Construction and Building Materials 49 (2013) 84–92

Contents lists available at ScienceDirect

Construction and Building Materials

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

Production, microstructure and hydration of sustainable self-compacting concrete with different types of filler

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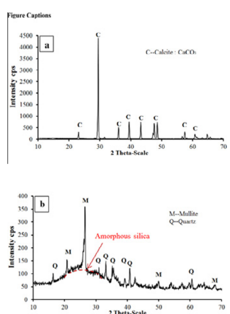
HIGHLIGHTS

- Production of economic sustainable SCC with high partial replacement of cement.
- First work to analyse the micro-characteristics of the interfacial transition zone (ITZ) of sustainable SCC.
- Addition of LP leads to less homogenous microstructure of in both the ITZ and the cement paste.
- LP gave an indication to the acceleration effect on the hydration. The analysis approved its inactivity.
- Fly ash addition showed its consistency for the production of sustainable SCC.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 22 April 2013
Received in revised form 2 July 2013
Accepted 21 July 2013
Available online 4 September 2013

Keywords:
Self-compacting concrete
Hydration
Microstructure
Interfacial transition zone
Fly ash
Limestone powder

ABSTRACT

Production, microstructure and hydration characteristics of sustainable self-compacting concrete (SCC) are investigated with two types of filler having significant differences mainly in chemical composition and physical properties. The purpose is to show how different fillers at high cement replacement levels can affect the composition, microstructural and hydration characteristics at early age. Several techniques, comprising X-ray diffraction, scanning electron microscopy (SEM) linked with energy-dispersive X-ray (EDX) analysis, image analysis, mercury intrusion porosimetry and thermo-gravimetric analysis, were used in order to demonstrate the effect of these two fillers at high replacement proportions.

The two types of sustainable SCC produced had a compressive strength of 50–60 MPa and used the same water to binder ratio. The replacement rate of both limestone powder (LP) and fly ash (FA) was about 33% of the total binder (450 kg/m^3).

In spite of the equal water to binder ratio and approximately the same compressive strength grade at 28-days, limestone powder self-compacting concrete (LP–SCC) had a different microstructure and hydration products from the fly ash self-compacting concrete (FA–SCC). The results indicate that the fly ash was the more suitable for the production of sustainable SCC.

1. Introduction

In recent years, there has been an increasing interest in using high quantities of fillers as a partial replacement for cement in self-compacting concrete (SCC). This helps to make SCC a more sustainable material [1]. Incorporation of high quantities of superplasticizer (SP) and a large volume of filler material is

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http://dx.doi.org/10.1016/j.conbuildmat.2013.07.107

essential to achieve high flowability and sufficient resistance to segregation. There are many types of filler that have been used successfully in SCC but the most common fillers are fly ash, limestone and silica fume [2]. Moreover, the use of mineral admixtures and micro-fillers as a partial replacement for cement may also reduce the high cost of SCC but the durability of such additives needs to be studied further [3]. The additions and the absence of vibration give self-compacting concrete a distinct microstructure [4]. The hydration and the microstructure are the most important characteristics that can affect the contaminant transport and durability properties of the concrete. This paper aims to investigate the microstructural characteristics of the cement matrix and the interfacial transition zone (ITZ) in addition to the hydration properties by examining two SCCs with different fillers at a high replacement proportion (33%) of the total binder.

In Europe, 300 kg/m^3 cement content for a powder-type self-compacting concrete is commonly used with limestone powder (LP) filler [5]. Generally, in SCC, the fillers can be classified into two types: reactive and non-reactive. However, for LP, there is no reliable evidence that it can participate chemically to improve the structure of the hydrated cement paste [5]. For this reason, fly ash and quartz fillers have also been used as mineral additions in SCC production in Europe.

The permeability and the water/vapour/contaminant transport properties of the concrete are highly dependent on the capillary pores and their interconnectivity. In general, the porosity of SCC is lower than that of normal vibrated concrete. This is due to the filling and dispersal effect of the fillers and the superplasticizer, respectively [6]. However, the type of addition is likely to determine the nature of the porosity of the cement paste (macro or micro) or the connectivity of the pores at high levels of replacement for the same water to powder ratios [7]. At the microscale, this might strongly affect the permeation properties such as diffusivity of substances like chloride or carbon dioxide.

Typically, the engineering properties of a concrete are understood to result from the combination of the response of the aggregate in the concrete, of the filler/fines matrix and of the interface (ITZ) between the two [8]. With regard to the opportunities for movement of water, gas or contaminant through a concrete, the aggregate is considered to be impermeable. Therefore, the composition and microstructure of the ITZ and of the matrix are likely to be the factors controlling fluid movement through the concrete [9]. For SCC, both the ITZ and the matrix are likely to be dense relative to their characteristics in normal vibrated concrete [1]. However, to date, the effect of different fillers at high level of cement replacement on the local porosity and permeability characteristics and the distribution of atoms in the hydrated phases of the ITZ and the matrix of SCC is not very well known. The main objectives of the present work, therefore, were to study the effect of two common fillers on the production, microstructure and hydration characteristics of two types of sustainable SCC.

