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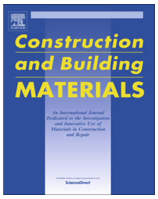

Reducing variations in the test results of self-consolidating lightweight concrete by incorporating pozzolanic materials

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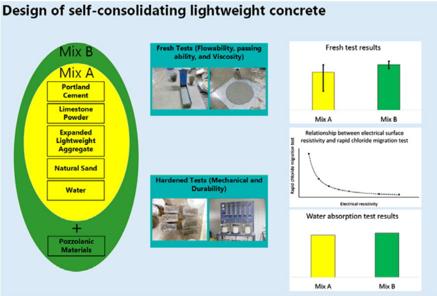
HIGHLIGHTS

- Less variation in flowability test results by incorporating of pozzolanic materials.
- Reduction in the variation of the V-funnel results as the mean value increases.
- Correlation between electrical resistivity and rapid chloride migration results.
- Insignificant variation in volumetric water absorption test results.

GRAPHICAL ABSTRACT



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ABSTRACT

Portland limestone cement (PLC) has been considered as a suitable alternative for portland cement in self-consolidating lightweight concrete (SCLWC) mixtures. However, certain inconsistencies were reported in terms of strength development and durability properties of the PLC concrete. In addition, fresh SCLWC mixtures are more likely to encounter test results variation than ordinary concrete mixtures. This paper experimentally investigates the fresh and hardened performance of SCLWC incorporating ternary blended cements containing PLC and silica fume (SF), fly ash (FA), natural zeolite (ZE) or metakaolin (MK). The fresh tests were repeated once for each 100-L concrete batch and coefficient of variation as a measure of dispersion of a frequency distribution used to determine the variation of fresh test results of the mixtures. The results show that the pozzolanic materials mixtures have greater but less variable results of flowability compared to the PLC mixture. The coefficient of variation in results of slump flow test is varied 0.8–2.9%. It was also observed that there is a reduction in variation of the V-funnel results as the mean value increased. The obtained coefficient of variation was as low as 7% for zeolite ternary mixtures and the highest variation belonged to the binary mixture by 19.2%. The result of rapid chloride migration test (RCMT) and electrical resistance test indicated that there is a strong correlation between these two variables. Comparing the results to other studies, we recognized that the correlation seems to be unique for each case study.

1. Introduction

Self-Consolidating Concrete (SCC) has been the subject of interest to many construction engineers due to its improved fresh and hardened properties. Self-consolidating lightweight concrete (SCLWC) combines desirable properties of SCC in fresh state as well

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as providing a lightweight construction material in hardened form. Substitution of normal weight gravel by a lightweight aggregate (LWA) in SCC mixtures is a common way to produce SCLWC mixtures. However, the use of the LWA in SCLWC can cause a severe problem in the fresh state. Since the density of the LWAs and the matrix phase in SCLWC are significantly different, the LWAs tend to move to the fresh concrete top surface as a result of buoyancy force [1]. In order to prevent this segregation, certain techniques, such as increasing the system viscosity, were proposed by researchers [2,3]. Of the viscosity increasing techniques, use of additional cementitious materials to increase the matrix viscosity is widely accepted by concrete practitioners. It should be noted that increasing ordinary portland cement content in concrete mixture introduces incremental environmental pollutions and energy consumptions. This can also negatively affect short-term (early-age shrinkage cracking) and long-term (permeability) durability properties of the mixture. Therefore, a portion of the portland cement should be replaced by other powders, such as inert or pozzolanic materials. Of these replacing materials, limestone is widely approved by international codes to be used in various concrete mixtures. The European standard allows up to 35% replacement of portland cement by limestone powder [4]. Based on the recent version of CSA-A3000 standard, Canadian cement producers are allowed to replace up to 15% of the cement clinker by the limestone powder [5].

In terms of fresh concrete properties, portland limestone cement (PLC) increases the viscosity of the cementitious systems compared to the ordinary cement mixtures [6]. A study by Ramezanianpour et al. showed that the use of PLC in concrete mixtures can increase slump of concrete [7]. In terms of hardened properties, certain differences were reported in terms of strength development and durability properties of the PLC concrete. In some studies, reduction in compressive strength and durability was reported while others demonstrate the positive or negligible effect of limestone on hardened concrete properties [8–11].

