Construction and Building Materials 67 (2014) 121–126

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Evaluation of the quality of fine materials and filler from crushed rocks in concrete production

Björn Lagerblad [a,*], Hans-Erik Gram [b], Mikael Westerholm [b]

[a] Swedish Cement and Concrete Research Institute, 10044 Stockholm, Sweden
[b] Cementa AB, Box 47328, 10074 Stockholm, Sweden

HIGHLIGHTS

- The fine material in crushed rocks is very variable.
- The fine materials from crushed rocks reflect the mineralogy of the rock.
- Mica minerals are flaky and detrimental for concrete workability.
- Clay size micas may accumulate in the ultrafine material and adversely effect concrete workability.
- By appropriate mortar tests, the quality of the fine material can be evaluated.

ARTICLE INFO

Article history:
Available online 8 December 2013

Keywords:
Concrete aggregate
Crushed rocks
Fine material
Filler
Test methods
Mineralogy
Micas

ABSTRACT

Crushed rocks are, in general, more flaky and irregular in shape than natural aggregates. Especially granitic rocks display variable amounts or flaky free micas in the finer fractions when crushed. Moreover, the crushed rocks result in more fine material. Fillers can, in combination with superplasticizers and if the quality is appropriate be used to expand the paste phase of the concrete and thus be used to lower the cement consumption. To utilize the filler optimally one needs to evaluate the filler quality.

There are several methods to evaluate the filler. In this article different methods both in regards to the material properties and the behavior in mortar and micro mortar tests are compared and evaluated. The analysis shows the importance of understanding the effect of both the particle shape and flakiness in the fine fractions and the properties of the material in the finest fraction i.e. <10 μm. This is very much related to the mineralogy of the rock.

1. Introduction

The properties and particle distribution of the raw materials is essential in concrete production. This is the case of both coarse and fine aggregates. The most critical component is the filler that is part of the micro mortar, which also includes cement and water. With filler it is possible to expand the micro mortar volume and compensate for irregularities in the aggregate. This article will treat how the quality of the filler can be classified and how to use filler to save cement in concrete production.

In Sweden, natural aggregates are becoming scarce and for environmental reasons these are to be preserved. The only alternative aggregate source for a sustainable society is crushed rock. In Sweden most of the bedrock is granitic and most of the quarries are situated in this rock type. These quarries were not initially thought to produce aggregate for concrete and it is known that crushed granitic rocks can contain flaky minerals which are not desired in concrete. This is especially true as regard the fine aggregates. In general, unsuitable fine aggregates cause an increased demand of cement to get a good workability. Clinker production consumes large amounts of energy and releases large amount of CO_2. Thus for a sustainable concrete production, the concrete producers must learn to use proper proportioning methods to minimize the cement consumption. This in particular is due to the aggregate properties and thus the aggregate producers must learn how to evaluate the rock type and crush with different methods.

To address this problem a national research program was initiated in Sweden. Crushed products from more than fifty different quarries have been analyzed for particle size distribution, particle shape and petrographic and mineralogical properties. These properties have been correlated to concrete mixes and their rheological

* Corresponding author. Tel.: +46 105166818; fax: +46 8 243137.
E-mail addresses: bjorn.lagerblad@cbi.se (B. Lagerblad), hans-erik.gram@cementa.se (H.-E. Gram), mikael.westerholm@cementa.se (M. Westerholm).

0950-0618/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.conbuildmat.2013.10.029

properties [1]. The major difference between crushed rocks and natural aggregates, in both the coarse and fine aggregates, is the grain shape. The grain shape of the coarser fragments can, by attrition, be made more cubic [2] in vertical shaft impact crusher (VSI). The attrition process, however, increases the amount of fines [3].

The outcome of the research program showed a large variation, were some materials were appropriate and resulted in aggregate that could easily replace natural aggregates, while others were not suitable as concrete aggregate. This was especially the case with some granites and granitic gneisses. Massive limestone and basic rocks produced better materials but these rock types sometimes also gave unsuitable materials in the finer fractions.

One early conclusion was that it was mainly the fine aggregate that determined the workability. Thus, the main work was focused on the 0–2 mm fraction. This work, turn, showed that the filler and filler "quality" was important, especially as regard cement consumption.

Not long ago large amounts of filler caused problems with workability. Today, however, with the modern superplasticizer it is possible to introduce larger amounts of filler into concrete than previously was possible. Proper use of the fillers, as will be shown in this article, can actually reduce the cement content.

1.1. The effect of grain shape on workability

Fresh concrete is a particle slurry consisting of aggregate, cement and water. When cast, all the particles interact; they collide and/or glide on each other. Thus for flaky particles, larger amounts of finer material is needed to achieve a good workability. A common practice in mix design, when the coarse aggregate is flaky, is to increase the amount of fine aggregate. If the smaller particles are also flaky, more materials are needed in the finer fractions. This holds true down to the finest particles. Thus, if the amount of free flaky particles is high this will increase the water demand or more specifically the amount of "micro paste". Micro paste contains cement, water and fillers.

