, low content of flaky and elongated particles, low free mica content and low particle void content is beneficial for the workability properties. As expected, Table 2 shows that MR1 has the highest particle shape quality, whereas MU1 and MU2 have the poorest. Consequently, the particle void content is higher in the combined sand material MR1/MF than the other combined sand material MR1/MU1/MR2 (see Figure 1). The combinations are presented as the quantity of crushed sand, specifically MF and MU1 + MR2 in percentage of total mass. MF has the highest content of free mica. This can be related to the application of VSI in the crushing process, which generally generate high amounts of fine particles. When dealing with rock types containing mica, the use of VSI may also cause high content of free mica minerals. In overall, MF seems to be a more suitable aggregate in concrete production than MU1. A final conclusion remains to be drawn after the fresh concrete mixes are tested.

Table 2 - Characterized properties for the sand materials.

	MR1	**MR2**	**MU1**	**MU2**	**MF**
Fines content	3,0 %	0,5 %	2,7 %	14,0 %	1,5 %
Particle density	2,68 Mg/m^3	2,67 Mg/m^3	2,96 Mg/m^3	2,96 Mg/m^{3}a)	2,76 Mg/m^3
Water adsorpt.	0,3 %	0,5 %	0,1 %	0,1 %a)	0,2 %
Particle shapeb)	25 % / 20 %	-	70 % / 55 %	70 % / 55 %a)	40 % / 25 %
Mica content	4 %	-	11 %	11 %a)	24 %

a) The value for MU2 is assumed to be the same as the value for MU1.

b) The values indicate the percentage of flaky/elongated particles. The first value is related to the 2 – 4 mm particles, whereas the second value is related to the 4 – 8 mm particles.

“-“ Not declared

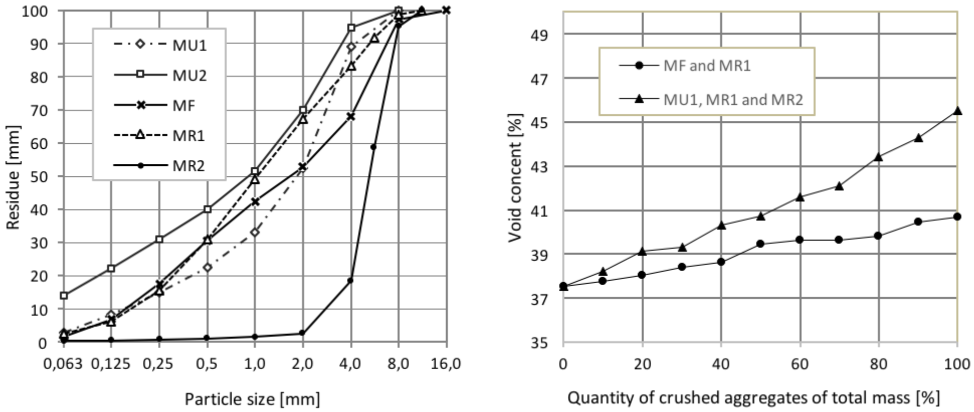


Figure 1 - Sieve curves (left) and void content (right) for the investigated sand materials.

ACKNOWLEDGEMENT

The project *Local Materials* is owned by Veidekke Entreprenør AS, started in 2016 and will proceed until 2019. The project is supported by the Norwegian Research Council, and SINTEF and NTNU are research partners. The other partners in the project are: Asplan Viak, Bane NOR, Bergen kommune, Geological Survey of Norway, Hordaland Fylkeskommune, Metso Minerals, Multiconsult, the Norwegian Public Roads Administration and Veidekke Industri AS.

REFERENCES

[1] Norwegian Tunnelling Society. Available from: http://nff.no/nyheter-og-tall/fagstoff/tunnelstatestikk/. Accessed October 25th 2016.
[2] Norstone Heidelberg Cement Group (2016). Available form: http://www.norstone.no/no/ardal. Accessed March 17th 2017.
[3] Løwø V. H., NCC, personal communication, 28th October 2016
[4] Ytterdal, S. G., personal communication, 10th March 2017
[5] Mørtsell E.: “Modelling the effect of concrete part materials on concrete consistency”, PhD, Norwegian University of Science and Technology (1996)

A method for obtaining optimum packing of aggregates for concrete at the onset of flow

Yahya Ghasemi
PhD-student
Div. Structural and Fire Engineering, Luleå University of Technology
S-971 87 Luleå
yahya.ghasemi@ltu.se