In addition to the limestone, various type of pozzolanic materials can be replaced by ordinary portland cement to mitigate the environmental and technical issues in SCLWC. Effects of pozzolanic materials, such as fly ash (FA) and metakaolin (MK) were studied in SCLWC by researchers. Karahan et al. studied fresh, mechanical, and transport properties of SCLWC mixtures containing MK as a replacement of FA. They reported an increase in MK replacement level leads to a decrease in the passing ability of SCLWC and negligible effect on its compressive strength [12]. Hwang et al. studied the effect of w/c ratio and cement content on the compressive strength of SCLWC. Their results showed up to 56 MPa at 91-days compressive strength when portland cement and water content are 386 and 150 kg/m^3, respectively [13]. In terms of durability, Topcu et al. explained that sorptivity properties of SCLWC containing pumice and tuff as LWAs is similar to SCC in all w/b ratios (from 0.48 to 0.36) [14].

From an economic point of view, although the pozzolanic materials can promote the fresh and hardened properties of the SCLWC mixtures, they are not accessible all over the world nor as cheap as a limestone. Consequently, consideration is being given to ternary blends but, from the research perspective, there are limited investigations on the effects of ordinary portland cement, limestone and pozzolanic material combinations on fresh and hardened properties, including mechanical and durability of SCLWC mixtures. In addition, the fresh SCC is more likely to have variability in the fresh test results rather than those in ordinary concrete. This variation can stem from a combination of detailed requirements, more complex mix design, and inherent low yield stress and viscosity properties [15]. Hence, an investigation of possible variation in the test results should be examined in SCLWC mixtures. Previous studies took the repeatability of SCC workability by various apparatus [16,17]. However, to the best knowledge of the authors, these variations of the workability tests in SCLWCs are not studied.

In this study, FA, MK, natural zeolite (ZE), and silica fume (SF) were added as partial replacements of limestone filler in PLC. The effects of these replacements on fresh and hardened properties of SCLWC mixtures are investigated. Workability of SCLWC mixtures was determined by implementing various tests, namely slump-flow, U-box, L-box, and V-funnel. Furthermore, compressive strengths of SCLWC mixtures were measured at the ages of 7, 28, and 90 days. Rapid chloride migration test (RCMT), electrical resistivity, water penetration, and water absorption tests were measured at 28 days to assess the durability of the SCLWC mixtures. Variability of the fresh tests are also considered by preparation of 5 batches (an SCLWC batch contains 100 L of concrete) and conducting the fresh tests followed by repeating them by a single operator to draw a meaningful conclusion on the tests variability.

2. Materials and methods

2.1. Materials

In this research, natural sand from a local source with a specific gravity of 2.62, water absorption of 2.61%, and fineness modulus of 3.61 was used. The coarse aggregate selected for the mixtures was lightweight expanded clay aggregate (LECA). The water absorption of LECA at 1 and 24 h were 6.8 and 11%, respectively. Sieve analysis of the natural fine aggregate and LECA are presented in Table 1. Dry loose density and particle density of the used LECA were measured being 650 kg/m^3 and 1080 kg/m^3, respectively.

Portland cement type II equivalent to ASTM C618 specification [18], was also used. Chemical analysis of the portland cement is presented in Table 2. The compositions and the physical properties of supplementary cementitious materials in this research are illustrated in Table 2. Superplasticizer used in this study is a polycarboxylate-based type with a specific gravity of 1.14 and 43% solid content. The particle shape of the mineral admixtures used in this study are captured by a scanning electron microscope (SEM) and are illustrated in Fig. 1.

2.2. Mixture proportions, mixing sequence, and sample preparation

The proportions of the SCLWC mixtures are presented in Table 3. The SCLWC mixtures were designed with the water-to-binder ratio (w/b) of 0.32. The total mass of cementitious materials was fixed at the value of 600 kg/m^3 and its 25% percent was replaced by inert or pozzolanic fillers. In the ternary blended mix designs, the limestone filler was partially replaced by MK, SF, FA, and ZE. The replacement rates were selected as economical and technical optimum percentages based on preliminary studies, previous research and field application results.

Table 1
Sieve analysis of LECA aggregate and sand.

Sieve (mm)		25	19	12.5	9.5	4.75	2.38	1.19	0.59	0.3	0.15
LECA	Passing (%)	100	67.1	59.8	53.9	38	26	16.3	6.9	0	0
River Sand		100	100	100	100	88.9	61.4	42.3	29.0	14.6	3.1