Construction and Building Materials 134 (2017) 116–122

Contents lists available at ScienceDirect

Construction and Building Materials

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

Workability retention and compressive strength of self-compacting concrete incorporating pumice powder and silica fume

Reza Bani Ardalan [a], Alireza Joshaghani [b,*], R. Douglas Hooton [c]

[a] Institute for Infrastructure Engineering, Western Sydney University, Sydney, Australia
[b] Zachry Department of Civil Engineering, Texas A&M University, College Station, TX, USA
[c] Department of Civil Engineering, University of Toronto, 35 St. George St., Toronto, ON M5S 1A4, Canada

HIGHLIGHTS

- SCC mixture incorporating pumice powder possesses better slump flow retention.
- Pumice replacement of 30% gives the best performance hardened and fresh test results.
- Pumice and silica fume blended cement satisfies all the criteria of EFNARC limit.
- A strong relationship between superplasticizer demand and slump loss of the mixtures.

ARTICLE INFO

Article history:
Received 19 July 2016
Received in revised form 8 November 2016
Accepted 18 December 2016
Available online 29 December 2016

Keywords:
Self-compacting concrete
Pumice
Silica fume
Fly ash
Slag
Fresh properties
SP demand
Slump loss
Compressive strength

ABSTRACT

This paper presents the results of an experimental study carried out to investigate the performance of self-compacting concrete (SCC) mixes, which produced using blended binders containing pumice powder in various proportions. As a volcanic material, pumice possesses pozzolanic properties and can effectively be added to the concrete mixture. The influence of pumice powder on the self-compactibility properties such as slump flow, V-funnel flow, U-box and J-ring flow and compressive strength was investigated. Also, in order to clearly understand the effect of pumice powder on the workability retention of concrete, the slumps were measured with elapsed time. The comparison has been made between SCC with pumice powder to other mixtures with fly ash and slag through tests on fresh and hardened concrete. In all of the mixtures the portland cement was partially replaced from 10% to 50% by pumice, fly ash and slag. The incorporation of more than 30% of pozzolanic materials in the binary blended portland cement mixtures results in a significant decline in the fresh and hardened test results. In addition, to improve the properties of SCC containing pumice, the ternary blended cement replacement with pumice and silica fume (SF) was developed. The results revealed that incorporation of SF substantially enhanced the properties of the mixtures.

1. Introduction

Self-compacting concrete (SCC) has been one of the most pronounced recent innovations in the building industry. SCC has the potential to spread into place. It fills the formwork even in the presence of congested reinforcement while requiring no compaction energy and vibration effort in site [1]. The SCC technology provides better economic and efficiency and productivity levels by the increase in casting speed and reduction in labor, energy, and cost of equipment [2]. In order to achieve high levels of fluidity and adequate stability for SCC during transportation and placement, costly chemical admixtures and also high volumes of sand and paste are commonly essential to use which leads the production to be more expensive compared to conventional concrete [3,4].

Mineral additives such as fly ash, slag, silica fume and natural pozzolans as partial replacement of portland cement are fundamental parts of SCC in order to mitigate the quantity of hydration heat [5]. One practical solution to reduce the cost of SCC is utilizing waste or industrial by-products [6–9]. One of the most important aspect in choosing mineral admixtures is the type and the amount with respect to water and cement [3,10]. It is well established that incorporation of some mineral additives to the mixture like fly ash

* Corresponding author at: Zachry Department of Civil Engineering, Texas A&M University, 3136 TAMU, College Station, TX 77843-3136, USA.

E-mail addresses: R.BaniArdalan@westernsydney.edu.au (R. Bani Ardalan), joshaghani@tamu.edu (A. Joshaghani), hooton@civ.utoronto.ca (R.D. Hooton).

http://dx.doi.org/10.1016/j.conbuildmat.2016.12.090
0950-0618/

and slag, substantially increase the workability, durability and long-term properties of concrete [11–14]. Recently, pumice powder, which is a sub product of extraction and manufacturing of pumice was added to the SCC mixture as a supplementary cementing material and its incorporation effect on the fresh properties of SCC was investigated. Volcanic materials like pumice have pozzolanic properties so that it is possible to use in SCC manufacturing with a double effect: on one hand as filler and on another hand as a pozzolanic element in the mixture [3]. It was proved that pumice use is applicable in SCC production as no segregation and bleeding were observed [15]. Pumice is a natural material of volcanic origin which is produced during the solidification of lava through the release of gases. As volcanic activities are common phenomena in various parts of the world, volcanic debris like pumice is found abundantly [16]. Since pumice has lower weight compared other aggregates, it has been used extensively as a coarse or fine aggregate in lightweight concrete mixtures [17]. In a recent study, Granata [3] investigated the applicability of pumice powder as filler in SCC and hardened states, and its pozzolanicity was confirmed. SCC containing pumice presented good workability properties and achieved reasonable compressive strength after 28 days of curing.