1.1. Research significance

With the increasing use of SCC, it is becoming increasingly difficult to ignore the influence of its microstructure and hydration on its durability and fluid transport properties. Nowadays, SCC plays a vital role in infrastructure across the world, and it is often exposed to external environmental attack. Therefore, this work aims to contribute to the understanding of the microstructure and hydration of sustainable SCC. The paper is one component of a larger research program that is investigating accelerated carbonation and chloride penetration in relation to the microstructural properties of sustainable SCC.

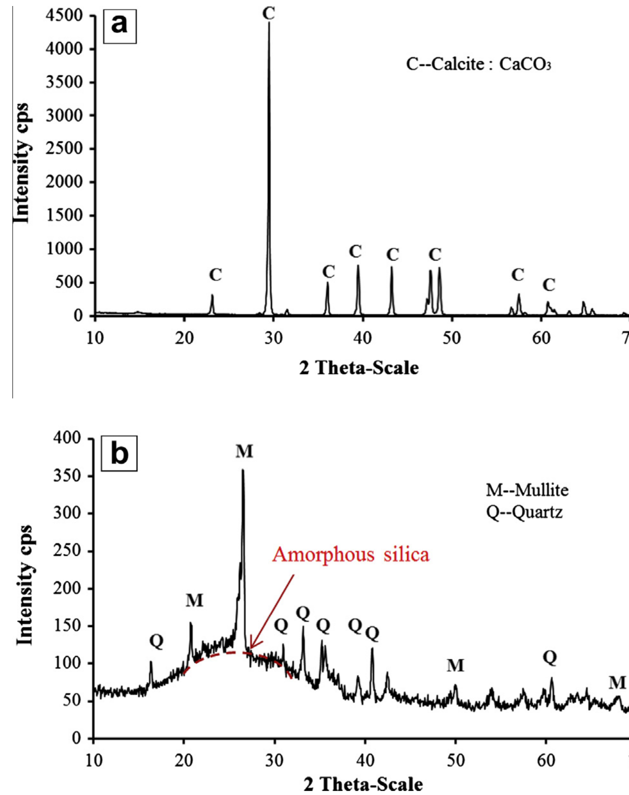

Fig. 1. XRD-patterns of (a) LP and (b) FA.

2. Experimental program

2.1. Materials

The materials used in this study were:

- Portland cement (CEM I 52.5R);
- Local river quartz sand with a maximum particle size of 4.75 mm;
- Natural rounded quartz gravel with a nominal maximum size of 10 mm;
- Fly ash (FA) type 450-S produced by Cemex Company which was prepared so that less than 12% was retained on a 45 μm sieve;
- Natural local limestone filler (LP) with a grain size less than 65 μm;
- Polycarboxylate-based superplasticizer (SP) with 1.08 specific gravity.

Parts of slices (see Section 3.2.1.1 of this paper) of hardened SCC were ground into a powder and passed through a 75 μm sieve for XRD examination. An XRD scanning speed of 2° per minute and a step of 0.05° were used in the range 10–90° using a Bruker – AXS D8 Advance equipment. The mineralogical phases of the FA and the LP, thereby determined, are given in Fig. 1a and b respectively. FA comprises a vitreous medium with two main crystalline phases: quartz (SiO_2) and mullite ($Al_6Si_2O_{13}$). Furthermore, the highlighted distinct hump in the XRD curve is indicative of the presence of an amorphous material which is likely to be amorphous silica, while only calcite was detected in the limestone powder.

Fig. 2a and b shows SEM images of typical particles of used LP and FA at high magnification. It can be seen that the FA is spherical in shape compared to the LP particles. This might explain the lower amount of SP needed to maintain the same workability properties in the FA–SCC as compared with the LP–SCC mixture as the FA particles are expected to move more easily. In addition, the angular shape of the LP particles may indicate a higher specific surface area for the same particle size and hence greater water demand for surface wetting.

2.2. Mixture design and preparation of specimens

The mixture designs are shown in Table 1. The two mixes were designed to have a compressive strength grade of 50–60 MPa using the same amount of water. Replacement with filler was to about 33% of the total amount of binder. The only difference was the type of filler and a small reduction in the coarse aggregate content (35 kg/m^3) in the FA mix due to the differences between the specific weights of FA and LP. For hardened properties, all specimens were cast in one layer, whatever