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Filler from crushed aggregate for concrete: Pore structure, specific surface, particle shape and size distribution

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ABSTRACT

Characteristics of fine particles (0–125 μm diameter) from seven different crushed and natural sands from five different Norwegian rock types were determined. The results suggest that the same water absorption values, as determined by EN 1097-6 on coarser sand fractions, can be applied to the fines. The values of specific surface area measurements vary widely between different materials and between different measurement methods. BET measurements seem to be strongly affected by the mineralogical composition (presence of mica) and surface morphology (weathering) of the particles. Specific surface area calculated from the particle size distributions (PSD) is mainly dependent on the precision of the test methods in the size range below about 3–5 μm, because these small particles contain most of the surface area. Shape measurements by both Dynamic Image Analysis (DIA), which is a 2-D method, and X-ray microcomputed tomography (μCT), which is a 3-D method, have yielded similar relative length-to-thickness aspect ratios of the particles between different mineralogies, though with lower absolute values for DIA due to 2-D projection of 3-D quantities.

1. Introduction, scope and approach

Crushed aggregates significantly affect properties of self-compacting concrete (SCC), in particular with respect to the fresh state properties that distinguish SCC from conventional vibrated concrete (CVC). Koehler and Fowler [1] have reported that fine crushed aggregates can have a much more substantial effect on the rheology of SCC when compared to the coarse aggregates. Therefore, it is essential for the purpose of concrete proportioning to understand the interaction between crushed fine aggregate properties and SCC rheology. Correct and economical proportioning for the fresh state properties is the first step in manufacturing concrete structures with desired hardened, durability, and sustainability properties.

Two characteristics typically distinguish an SCC mix design from a corresponding CVC composition. First, an increased cement paste matrix volume, which is defined as all fluids, such as water and liquid admixtures, and all particles with size $\leqslant$0.125 mm, which includes cement and fine mineral filler particles [2]. This increased cement paste volume is supposed to reduce the possibility of blocking and interlocking between larger aggregate particles. Second, a capacity to flow along with matrix stability when combined with particles of size >0.125 mm is also necessary to achieve the desired SCC rheological properties.

An increased volume of cement paste matrix is usually achieved by introducing comparably high amounts of additional mineral fillers. The latter are normally preferred over an increased amount of cement, which often results in many disadvantages of high binder content (*e.g.*, undesirably high strength, increased heat of hydration, shrinkage, durability issues) or simply due to economic/sustainability reasons (*i.e.* price/environment). It must be noted that, as reported by Wallevik and Wallevik [3], the practice of SCC mix design can in fact vary from country to country. For example, the effect of using viscosity modifying admixtures (VMA) as a partial substitution for mineral fillers has been investigated [4]. In

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addition, the price and availability of suitable mineral powders, such as limestone and dolomite fillers, which are normally used today for SCC production in Sweden and the Baltic states, can be a problem at some locations. Another practical problem can simply be lack of extra dry material silos at the concrete plants. As a result of the latter, the current practice in Norway has been to use an increased fraction of natural sand with high fines content.

Natural sand, which may be weathered, differs from most fine crushed aggregates (manufactured sand) in its grading, particle shape and surface texture. Compared to natural sand, crushed fine aggregates incorporate significantly more fine particles (fillers), have different particle size distributions, and tend to be more angular with rougher surfaces. Due to these differences, concrete with crushed fine aggregate often displays different rheology (increased yield stress and plastic viscosity) and lower workability (reduced slump and slump-flow values) due to higher water demand than the same concrete made with glaciofluvial and fluvial aggregate [5–10]. The differences are more pronounced if the crushed fine aggregate is a by-product (also known as "waste sand" or leftover rocks from quarrying) of coarse aggregate production and if no special processing techniques, such as vertical shaft impactor (VSI) crushing, washing or air-sieving, have been utilized to improve the particle characteristics.

Due to the above rheological problems, which in most cases are believed to arise from the finest part of the manufactured sand [7], concrete producers would still prefer natural sand, even at a much higher price. On the other hand, crushed sand can be a perfectly suitable product for SCC production due to the great availability and naturally high fines content. Thus it is obvious that, in order to use these advantages for producing more sustainable SCC, one needs to have a clear understanding about how different crushed aggregate filler particles affect fresh concrete properties.

