Construction and Building Materials 61 (2014) 270–277

Contents lists available at ScienceDirect

Construction and Building Materials

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

Effects of fines content on packing density of fine aggregate in concrete

A.K.H. Kwan *, P.L. Ng, K.Y. Huen

Department of Civil Engineering, The University of Hong Kong, Hong Kong, China

HIGHLIGHTS

- The effects of fines content in aggregate on concrete are still not clear.
- The allowable fines content has been a controversial issue for many years.
- The fines content would increase the surface area and thus the water demand.
- But the fines content would also increase the packing density as shown herein.
- Hence, the fines content has both undesirable and desirable effects.

ARTICLE INFO

Article history:
Received 29 December 2013
Received in revised form 17 March 2014
Accepted 18 March 2014
Available online 5 April 2014

Keywords:
Aggregate
Concrete
Fines content
Packing density

ABSTRACT

The fines content (particles finer than 75 μm) in aggregate has substantial effects on the performance of concrete. Since the fines content has large surface area that would increase the water demand, maximum limits are often imposed. However, the fines content would also fill into the voids between larger particles to increase the packing density and thus reduce the volume of voids to be filled with cement paste. Hence, the fines content is not entirely undesirable and it has been suggested to raise the limits on the fines content. Somehow, due to measurement difficulties, the effects of fines content on the packing density are still not well understood. Herein, the packing density of fine aggregate with varying fines content was measured using both the dry and wet packing methods. It was found that under wet condition, the highest packing density generally occurs at a fines content of about 15%.

1. Introduction

The particle size distribution of the aggregate in concrete has great effects on the performance of the concrete mix produced. First, the particle size distribution would affect the packing density of the aggregate, which in turn would determine the volume of voids to be filled with paste. With a higher packing density, the volume of paste needed to fill the voids would be smaller and the volume of excess paste (paste in excess of that needed to fill the voids within the aggregate) available to form paste films on the surfaces of aggregate particles would be larger [1,2]. Second, the particle size distribution would affect the mean particle size and specific surface area of the aggregate, which in turn would determine the surface area of the aggregate particles to be coated with paste. With a larger specific surface area, the paste film thickness would be smaller, leading to lower workability or higher water demand [3]. In this regard, it has been found that the paste film thickness has effects not only on the workability but also on the strength of the concrete [4]. Hence, both the packing density and specific surface area of the aggregate are important.

Among the fine and coarse aggregates, the fine aggregate has greater effects because the fine and coarse aggregates are generally blended such that the fine aggregate is more than enough to fill the voids within the coarse aggregate [5], or in other words such that the fine aggregate is dominant. The provision of more than enough fine aggregate to fill the voids would ensure that there is a certain amount of excess fine aggregate (fine aggregate in excess of that needed to fill the voids within the coarse aggregate) coating the coarse aggregate particles to alleviate the particle interlocking action and improve the flowability and passing ability of the concrete produced [6]. With the fine aggregate being dominant, the packing density of the blended aggregate would be determined mainly by the packing density of the fine aggregate. Moreover, since the fine aggregate has smaller mean particle size and larger specific surface area, the specific surface area of the blended aggregate would also be determined mainly by the specific surface area of the fine aggregate.

There are several different types of fine aggregate, namely, river sand (RS), crushed rock fine (CRF) and manufactured sand (MS)

* Corresponding author. Tel.: +852 2859 2647; fax: +852 2559 5337.
E-mail address: khkwan@hku.hk (A.K.H. Kwan).

http://dx.doi.org/10.1016/j.conbuildmat.2014.03.022
0950-0618/

[7,8]. RS is obtained by dredging river beds. As it has been subjected to washing and attrition when carried downstream along the river, RS tends to have low fines content (particles finer than 75 μm) and is generally rounded in shape. On the other hand, CRF is produced by crushing rock from quarries. Depending on the type of parent rock and the crushing equipment used, CRF tends to have high fines content and is generally angular in shape. Lastly, MS is produced by processing CRF to control its particle size distribution and reduce its fines content. If so desired, it can also be ground smooth to reduce its angularity, or in other words, to improve its particle shape [9].

In recent years, to avoid adverse environmental impact and possible river bank instability, dredging for river sand is severely limited, leading to acute shortage of RS [10]. Hence, the construction industry is compelled to look for substitutes. Both CRF and MS have been used as RS substitutes. The CRF is a relatively cheap fine aggregate for use in place of RS. However, it is generally believed that its high fines content would lead to excessively high water demand and is therefore undesirable. Hence, maximum limits on the fines content are imposed in some national standards, such as the British Standard BS 882: 1992 [11], American Standard ASTM C 33-13 [12] and Chinese Standard GB/T 14684-2011 [13]. On the other hand, the MS, though generally more costly, should be a better fine aggregate for use in place of RS because it has been processed to control its particle size distribution, fines content and even particle shape for enhanced performance. However, there is up to now no generally accepted standard or specification for MS and as a result, MS from different producers may have different characteristics.