Mats Emborg
Professor LTU/Head of R&D Betongindustri AB
971 87 Luleå, Sweden./Betongindustri AB, 100 74 Stockholm, Sweden
mats.emborg@betongindustri .se
mats.emborg@ltu.se

ABSTRACT

Particle packing models have been studied extensively during past decades and led to development of some complex and relatively accurate predictions of packing of granular materials. While the models are capable of calculating the packing density for different volumetric share of constitutes, the concept of optimum packing remains unclear. The study aims to define optimum packing based on particle packing theory and excess water layer theory. The approach makes it also possible to calculate amount of paste that is required to put a concrete mixture at the onset of flow. Some pilot tests conducted in the laboratory showed good agreement with calculated data.

Keywords: Excess layer theory, Optimum packing, Specific surface area, Zero-slump, Mix design.

1. INTRODUCTION

Workability is one of the most important characteristics of concrete in fresh state which in simplest scenario depends on viscosity of the paste, packing density of aggregates, particle shape, grading curve, and the amount of water in the mixture. A particle mixture with high packing density leaves little volume of voids in the structure to be filled with paste. Reduction of paste and specifically cement has several benefits i.e. reduction of cost, pollution, shrinkage, cracking, etc.

Predicting the packing density of solid particles in a mixture has been studied extensively [1,2] and led to compiling some advanced and complex models such as CPM (Compressiblie Packing Model) that can estimate the packing for combination of different volume shares of the constitutes in the mixture. Models for calculating packing density have two purposes:

1- Determining predicted packing density.
2- Finding the optimal blend of particles.

Particle packing models can calculate the maximum packing density (minimum voids) in the mixture, however, making concrete at maximum packing usually results in “harsh” concrete [3].

The current paper aims to introduce a method for mathematical calculation of optimum packing based on input from packing models and the concept of water layer theory.

2. METHOD

As mentioned earlier, the approach is based excess water layer theory and void ratio in particle mixture. The basics of water layer theory and related concepts are explained in the coming sections.

2.1. Excess water layer theory

The excess water layer theory was derived from excess paste layer theory originally developed for slef-compacting concrete [4,5,6]. According to excess water layer theory, in addition to the water and cement that is required to fill the voids in aggregate structure, some extra water is required for surrounding the particle with a certain layer thickness in order to overcome the interlocks in aggregates by separating them which governs flowability of the mixture. The amount of required water is directly related to specific surface of the particles. At a constant volume of water, the mixture with higher specific surface area (SSA – surface area of particles relative to their volume or mass) will have thinner water layer around the particles comparing to a mixture with lower SSA.

The main difference between excess paste layer theory and water layer theory roots in the way that the two approach view concrete mixture. According to paste layer theory, concrete is divided into paste and aggregate phase while in excess water layer theory concrete is viewed as a mixture of all particles (aggregates plus cement) and water.

2.2. Specific surface area

Measuring surface area of the particles is complex, costly and in cases inaccurate process. The measurements are usually conducted using Blaine [7] or BET test [8]. Blaine test is developed for particles with relatively spherical shape and certain packing density which makes it suitable for measuring SSA of cement but not necessarily any other particle that does not fulfil the requirements of the test. BET test involves absorption of a gas (usually nitrogen) on the surface of particles, in a case where the particles include open inner pores; the surface of the pores will be included in the test results which are not of interest for concrete mix design purposes.

An alternative to conducting the measurement is to calculate the surface area of the particles based on the size distribution curve data and the assumption of spherical shape for the particles using the following equation:

$$a_{sph} = 6\sum_{i=1}^{n} \frac{m_i}{\bar{d}_i \cdot \rho_s} \qquad (1)$$

where m_i is the mass of a grain fraction *i*, being the mass percentage of the fraction between d_i and d_{i+1}. $\bar{d}_i$ is the mean diameter of fraction *i* and *i+1*. ρ_s is the relative density of the particles.

It is also possible to assume one of the platonic solids instead of a sphere as the representative shape of particles. Platonic solids are set of five regular, convex polyhedrons. Replacing platonic solids with spheres will not only changes the calculated value of surface area but also provides the opportunity to take into account the effect of square-cube law and the pace in growth of surface area to volume ratio as the particles become smaller in size and eventually increase the accuracy of the calculations. For this purpose Eq.1 can be written in its general form:

$$a_{poly} = \sum_{i=1}^{n} \frac{SA_i.m_i}{V_i.\rho_s} \qquad (2)$$

where SA_i/V_i is the surface area to volume ratio of fraction *i* and is related to the assumption made for the shape of particles. The concept of square-cube law and the principals of substituting spheres with platonic solids are discussed by [9].

