

Excavated Rock Materials from Tunnels for Sprayed Concrete

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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 m³ 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.

Material name	Source	Particle sizes	Type of aggregate	Production process		Rock types
				Main process	Secondary process	
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	Follobanen	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 in the primary stage, a gyratory crusher in the secondary stage and a cone crusher in the tertiary stage [3]. The sand material from Follo Line is produced by crushing TBM muck into smaller particles [4]. The crushing includes a cone crusher in the tertiary stage and a Vertical Shaft Impacter (VSI) in the quaternary stage. Crushers in the primary and secondary stage are excluded as the TBM muck contains rather small rock fragments compared to those produced from drill&blast.

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 a 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, which contains 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 ^{3a)}	2,76 Mg/m ³
Water adsorption	0,3 %	0,5 %	0,1 %	0,1 % ^{a)}	0,2 %
Particle shape^{b)}	25 % 20 %	-	70 % 55 %	70 % ^{a)} 55 % ^{a)}	40 % 25 %
Free mica content	4 %	-	11 %	11 % ^{a)}	24 %

a) The value for MU2 is assumed to be the same as the value for MU1, as the differences are assumed to be negligible.

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 relevant for MR2, as these properties are related to the fine particles (the effect of these properties is most significant when they are related to the fine particles).

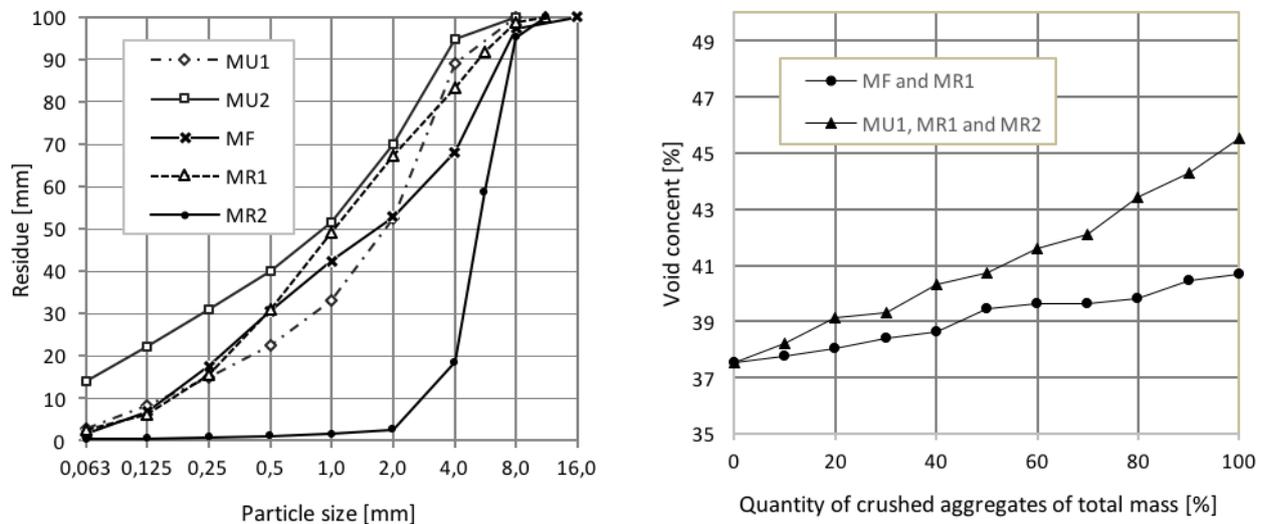


Figure 1 - Sieve curves of the different sand materials (left). Void content for different content of crushed aggregate (right).

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