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A comprehensive study on no-slump concrete: From laboratory towards manufactory

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ABSTRACT

No-slump concrete has two major applications including roller compacted concrete and prefabricated concrete. The durability concerns of the later one; in particular the deterioration of sewer concrete pipes in natural acidic environment, are the authors' motivation to study the durability properties of no-slump concrete. To this aim, a comprehensive experimental investigation was carried out on different mixtures designed by ACI and dense packing methods to assess the durability aspects and verify the most suitable methods for mix design and production of no-slump concrete. In this regard, 14 and 8 mixtures were designed and made by ACI 211.3 and dense packing methods respectively. Of these, three elite mixtures were chosen based on the strength and durability indexes. Moreover, ACI method was proposed to modify with the aid of an especial admixture used for upgrading the compaction of dry cast concrete. Elite mixtures were then subjected to evaluate in the laboratory and concrete pipe manufactory. The results of ACI elite mixture revealed its feasibility and suitable performance in the laboratory, whereas the concrete pipes produced in the manufactory based on ACI methods emphasized the necessity of better compaction. In this regard, the application of admixture effectively provided the required compaction. In addition, dense packing approach showed relatively suitable performance with the aid of silica fume and siliceous filler; however, it presented a lower strength level in comparison with the ACI-designed mixtures.

1. Introduction

No-slump concrete, commonly known as dry cast concrete, is generally defined as concrete having slump in a range of 0–25 mm [1,2]. An alternative definition is "freshly mixed concrete exhibiting a slump of less than 6 mm" [3].

As early as 1868, Henry Reed suggested "concrete be mixed with the least amount of water for the best results", theory of using minimum water in concrete has been expanded. At the earlier decades of 20th century, dry mixed concretes without heavy ramming resulted in poor quality and low strength concretes [2], but with the advent of vibrators no-slump concrete became a realistic construction material. Thereafter, application of no-slump concrete has been extended and nowadays it is well-known by two important typical applications, i.e. roller-compacted concrete (RCC) and prefabricated concrete [1,4–12].

The major application of RCC commenced in the 1960s, when a high-production of no-slump mixture was used at Alpe Gere dam in Italy [5–7] and at Manicougan-I in Canada [5,8] with the aid of large internal vibrators mounted on backhoes or bulldozers. Over the last few decades, RCC has been significantly expanded in the North America. For instance, an increasing proportion of highway pavements and dams have been constructed using RCC technology [5–10]. Moreover, many manufacturing concrete products require to be immediately removed from the moulds to minimize the production time. Very dry cast concrete with effective vibration is a suitable method to reach this aim. Nowadays, the economical benefits and easiness encourage the producers to widely use this technique in the prefabricated concrete products, such as concrete masonry units, paving blocks, prefabricated curbs, concrete pipes and the like [1,2,11–15].

Unlike valuable research available in the field of RCC, there are rare studies in the field of the later application and the available research studies have been usually limited to the strength determination, workability, frost related durability or proposing models for predicting the compressive strength [15–22]. In this regard, the current research is dealt with the durability properties of no-slump concrete as a major constituent of prefabricated sewer concrete pipes.

Abbreviations: DP, Dense packing approach; FTC, Fuller Thompson grading curve; WPD, water penetration depth; WA, water absorption; CS, compressive strength; RCC, roller compacted concrete; DF, damage factor; DR, damage ratio.

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2. Research significance

Despite the fact that there are numerous applications of no-slump concrete and ACI Committee 211 has been established a comprehensive method for its mix design, unfortunately adequate research studies have not been conducted to investigate its different properties yet. Moreover, some observed deteriorations regarding the imperfect durability of no-slump concrete are the author's motivations to conduct a comprehensive research regarding the mechanical and durability problems to recognize the most suitable method for design and production.

3. Materials

3.1. Aggregates

The physical and mechanical properties of the rounded fine and coarse aggregates are summarized in Table 1. As can be seen, the nominal maximum size of coarse aggregate is 19 mm which is an usual size for producing concrete pipes. The specific gravity and absorption of aggregates are in the normal range of aggregates.