As reported by Cepuritis [7] and Ferraris et al. [11], the effect of very different mineral fillers on the rheology of fresh cementitious materials (both concrete and matrix) has been studied by several authors. However, none of them have reported a clear relationship between the filler characteristics and flow properties of the cementitious suspensions [7,11]. As a result, at present the selection of crushed mineral fillers for optimal SCC mix design cannot be predicted from the physical or mineralogical characteristics of the crushed fines and can only be determined using a properly designed performance test. One reason for this situation is the complexity of such a correlation due to the characteristics of fine particles such as surface physics, chemistry, mineralogy, material structure, and physical properties, about which there is a lack of knowledge. For example, to properly proportion matrix or concrete mixes, one would need to know the actual water absorption and saturated surface dry (SSD) density of the filler particles. Until now, no research investigated the open porosity of Norwegian crushed aggregate fillers that is accessible to water, which can thus affect the water absorption and rheology of the tested mixes. In addition, similar to the vigorous debate between the values of cement paste specific surface area obtained using water vapour adsorption BET vs. nitrogen adsorption BET [12], different mineral filler particle characterization techniques (*e.g.* Blaine, BET, laser diffraction, sedimentation) can easily give specific surface area results that differ by up to a factor of ten [7,13,14]. So the question of the "real" mineral filler specific surface area is still not resolved. On the other hand, due to its large surface area, quantification of this filler characteristic is essential for controlling the rheological parameters of fresh concrete and its matrix cement paste [7,15].

In addition, there is also the important question of filler particle shape, which will affect the rheology of the matrix down to some size due to the increased resistance to flow of non-spherical shapes and the decreased packing limit of angular shapes vs. spherical shapes, so the particles are closer to their ultimate packing density [16] and thus have more effect on rheology [17–19].

The scope of this work has thus been to obtain a clearer knowledge about the pore structure, water absorption, specific surface area, and size and shape distribution properties of some widely used Norwegian crushed aggregate fillers. We have investigated the particle shape of the fillers with two different techniques: Dynamic Image Analysis (DIA) [20] and X-ray microcomputed tomography (μCT) combined with spherical harmonic analysis [21,22]. The intent is to learn more about what aggregate particle parameters to study in order to understand the effect of crushed fillers on the flow of cementitious materials (especially SCC) and in addition point towards the best methods available, or that need to be developed, for crushed aggregate filler characterization in both scientific and industrial terms.

2. Materials and experimental procedures

2.1. Aggregate fillers

A total of seven aggregate fillers from five different quarries in Norway have been used for the study and are listed in Table 1. Six of the samples were produced by crushing (or crushing and grinding in case of limestone) of different rock-types in various processes while one was produced originally from a natural deposit. As shown in Table 1, the first three materials are from the same deposit at the Årdal quarry on the west coast of Norway; the only difference between them is the sand production process used. The first filler comes from natural glaciofluvial sand. Production generally included only extraction with a wheel loader followed by a sieving and a washing process. Fines No. 2 and No. 3 come from crushing large boulders (moraine material) that can be found at the same natural sand deposit as No. 1. The difference between No. 2 and No. 3 is that the No. 3 sand has been subjected to washing in addition to crushing and sieving. A more detailed description and production process flow sheets for most of the filler materials are available elsewhere [7]. Table 1 also holds mineralogical composition of the fillers as analysed by X-ray diffraction, with the exception of fines Nos. 2, 3, and 7. For fillers No. 2 and No. 3, the composition is believed to be somewhat similar to No. 1 due to the same origin. The difference could be that some weaker minerals, such as biotite, muscovite and chlorite, which are concentrated in the very fine fractions (<30 μm), have been washed away during weathering of the natural sand. Sample No. 7 is known to be a rather pure limestone consisting mainly of calcite.

It is also worth mentioning here that, for the fines from Hokksund (No. 6), some previous practical experience (*i.e.,* visual inspection of the coarse aggregate fraction from the same quarry) has revealed comparably very high amounts of flaky free mica particles.

2.2. Experimental procedures

2.2.1. Filler particle size distribution and specific surface

Particle size distribution (PSD) of the fillers has been characterized by a wet-method laser diffraction device (Backman Coulter LS 230),[1] based on a sphere with equivalent scattering [23], and a sedimentation device (Micromeritics SediGraph 5100), which is based on particle sedimentation speed and equivalent Stokesian diameter [23]. Specific surface area measurements have been performed with

[1] Commercial equipment, instruments, and materials mentioned in this paper are identified in order to foster understanding. Such identification does not imply recommendation or endorsement by the National Institute of Standards and Technology (NIST), nor does it imply that the materials or equipment identified are necessarily the best available for the purpose.