3. THE MODEL

The suggested model works under the assumption that in addition to the water needed to fill the voids between the particles, some extra water is required to cover the surface of the particles with a certain thickness in order to put the mixture on the onset of flow. The thickness of the water layer is measured as 25nm in the case that calculation of SSA is based on spherical shape [10]; the thickness of water layer is assumed to be constant for different sizes of particles.

The packing densities of the aggregates are required too in order to find the volume of the voids. Following equation is based on the volume of constitutes of a mix for a cubic meter of concrete:

$$\varphi_{agg} + c + \left(\frac{w}{c}\right)c + A = 1 \qquad (3)$$

where φ_{agg} is the maximum packing density of aggregates, *c* is the volume of cement, *w/c* is the volumetric water to cement ratio and A is the volume of air.

Solving Eq.3 for a known packing density of aggregates and assumed volume of air results in the amount of cement and water needed to fill the voids. As the next step in the procedure, the amount of additional water needed to form a layer surrounding the particles can be calculated based on the SSA of particles:

$$w_l = SSA \times t_w \qquad (4)$$
$$w_t = w + w_l \qquad (5)$$

where w_l is the amount of water surrounding the particles, *SSA* is the specific surface area of all the solid particles in the mixture and t_w is the thickness of water layer (for simplification can be assumed as 25nm in the case that SSA was calculated rather than measured). Total amount of water, w_t, is considered as sum of the water that fills the voids, *w*, and the water that is needed to form the layer around particles. Since the water to cement ratio is supposed to be constant, an additional amount of cement should be calculated to compensate for the added particle surrounding water. New values of cement and water will be replaced in Eq.3 which will result in a new value for packing density. The new packing can be considered as the optimum packing as it indicates a point close to the climax of packing diagram where the solid structure provides enough space for the amount of water and cement that puts the mixture on the onset of flow.

In addition to the optimum packing value, the model can theoretically predict the amount of paste for zero-slump in the slump diagram. Moreover, adding 5 to 10% paste to the mixture will result in a recipe for workable concrete. It should be mentioned that the excess paste should be calculated for the onset of flow by implementing the same principal of having a constant thickness of water layer around the particles.

4. DISCUSSION

As mentioned earlier, the suggested model provides a basis for calculation of optimum packing and the amount paste needed to put the mixture on the onset of flow. A proper estimation of water requirement of the mixture results in mixtures with controllable workability. Moreover, the model can be further developed to potentially be used as a mix design model once the effect of admixtures, viscosity of the paste, and the cement type is introduced to the model.

Some pilot test recipes were made based on the calculations by the model in LTU laboratory and showed promising results.

REFERENCES

[1] Larrard, F. De. “Concrete mixture proportioning: a scientific approach”. London: E & FN Spon. (1999).

[2] Toufar, W., Born, M., & Klose, E. “Contribution of optimisation of components of different density in polydispersed particles systems”. Freiberger Booklet A, pp. 29-44 (1976).

[3] Fennis, S. A. A. M.“Design of ecological concrete by particle packing optimization” Dissertation, Delft University of Technology. (2011).

[4] Kennedy, Charles T. "The design of concrete mixes." In Journal Proceedings, 36, no. 2,pp. 373-400 (1940).

[5] Reschke, T., E. Siebel, and G. Thielen. "Influence of the granulometry and reactivity of cement and additions on the development of the strength and microstructure of mortar and concrete." Concrete Technology Reports ,200, pp. 25-38 (1998).

[6] Grünewald, Steffen. "Performance-based design of self-compacting fibre reinforced concrete." PhD diss., TU Delft, Delft University of Technology, (2004).

[7] ASTM C204-16. Standard test method for fineness of hydraulic cement by air permeability apparatus.

[8] Brauneur, S., P. H. Emmet, and E. Teller. "Adsorption of gases in multi molecular layer." Journal of Am. Chemical. (1938).

[9] Ghasemi, Y. "Aggregates in concrete mix design." Lic. diss., Luleå University of Technology, (2017).

[10] Hunger, M., and H. J. H. Brouwers. "Flow analysis of water–powder mixtures: Application to specific surface area and shape factor." Cement and Concrete Composites 31, no. 1 . pp. 39-59 (2009).