For many years, it has remained a controversial issue as to whether the fines content is really undesirable and what maximum limits of the fines content should be imposed [14–16]. In fact, the European Standard EN 12620: 2013 [17] sets no maximum limits on the fines content, albeit the British Standard BS 882: 1992 [11] that it replaces has imposed certain maximum limits. In general, the fines content has two opposite effects. First, the fines would fill into the voids between larger particles to increase the packing density of the fine aggregate. Second, the high fineness of the fines content would increase the surface area of the fine aggregate. Whilst the increase in packing density would for the same paste volume increase the volume of excess paste for forming paste films, the increase in surface area would thin down the paste film thickness. The net effect depends on whether the increase in excess paste or the increase in surface area is proportionally larger. Ideally, the fines content should be such that the packing density would be increased to near maximum but the surface area would not be excessively increased. The question is: what the optimum fines contents under different conditions are.

The packing density of fine aggregate is not easy to measure. There are codified test methods for measuring the packing density of aggregate under dry condition [18–21]. However, such dry packing methods generally have the major problems that the measured packing density is sensitive to the amount of compaction applied [22] and that they do not include the possible effect of water. These problems are more serious when finer particles are dealt with because the inter-particles forces causing agglomeration and loose packing [23,24] are then comparatively larger. Hence, the dry packing methods are not applicable to fine particles. To resolve these problems, Wong and Kwan [25] have, in 2008, developed a wet packing method for measuring the packing density of cementitious materials under wet condition. This method has been used to study the effects of packing density on rheology of cement paste [26,27]. Later, it was extended for application to fine aggregate [28] and employed to study the effects of packing density on rheology of mortar [29,30].

There is a common belief that the effect of water on the packing density of aggregate is not really significant because the aggregate particles are relatively large compared to the cementitious materials. However, this belief has never been proven by actual packing density measurement. In a recent study [28], it was found that the packing density of fine aggregate can be 24% higher under wet condition than dry condition. Hence, the effect of water on the packing density of fine aggregate is not small. In this research, the wet packing method was applied to study the effects of the fines content (particles finer than 75 μm) and powder content (particles finer than 150 μm) on the packing density of fine aggregate. In addition, the effects of compaction, water and superplasticizer were also investigated. It will be seen that the beneficial effects of the fines and powder contents on the packing density are much larger in the presence of water and superplasticizer.

2. Definition of terms

For clarification, the terms describing the packing of a particle system are first defined herein. In the bulk volume of solid particles, the interstitial space between the particles can be described by either the voids content or the voids ratio. The voids content (denoted by ε) is defined as the ratio of the volume of voids to the bulk volume of the particles while the voids ratio (denoted by u) is defined as the ratio of the volume of voids to the solid volume of the particles. They are inter-related by:

$$\varepsilon = \frac{u}{1+u} \tag{1}$$

On the other hand, the solid concentration (denoted by ϕ) is defined as the ratio of the solid volume of the particles to the bulk volume of the particles. It is given by:

$$\phi = 1 - \varepsilon = \frac{1}{1+u} \tag{2}$$

3. Testing program and methods

In a fine aggregate with a fixed maximum size, the finest portion, which fills into the voids between larger particles, has substantial effects on the packing density. Herein, the finest portion with particle size <75 μm is called the fines content whereas the finest portion with particle size <150 μm is called the powder content. Being finer and more effective in filling into voids, the fines content should have greater effects. However, the effect of the particles finer than 75 μm and the effect of the particles coarser than 75 μm but finer than 150 μm are not independent because of particle interaction between the two different size classes of particles. Hence, the testing program was designed to study the combined effects of the two size classes of particles on the packing density under different conditions. For this purpose, the fine aggregate to be tested was first mechanically sieved to separate the fine aggregate into three size classes, namely, aggregate A, aggregate B and aggregate C. Aggregate A was the size class finer than 75 μm. Aggregate B was the size class coarser than 75 μm but finer than 150 μm. Aggregate C was the size class coarser than 150 μm.

The three size classes of fine aggregate are depicted in Table 1. In order to investigate the effects of water, compaction and superplasticizer (SP), a total of six testing conditions were applied, as summarized in Table 2 and explained later. From the three size classes, aggregate samples were produced by mixing different proportions of aggregate A, aggregate B and aggregate C together. The mix proportions of an aggregate sample were defined in terms of the A content (proportion of aggregate A by mass in the sample), B content (proportion of aggregate B by mass in the sample) and C content (proportion of aggregate C by mass in the sample), each expressed as a percentage. To study the effects of the A and B contents, both the A and B contents were each varied from 0% to 15% in steps of 5%. For easy identification, each aggregate mix was assigned a mix number in the form of A content + B content + C content, as listed in the first column of Table 3. In total, 16 aggregate mixes were produced for packing density tests.

3.1. Dry packing tests

The test methods stipulated in the British Standard BS 812-2: 1995 [19] for measuring the uncompacted and compacted packing densities of aggregate were adopted. Herein, the testing conditions under which the uncompacted and compacted packing densities were determined are designated as D1 and D2, respectively, as depicted in Table 2. For testing under condition D1, the aggregate