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The performance of high fluidity concrete for normal strength structures

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HIGHLIGHTS

- High fluidity concrete offers an economical alternative for ordinary structures.
- Ground limestone and fly ash fillers are also essential for the high fluidity of concrete.
- Ground limestone and fly ash improve the durability of high fluidity concrete.
- An optimum content of powder filler can ensure the high performance of concrete.

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ABSTRACT

Self-compacting concrete (SCC) represents high quality concrete with exceptional workability and enables the easy production of heavily reinforced concrete structures of complex geometry. In spite of its obvious advantages, the high cost of SCC prevents its wider use. For normal strength concrete structures, the performance of high fluidity concrete would be sufficient, providing an affordable and more cost-effective solution than SCC for the construction market. The objective of the current research was to explore the properties of fresh and hardened high fluidity concrete composed of a high amount of fine fillers from industrial by-products (ground limestone filler and fly ash filler) and polycarboxylic ether polymers. The enhanced performances of the resulting concrete mixtures are discussed in terms of the mechanisms involved and the implications of their application in construction.

1. Introduction

The development of self-compacting concrete (SCC) began in Japan about 30 years ago [1]. Since then advances in the formulation of SCC have minimized the problems associated with the long-term durability of heavy-reinforced concrete structures of complex geometry. A unique feature of the SCC is its particular ability to fill the niches of formwork and to completely cover steel reinforcements under solely the effect of gravitational forces. The studies of Graures [2] and Billberg [3], carried out in Europe within the last two decades, have revealed the numerous advantages of using SCC, for example: a quicker casting cycle, the resulting high quality of concrete castings, the high durability of its hardened concrete and its smooth surface finish. Due to its ease of use, human errors may be avoided during concrete casting.

The addition of superplasticizers and viscosity modifying agents to SCC define its unique characteristics. These admixtures (a) give an extremely strong plasticizing effect, (b) allow for a high reduction in water use, (c) help to keep concrete stable and homogeneous and (d) improve the thixotropic behaviour of concrete.

The specific rheological behaviour of SCC is also achieved by fine fillers, in addition to the use of superplasticizers and viscosity modifying agents. These additions greatly improve the flowing ability and segregation resistance of concrete [1–4]. Superplasticizers based on polycarboxylate technology are able to maintain the high quality requirements of SCC through the use of specially designed formulations and due to the improved chemistry of such mixtures [5–7]. Several studies have examined the impact of viscosity modifying agents on fresh cement matrices [8–14] and on the characteristics of hardened SCC [15].

However, in spite of the obvious advantages of SCC in comparison with ordinary concrete mixes, the perceived high cost of SCC prevents its wider use since the use of fine fillers and admixtures can increase the price of a cubic meter of concrete from $15 to $35 [16]. In normal strength structures under several specific scenarios, the use of the high fluidity concretes could provide customers with a more economical alternative due to the improved rheology of these mixtures. However, questions remain in regards

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to the long-term behaviour of this group of concretes. No study has been done yet to reveal the optimal composition of normal-strength concrete mixes in order to allow the best service properties of concrete in their fresh and hardened states. These mixes promise to be much cheaper than SCC concrete.

2. Research objective

The objective of the current research was to optimize the composition of high-fluidity concrete through the use of high amounts of powder fillers (PF) from industrial by-products, e.g., fly ash from a local power plant and limestone powder filler from asphalt manufacturing, in combination with polycarboxylic ether polymers. Normal strength concrete (~40 MPa) with a workability comparable to near-SCC was developed in order to study the potential of high-fluidity concretes for use in regular applications in order to enhance performance and reduce labour, similar to the use of regular SCC.

3. Experimental methods

3.1. Materials and mixture of concrete samples

Twelve concrete mixes were prepared and tested: (a) two mixes without powder filler, (b) four mixes with limestone powder filler, (c) two mixes with fly ash filler and (d) four mixes with a blend of fly ash and limestone powder filler.

The particle size distribution of the fine powder fillers was tested with the Mastersizer 2000 particle size analyser (Malvern Instruments Co., United Kingdom) [17]. The particle size distribution curves are presented in Fig. 1. The mineralogical composition of limestone powder filler was tested using the X'TRA Powder Diffractometer manufactured by Thermo Fisher Scientific, Switzerland, courtesy of Nesher Israel Cement Enterprises. The X'TRA Powder Diffractometer provides qualitative and quantitative analysis of structures, phases, and compounds of polycrystalline materials. The results of the test are presented in Table 1.

