Construction and Building Materials 94 (2015) 90–104

Contents lists available at ScienceDirect

Construction and Building Materials

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

Comparative study on effects of Class F fly ash, nano silica and silica fume on properties of high performance self compacting concrete

Mostafa Jalal [a,*], Alireza Pouladkhan [b], Omid Fasihi Harandi [c], Davoud Jafari [d]

[a] Young Researchers and Elites Club, Science and Research Branch, Islamic Azad University, Tehran, Iran
[b] Young Researchers and Elite Club, Najafabad Branch, Islamic Azad University, Najafabad, Esfahan, Iran
[c] Department of Civil Engineering, Najafabad Branch, Islamic Azad University, Isfahan, Iran
[d] Pishtazan Sanat Poolad Company, Isfahan, Iran

HIGHLIGHTS

- High performance self compacting concrete (HPSCC).
- Comparative effects of pozzolanic admixtures and nanopowder on properties of HPSCC.
- Strength and durability enhancement via blend of mineral admixtures and nanopowder.
- Energy saving in construction and building industry by traditional and new materials.

ARTICLE INFO

Article history:
Received 9 May 2013
Received in revised form 2 April 2015
Accepted 1 July 2015

Keywords:
High performance self compacting concrete (HPSCC)
Nano silica
Silica fume
Class F fly ash
Rheological properties
Mechanical properties
Transport properties
TGA

ABSTRACT

This paper presents the effects of some admixtures including silica nanoparticles, silica fume and Class F fly ash on different properties of high performance self compacting concrete (HPSCC). For this purpose, a fraction of Portland cement with the aim of cement content reduction was replaced different fractions of pozzolanic admixtures. The rheological properties of fresh concrete were observed through slump flow time and diameter and V-funnel flow time. Thermal properties were investigated via thermogravimetric analysis (TGA) test. Transport properties evaluated by water absorption, capillary absorption and chloride ion penetration tests. The results indicated that increase of fly ash content improves the rheological properties of HPSCC. The results also showed that mechanical and transport properties improved in the mixtures containing admixtures especially blend of silica nanoparticles and silica fume. It can also be concluded that higher amount of mineral admixtures combined with small fractions of nanopowders could be promising technique toward high performance concrete as a key material along with energy saving in construction and building technology.

1. Introduction

High performance concrete (HPC) offers high strength, better durability properties, and good construction. High strength is one of the important attributes of HPC. High strength concrete, according to American Concrete Institute Committee ACI 363 R [1], is the concrete which has specific compressive strength of 41 MPa or more at 28 days. The HPC offers significant economic and architectural advantages over NSC in similar situations, and is suited well for constructions that require high durability.

Self consolidating concrete (SCC) is a concrete which has little resistance to flow so that it can be placed and compacted under its own weight with no vibration effort, yet possesses enough viscosity to be handled without segregation or bleeding [2,3]. The most important advantage of SCC over conventional concrete is its flowability. Other advantages of using SCC include shorter construction periods, reduction in the labor cost, and better compaction in the structure especially in confined zones where compaction is difficult. SCC can also provide a better working environment by eliminating the vibration noise.

By combining the characteristics and advantages of HPC and SCC, high performance self-compacting concrete (HPSCC) can be produced which possesses the advantages in both forms of fresh and hardened concrete, i.e. while presenting higher strength and

* Corresponding author.
E-mail addresses: m.jalal.civil@gmail.com, mjalal@aut.ac.ir (M. Jalal).

http://dx.doi.org/10.1016/j.conbuildmat.2015.07.001

durability, it has a good workability and rheological properties [4–6].

In order to maintain sufficient yield value and viscosity of fresh mix of SCC, and to reduce bleeding, segregation and settlement, the common practice is to use new generation high range water reducers, to limit the maximum coarse aggregate size and content, and to use low water powder ratios or use viscosity modifying admixtures. Therefore, one of the disadvantages of SCC is its cost, associated with the use of chemical admixtures and use of high volumes of Portland cement. High cement content usually introduces high hydration heat, high autogenous shrinkage and high cost. Moreover, the consumption of natural resources and carbon dioxide emissions associated with cement production can cause serious environmental impacts.

On the other hand, it is worldwide accepted that energy saving in building technology is one of the most important problems in the world. Reduction of energy usage can be taken place even by design methods [7,8] or using waste materials [9–11].

Nowadays, most industrial wastes are being used without taking full advantages of their characteristics or disposed rather than used. Among these materials, fly ash (FA), a by-product of thermal power plants, and ground granulated blast furnace slag (GGBFS) have been reported to improve the mechanical properties and durability of concrete when used as a cement replacement material [12,13]. It is worth mentioning that for example in Turkey, more than 13 million tons of FA has been produced per year, however, because of insufficient data on the properties of fly ash and concrete incorporating FA, only 5% of this amount is utilized in construction industry [14]. Therefore, one solution to reuse such industrial wastes and reduce the cost of SCC is the use of mineral admixtures such as limestone powder, natural pozzolans, GGBFS and FA.