It is well understood that when SCC is used as a ready-mixed concrete, the fresh property requirements need to be met at the time of placement. Thus the effect of production and transport on the workability properties of SCC must be considered in the initial and time dependent workability testing of SCC [18–20]. Slump loss is known to be one of the main reasons of concrete strength and durability [21]. Since the conditions for the transport process involved in concrete's degradation mechanism strongly depend on its pore structure [22], still more investigation is required to account for a clear understanding of required quantity of superplasticizers (SP) to achieve superior workability and placeability. Workability properties of SCC containing pumice powder especially with respect to other mineral admixtures performance which is still lacking in the literature. To do so, the effect of using pumice, fly ash and slag as supplementary cementitious materials in binary (two-component) blends at different levels of replacements was taken into account on fresh and hardened properties. For each mixture, the SP dosage for obtaining initial slump flow value of 650 ± 25 mm and also slump flow loss over time up to 50 min after casting was measured. The aforementioned properties were measured for ternary (three-component) systems of pumice and silica fume as well. The fresh properties of SCC, including the slump flow, U-box, V-funnel flow and J-ring flow were investigated. Also, the effectiveness of the mineral admixtures on the compressive strength of SCCs was assessed at 7, 28 and 90 days. Finally, the optimum percentage of cement replacement by pumice was proposed for binary and ternary mixtures considering the results of the experiments.

2. Experimental study

2.1. Materials

A commercially available ASTM type II portland cement with specific gravity of 3.16 and fineness of 290 m^2/kg has been used for the production of all SCC mixtures. The volcanic pumice used in this experimental program, which has a specific gravity of 2.85 and a fineness of 3200 m^2/kg was collected from the resources in Khash area, Iran. As presented in Table 1, the total content of SiO_2, Al_2O_3, and Fe_2O_3 in the pumice was approximately 73% which is more than the minimum requirement (70%) specified in ASTM C 618 for natural pozzolans.

Silica fume was obtained from Azna ferro-silicon alloy manufacturer with a specific gravity of 2.35 and a specific surface area of 20,000 m^2/kg. The fly ash class F and slag used have a specific gravity of 2.2 and 2.85 and fineness of 260 and 445 m^2/kg, respectively. The chemical compositions of the cementitious materials are shown in Table 1.

The coarse aggregates have a maximum size of 19 mm, a specific gravity of 2.78 and water absorption of 1.9%. The natural river fine aggregate in this study with fineness modulus of 3.2, the specific gravity of 2.6 and water absorption of 2.3% was used. The particle size gradation obtained through the sieve analysis of the fine and coarse aggregates are given in Table 2. Superplasticizer (SP) which is a high-range water-reducing, plays a vital role in SCC mixture and help SCC flow under its own weight [23]. A polycarboxylic-ether type SP with a specific gravity of 1.08 was employed to achieve the desired workability in all concrete mixtures.

2.2. Mix design

In this study several SCC mixtures were made having a constant water to cementitious materials ratio (w/cm) of 0.38 and fixed cementitious materials content of 500 kg/m^3, incorporating different replacement levels of pumice, fly ash and slag (0–50% weight of cement) in binary mixes, in order to evaluate and compare the effect of these mineral admixtures on properties of SCC. Also, ternary cementitious blends of pumice and silica fume were designed to clarify the influence of these mineral admixtures on properties of SCC. Superplasticizer was adjusted to attain a slump flow of 650 ± 25 mm. Details of the mix proportions are shown in Table 3.

2.3. Specimen preparation and testing methods

All the materials were mixed using a rotary drum mixer with a maximum capacity of 80 L. SCC production requires careful consideration in terms of mixing sequence and duration as to supply similar homogeneity and uniformity in all mixtures [24]. First, the dry ingredients were combined. Next, the wet ingredients (water and SP) were added, and the ingredients were mixed until a homogeneous mixture was achieved. The concrete was designed to give a slump flow of 650 ± 25 mm according to EFNARC committee [25] recommendation which was obtainable by using SP in varying dosage. When the initial slump flow of the SCC was deemed satisfactory, the SCC was placed into five slump cones and the slump flow test was conducted at intervals of 10 min, i.e. ten-minutes after the initial slump flow test, one slump cone was lifted, after another 10 min another cone was lifted and so on. The slump flow value was recorded for five cones for each mixture.

Besides, upon achieving target slump flow, the V-funnel, J-ring and U-box self-compactibility tests were conducted on the fresh properties for each mixture in accordance with EFNARC standards, in the following order:

(a) J-ring flow test (flow diameter and difference in concrete height inside and outside J-ring (h_2–h_1)). The J-Ring is a cage of rebar that is set up around the slump cone. The slump flow test is run both with and without the J-Ring in place and the passing ability is the difference in slump flow;

(b) V-funnel flow test (time taken by concrete to flow through V-funnel after 10 s ($T_{10\,s}$), time taken by concrete to flow through V-funnel after 5 min ($T_{5\,min}$)). The described V-funnel test is used to determine the filling ability (flow ability) of the concrete with a maximum aggregate size of 20 mm. The funnel is filled with about 12 L of concrete and the time taken for it to flow through the apparatus measured. If the concrete shows segregation, then the flow time will increase significantly.