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Behaviors of Fine Glass Powders and Coarse Glass Aggregates on Concrete

Author: AMIR ABBASPOUR

M.E Student - Civil Engineering department

Andhra University, 530003

Visakhapatnam, INDIA

Tel: 0091-8801300056

E-Mail: amir.abbaspour.1360@gmail.com

ADDRESS: ROOM NO. (NS-3), A.U. INTERNATIONAL STUDENTS HOSTEL, SOUTH CAMPUS, 530003, VISAKHAPATNAM, INDIA

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Authored by: AMIR ABBASPOUR

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AMIR ABBASPOUR

M.E Student - Civil Engineering department

Andhra University, 530003

Visakhapatnam, INDIA

Abstract

This paper deals with the incorporation ofglass cullet in cement-based materials. The aim is to help understand the differing behaviors observeddepending on the particle size of the glass: it is necessary to be mentioned here that the use of fine powders usually improves the concrete propertiesdue to pozzolanic reaction, while coarse aggregates are generally detrimental for concrete due to alkalisilica reaction. Needless to say,glass is a material mostly made up of amorphous silica. According tosome results, as well as other studies, nobody can reject this reality that glass can display two maintypes of behavior in cement-based materials an ASR and a pozzolanic reaction.On the other words, highly alkali-reactive materials can be less problematic, and even beneficial, when introduced into the concrete as a fine powder. It shows that the lack of swelling of gels resulting from the reaction of glass fines can be partly due to the nature of these gels. Some comparative investigations carried out on reaction products resulting from glass grains of various sizes, in the presence of both portlandite Ca(OH)2 and C3S (tricalcium silicate: 3CaO SiO2), has shown that glass aggregates produce detrimental gels while glass fines produce gels that help to improve concrete properties.

Keywords: Glass cullet, Alkali-silica reaction, Pozzolanic reaction,Gels, Particle size

1. Introduction

The alkali-silica reaction (ASR) can be described as a process of internal degradation of concrete involving certain siliceous phases of aggregates, alkalis found in the pore solution of concrete, and portlandite. One of the most effective solutions proposed to counter the detrimental effect of ASR is to use pozzolanic supplementary cementing materials (SCM) (artificial or natural) [10]. Glass is a material principally made up of amorphous silica. It has been observed that, when used as an aggregate in concrete, it systematically provokes swelling linked to ASR [6]. Results of expansion measurements on mortar prisms incorporating 20 % of glass of different sizes can be found in a complementary study [6]. These results, as well as other studies, show that glass can display two main types of behavior in cement-based materialsan ASR and a pozzolanic reactionfor which a critical grain-size threshold of approximately 0.9-1 mm has been observed, under which no expansion occurs [2, 12, 14, 15].

2. Assessing the alkali-silica reaction (ASR) on the finest and coarsest aggregate

According to researches and studies in this field, compressive strengths obtained on these mortars increased with the fineness of the glass used. This observation raises questions regarding the origin of swelling linked to ASR of glass aggregates and theeffect of glass grain size on the passage from an ASRto a pozzolanic reaction [2].This antagonistic behavior has been observed along time ago, as highly alkali-reactive materials canbe less problematic, and even beneficial, when introducedinto the concrete as a fine powder [10]. Ithas usually been explained as the rapid reaction that isfacilitated by the high surface area of the powderedmaterial.The goal of this investigation is to assess the effectof glass grain size on the nature of reaction products(morphology and composition) and attempt to explainthe consequences of this difference. A comparativestudy was carried out on the reaction productsresulting from the use of various glass grain sizes.The study was first conducted in the simplest case, inwhich glass was attacked by a potassium solution [8]. A subsequent step was then carriedout in a reactive environment enriched with lime($Ca(OH)_2$), an element that plays a vital role in bothalkali-silica and pozzolanic reactions. Finally, thebehavior of glass was evaluated in conditions close tothose found in concrete: glass placed in an alkalinesolution in the presence of C_3S, selected as amodel for ordinary Portland cement. The techniquesused to characterize the solid products were X-raydiffraction (XRD) [9].

3. Procedures of assessing the behaviors

3.1 Materials

The glass used in this study was soda-lime silica bottleglass of mixed colours. It was composed of 40, 33,20and 1 % of colourless, brown, green, and blue glassesrespectively. Thematerial also contained around 6 % of plastic, metaland paper impurities [12]. Different sizes of glass particles,noted as CX (from the finest X = 8, to the coarsestX = 1), were obtained after grading, washing, drying,crushing and sieving the raw material. It means that after this the finest one will be considered **C8** and the coarsest one will be considered as **C1**. It can be seenthat the chemical compositions of these two categories weresimilar, confirming the homogeneity of the material.Minor element contents werenot significantly different between the different categories [4, 5].