The chemical composition of fly ash filler was determined by Israeli Ceramic and Silicate Institute, Haifa, as follows:

- Al, Ti, Ca, Mg, Na, K, P, and Fe were determined after digestion in the solution of HF and HNO_3. The element concentrations were determined as follows: Al, Ca, and Mg by atomic absorption spectroscopy (AAS); P, Fe^{3+}, and Ti by colorimetry; and Na and K by flame photometry.
- Si was determined gravimetrically after fusion in Na_2CO_3 and immersion in the HCl solution.
- SO_3 was determined gravimetrically after fusion in Na_2CO_3 and $NaNO_3$ by a titration procedure involving the addition of $BaCl_2$ to the resulting H_2SO_4 solution to precipitate $BaSO_4$.

Table 1
Mineralogical composition of limestone powder filler.

Mineral	Chemical formula	Content, % of mass
Calcite	$CaCO_3$	85.0–92.0%
Clinoptilolite	$(Ca,Na,K)_2\text{-}3Al_3(Al,Si)_2Si_{13}O_{36}\cdot 12(H_2O)$	3.0–9.0%
Quartz	SiO_2	3.0–6.0%
Smectite & palygorskite	$(Na,Ca)_{0.3}(Al,Mg)_2Si_4O_{10}(OH)_2\cdot n(H_2O)$ & $(Mg,Al)_2Si_4O_{10}(OH)\cdot 4(H_2O)$	Up to 2%

The results of the tests are presented in Table 2.

The content (C) of fly ash filler (PFA) and limestone powder filler (LPF) in 1 m^3 concrete varied from ~100 to ~200 kg and from ~150 to ~300 kg, respectively. The mixes were prepared with a small to moderate amount of CEM I 52.5N Portland cement (C = 170–280 kg per 1 m^3 concrete). The properties of the aggregates used in the high fluidity concrete mixtures are shown in Table 3.

The total amount of aggregates used in the mixes was ~1500 to ~1900 kg per 1 m^3 concrete. The ratio of coarse- to medium-sized aggregate was approximately 1.5:2. The ratio of coarse- and medium-sized aggregates to sand was approximately 1.8:2. The ratio of powder filler to cement and sand was approximately 0.18:0.35. The effective water (W) to cement (C) ratio (ω_{eff}) of the mixes made with or without one type of powder filler was 0.7. In the mixes made with blended powder filler, the ω_{eff} varied from 1.1 to 1.4. In the mixes prepared with powder fillers, the ratio $\frac{W}{C+LPF+FA}$ was approximately 0.4 to 0.8.

Eleven mixes were prepared with Glenium 51 superplasticizer (SP) (Degussa Construction Chemicals, United Kingdom) [18].

Table 2
Chemical composition of fly ash filler.

Component	Content, % of mass
SiO_2	51.33
Al_2O_3	30.23
Fe_2O_3	8.81
CaO	1.90
MgO	1.02
TiO_2	0.84
K_2O	2.74
Na_2O	0.51
SO_3	1.48
P_2O_5	0.3

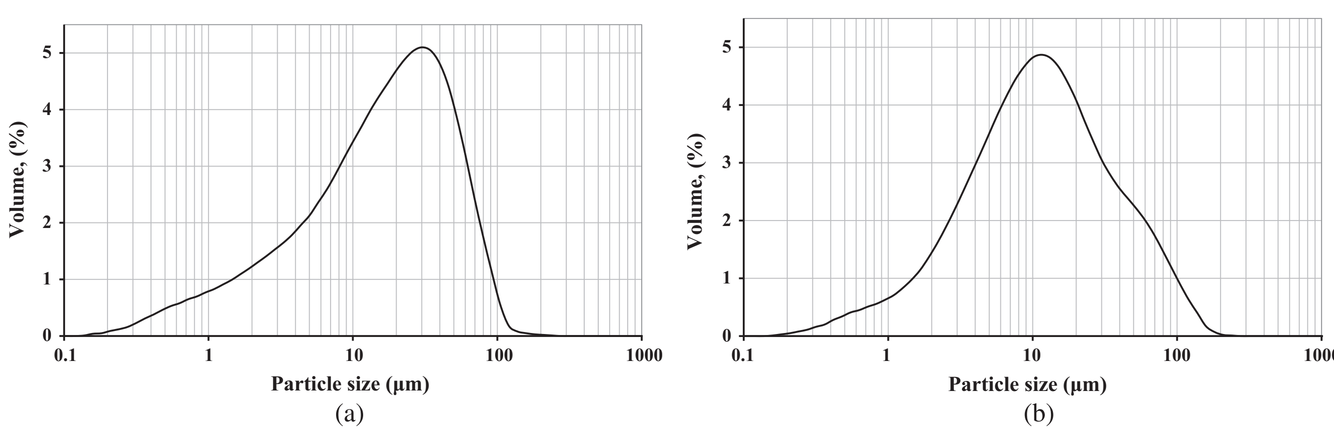

Fig. 1. Particle size distribution of powder fillers (PF). (a) Limestone powder filler (bulk density = 2.74 g/cm^3); (b) fly ash filler (bulk density = 2.2 g/cm^3).