Below a certain size the particles from crushed rocks are mainly free mineral. The types of minerals depend on the rock type and when free minerals are appear by the coarseness of the rock. The shape of the particle depends on crystallographic structure of the individual mineral. The most troublesome minerals are those of the mica group as the crystal structure as such is flaky. Moreover, clays that also belong to the mica group of minerals may be detached and cause problem. If the amount of free micas and clays in the fine fractions is high the workability of concrete decreases and the water demand increases. Mica minerals (biotite, muscovite and chlorite) are common in granitoid rocks. Mica as a free mineral accumulates in the finer fractions [4]. Chlorites can often be found in basic rocks.

Thus it is important to be able to proportion the micro mortar so that the amount of water is kept to a minimum in order to obtain good compressive strength. The filler is difficult to analyze due to the small grain sizes. Either a microscope or an indirect method is needed.

1.2. The effect of fillers in the micro mortar

Aggregates always contain some filler. In European standards particles smaller than 63 μm are classified as fines. In practice particles smaller than 125 μm are called fillers and commonly the micro mortar includes water and all particles including cement that are smaller than 125 μm. The quality and size distribution of the filler affect the rheology of the fresh concrete as well as the physical properties of the hardened concrete.

The effect of filler and how it can be used to save cement in concrete production has been studied for some time. A comprehensive summary can be found in [5]. Basically, the particle distribution in the micro mortar, including the cement particles, should be based on packing models [5,6] and follow a smooth distribution curve. Thus micro particles, particles smaller than cement, are important while particles similar in size to cement are negative. The packing models, however are based on round particles and do not consider particle shape. Thus the particle shape must be considered. The quality of filler is related to both grain size distribution and grain shape.

Especially the ultrafine particles, those with a size smaller than the cement, have a profound effect on the strength of the concrete. The cements of today often include limestone co-ground with clinker where the limestone becomes ultrafine filler. The same effect can be achieved with almost any mineral if the particle size is smaller than that of the cement [7,8]. Other experiments [8] also showed that the amount of ultra filler could be increased further and replace even more cement without loss in either porosity or strength (Fig. 1). Cement reduction demands good quality ultra fine filler. The mineral particles have to be cubic. Flaky clays give bad workability.

In the example above ultrafine (<10 μm) filler is used. It is also possible to increase strength or to reduce the amount of cement by adding more normal size fillers (and superplasticizer) to a concrete mix. In an experiment [9,10] fillers were separated from crushed granite by air classification. The material was less than 0.25 mm in size and consisted mostly of quartz and feldspar crystals. The results show that an increase in strength or a cement reduction can be achieved by replacing cement with added fines and keeping the w/c ratio constant. This, however, requires higher addition of an effective superplasticizer and the concrete becomes more viscous, which makes casting and finishing of normal slump concrete more difficult. Superplasticizer was added in all mixes to achieve a slump of 200 mm.

This shows that one can minimize the cement content by careful proportioning of fines or filler, but the fines need to be of good quality (See Fig. 2). Thus a classification of quality is needed for a proper concrete proportioning.

2. Quality of fine material

The effect of the fine aggregate is related to the particle size distribution and to the particle shape. The effect of this is shown in Fig. 3. The rheology of a 0–2 mm mortar was investigated in a viscometer (Contec 4-SCC). The mortar is based on the fine fraction of a normal house construction concrete with a w/c of 0.57 [12,1]. No

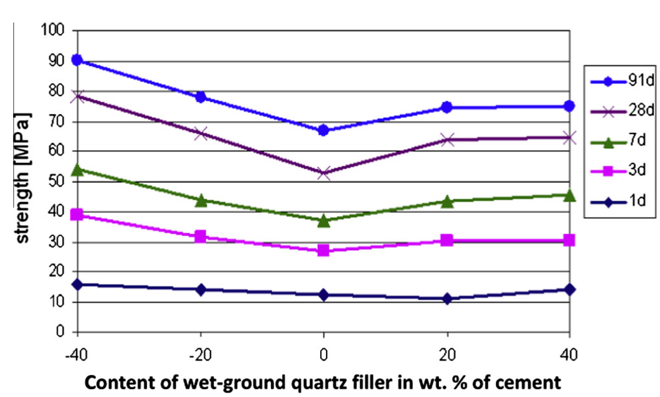

Fig. 1. Strength development of concrete with cement replacement (defined as negative value and filler addition (defined as positive value) and constant w/c (0.46) and addition of ultrafine filler. In this test wet ground quartz was used. The reference concrete (value 0) contained 433 kg/m^3 of cement (CEM I). Maximum grain size was 16 mm. From [7].