3.2. Cementitious materials and filler

In this study, Type II Portland cement met the requirements of ASTM C150, silica fume and two natural Pozzolans (Trass and Khash) were used as cementitious materials. The chemical composition of cementitious materials, physical properties of cement and identifications of natural pozzolans are presented in Tables 2–4, respectively. Moreover, siliceous filler with purity of 99.0% was used in this study.

Table 1
Aggregate properties.

Aggregate type	Specific gravity (g/cm^3)	Absorption (%)	Fineness modulus	Passing from 75 μm sieve (%)
Fine aggregate (0–4.75 mm)	2.53	2.60	3.3	1.1
Coarse aggregate (4.75–19 mm)	2.56	1.46	–	0.2

Table 2
Chemical composition of cementitious materials.

Chemical analysis (%)	Cement	Silica fume	Pozzolan trass	Pozzolan khash
Calcium oxide (CaO)	61.9	0.6	4.50	7.16
Silica (SiO_2)	21.2	90.9	65.69	58.84
Alumina (Al_2O_3)	4.2	0.6	12.04	17.13
Iron oxide (Fe_2O_3)	4.6	0.7	2.94	5.10
Magnesia (MgO)	3.4	1.30	1.29	2.37
Sodium oxide (Na_2O)	0.6	0.4	1.97	3.66
Potassium oxide (K_2O)	0.5	1.1	2.64	2.01
Sulfur trioxide (SO_3)	1.7	–	<0.10	<0.10

Table 3
Physical properties of cement.

Tri calcium silicate (C_3S) (%)	52.74
Di calcium silicate (C_2S) (%)	20.31
Tri calcium aluminate (C_3A) (%)	3.35
3 days compressive strength (MPa)	22.3
7 days compressive strength (MPa)	30.6
28 days compressive strength (MPa)	41.4
Initial setting time (min)	150
Final setting time (min)	190
Specific surface (m^2/kg)	329.6

3.3. Admixture

An especial polycarboxylate-based admixture commonly used for providing better compaction in dry-cast concretes was applied in this study. By adding this admixture, the dispersion of cementitious materials could be enhanced in a manner that the concrete integrally lubricate without any effect on flowability. The physical properties of this admixture are presented in Table 5.

4. Aims and methodology

In spite of suitable and adequate strength properties of no-slump prefabricated concrete products, attributing to their lower water to cement ratio, these products have been faced some

Table 4
Identification of utilized natural pozzolans.

		Pozzolans		
		Trass	Khash	Class N, ASTM C618
Chemical properties	$SiO_2 + Al_2O_3 + Fe_2O_3$ (%)	80.67	81.07	min, 70.0
	Sulfur trioxide (SO_3) (%)	<0.10	<0.10	max, 4.0
	Moisture content (%)	2.48	0.18	max, 3.0
	Loss on ignition (%)	8.49	1.88	max, 10.0
Physical properties	Amount retained when wet-sieved on 45 μm sieve (%)	4	7	max, 34
	Strength activity index, at 7 days, percent of control	110	89	min, 75
	Strength activity index, at 28 days, percent of control	118	91.5	min, 75
	Water requirement, percent of control	106	100	max, 115
	Autoclave expansion or contraction (%)	0.05	0.09	max, 0.8
Pozzolanic activity	Thermo-gravimetric measurement*, at 8 days (%)	34	36	–
	Thermo-gravimetric measurement*, at 30 days (%)	40.5	38.5	–
XRD results	Quartz (%)	18	1	–
	Plagioclase (Albit) (%)	18	68	–
	K-Feldspar (Sanidine) (%)	9	–	–
	Mica (%)	17	6	–
	Cristobalite (%)	12	13	–
	Calcite (%)	8	1	–
	Hornblende (%)	(traces)	11	–
	Clay minerals (%)	Traces (Smectite)	–	–
	Zeolite minerals (%)	17 (Clinoptilolite)	Traces (Mordenite)	–
	Amorphous phases (%)	Clear	Traces	–

* Thermo-gravimetric analysis was done by combining 50% pozzolan with 50% $Ca(OH)_2$ powder.