The amount of FA in concrete for structural use is generally limited to 15–25% of the total cementitious materials. Concretes containing large amounts of FA were initially developed for mass concrete applications to reduce the heat of hydration [15]. Canada Centre for Mineral and Energy Technology first developed high volume FA concrete for structural use by the late 1980's [16]. In a study undertaken by Bouzoubaâ and Lachemi, it was shown that it was possible to design SCC with high volumes of FA by replacing up to 60% of cement with Class F FA [17]. Moreover, Nehdi et al. also studied the durability of SCC with high volume replacement materials (FA and ground granulated blast furnace slag), and concluded that SCC with 50% replacement with Portland cement of FA and slag can improve the workability and durability [18]. With this respect, it should be mentioned that a 50% replacement of each ton of Portland cement would result in a reduction of approximately 500,000 t of CO2. Using GGBFS or FA as a partial replacement takes advantage of the energy saving in Portland cement which is governed by AASHTO M302 [19].

According to Fava et al. [20], in SCCs with ground granulated blast furnace slag (GGBFS), strength increase can be achieved. Kulakowski et al. [21] reviewed the silica fume influence on reinforcement corrosion in concrete and the effect of metakaolin on transport properties of concrete were also investigated by Shekarchi et al. [22].

There are also some works on incorporating nanoparticles into concrete specimens to achieve improved physical and mechanical properties which most of them have focused on using SiO_2 nanoparticles in normal concrete [23], generally cement mortars and cement-based materials [24–26], self compacting concrete (SCC) [27] and high performance self compacting concrete (HPSCC) [4].

Production and application of HPSCC containing nanomaterials and mineral admixtures seems to be a promising and energy saving step toward sustainable construction and building technology. However, this would not be achieved without studying its performance before being widely adopted in construction. Also, the behavior of structural elements made with HPSCC needs better understanding, together with design provisions.

This paper investigates the effects of silica nanoparticles, silica fume and Class F fly ash on rheological, mechanical, thermal, transport and microstructural properties of HPSCC with different binder contents. The mechanical properties were assessed by compressive, splitting tensile and flexural strengths. Thermal properties were evaluated by thermogravimetric analysis and transport properties were evaluated by water absorption, capillary absorption and chloride ion penetration tests. The microstructure was also investigated through scanning electron microscopy (SEM) micrographs.

2. Materials

An ASTM Type II Portland cement (PC) was used to produce the various HPSCC mixtures. In addition, silica nanoparticles, silica fume and Class F fly ash were used as admixtures which are hereafter named as nano silica (NS), silica fume (SF) and fly ash (FA) respectively. Table 1 summarizes physical properties and chemical composition of the cement and silica fume. Scanning electron microscopy (SEM) of the silica nanoparticles is shown in Fig. 1 and the nanoparticles properties are presented in Table 2. Class F fly ash was used in this study which its physical and chemical properties are given in Table 3. SEM micrograph of Class F fly ash is also shown in Fig. 2. The coarse aggregate used was limestone gravel with a nominal maximum size of 12.5 mm. As fine aggregate, a mixture of silica aggregate sand and crushed limestone (as filler) was used with a maximum size of 4.75 mm. physical properties of the filler, fine and coarse aggregates are presented in Table 4. All aggregates in this research were used in dry form and the aggregates are a mixture of eight

Table 1
Chemical composition and physical properties of cement and silica fume.

Chemical analysis (%)	Cement	Silica fume
SiO_2	20<	93.6
Al_2O_3	6<	1.3
Fe_2O_3	6<	0.9
CaO	<50	0.5
MgO	<5	1
SO_3	<3	0.4
K_2O	<1	1.52
Na_2O	<1	0.45
Loss of ignition	<3	3.1
Specific gravity	3.15	2.2
Blaine fineness (cm^2/g)	3260	21090

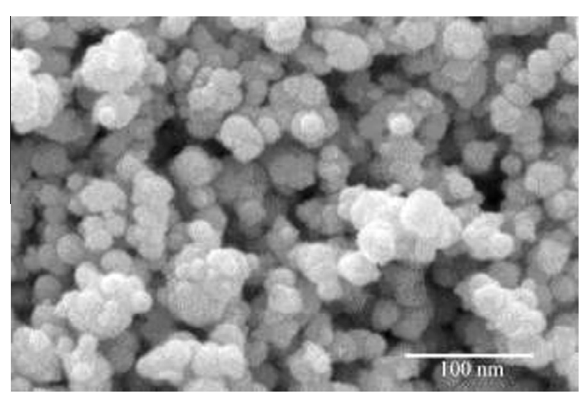

Fig. 1. SEM micrograph of silica nanoparticles.

Table 2
Properties of silica nanoparticles.

Diameter (nm)	Surface volume ratio (m^2/g)	Density (g/cm^3)	Purity (%)
15 ± 3	165 ± 17	<0.15	>99.9