3.2 Sample preparation and test methods

Analysis of newly formed hydrates versus glassparticle sizes was performed on suspensions containing$Ca(OH)_2$ or C_3S, glass and potassium solution. These suspensions were prepared insmall stainless steel reactors and stored in a thermostaticbath maintained at 60 C until their analysis [1, 3].Precipitates were separated by filtration from thesolution, washed with deionized water and then driedat 20 C in a vacuum-freeze dryer. The two differentmixtures weremeasured usingXRD with a rear monochromator.The morphology of hydrates was determinedby scanning electron microscopy (SEM-JEOL JSM 6380 LV). Their elementary compositionswere measured using energy dispersive X-ray spectroscopy and X-ray fluorescence(XRF)[9].

3.3 Results

C1(Coarsest Glass Aggregates):

The surface of the layer covering the coarsestgrains was characterized by crystals of very definiteshape. Analyses showed that these crystals werezeolitic-type alumino-silicates incorporating alkalis. This result is in agreement with the findingsof Stark [11], who worked on attacks of varioussiliceous materials by sodium and potassium solutionsat 60 and 80 C. This author showed that glassaggregate attack by a potassium solution resulted inthe appearance of zeolites.

C8(Fine Glass Powders orFinest GlassAggregates):

Examination of products resulting from C8attack did not show well-defined products. Theanalysis revealed an undefined, amorphous mass,similar to those usually found in materials obtained inthe presence of cement [7, 13].

4. Discussion

These tests conducted on a model environment showthat at least two types of products can form:

1-Fine glass particles:

The reaction products appear tobe silico-calco-alkaline gels

2-Course glass particles: two types of products areformed:

-Less alkalis than for fine products

-Abundant near the grains.

Some authors have proposed that the propertiesof gels differ depending on their composition.Destructive and non-destructive gels would also exist,in particular according to their calcium content[11].

The compositions of ASR gels vary greatly. However,published data indicate that it is possible to seethese gels merely as mixtures of two constituents, eachhaving a nearly constant composition (except for waterquantity).

From data in the presence of C3S, it can beconcluded that:

1- C1 coarse grains produce gels within the detrimentalzone, as opposed to C8 fine grains.

2- Upon contact with the external face of glassparticles, C1 gels absorb calcium, thereby movingto the safety zone.

Therefore, it is possible that two reactions cocoexist,one becoming predominant depending on ofthe size of the reactive particles. For example, forcoarse particles, the chronology of reactions could beas follows:

(1) A pozzolanic reaction affecting the external partof the grains. At the beginning of this reaction,the surface contact of grains with the aqueousenvironment promotes the more or less rapiddissolution of the siliceous network [2, 10].

(2) A production of gel.The presence of calcium nearby promotes theprecipitation of gels at relatively highrates, as detected for C1 particles(this step is facilitated in a model environment).This production continues until the diffusionprocesses take over and delay the silica attack.

(3) A modification of reaction kinetics as the reactionadvances (through the formation of a barrierlimiting contact with the grains). The diffusionprocesses then become more important. Thepenetration of alkalis into the grains leads to areaction with the silica, and therefore to theproduction of silico-alkaline gels. Thesegels, due to the low calcium content, lead toswelling of the cement matrix [5]. The latearrival of calcium (as it diffuses less quickly thanalkalis)

allows subsequent modification of thecomposition of the gels.

5. Conclusion

The goal of this investigation was to study the effect ofglass grain size on the nature of their reaction products(morphology and composition) and to try to explainthe consequences resulting from this difference.The main results were that:

- Depending on their coarseness or fineness, glassparticles have different chemical behaviors.Newly formed gels vary in their chemical compositionsand their mineralogical structures:

1. Coarse glass grains (C1), not completelyattacked, are covered by a double layer(massive alkali gel)

2. Finer grains (C8) are completely dissolved.Newly formed products resulting from fineparticles have higheralkali contents resultingfrom C1.

- The study revealed the formation of phyllosilicatesresponsible for the alkali-reactivebehavior of C1, as opposed to C8 associated with pozzolanic predominate.

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