Construction and Building Materials 52 (2014) 202–208

Contents lists available at ScienceDirect

Construction and Building Materials

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

Evaluation of the effect of concrete compositional changes and the use of ethyl-alcohol and biodegradable-oil-based release agents on the final surface appearance of self-compacting concrete precast elements

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HIGHLIGHTS

- An image analysis tool for classifying concrete surface finish is proposed.
- The performance of the image analysis tool was verified in a case study.
- The tested release agents showed similar effect on concrete surface finish.
- The image analysis tool permits an objective analysis of concrete surface.
- The image analysis tool can be used systematically in experimental investigations.

ARTICLE INFO

Article history:
Received 16 May 2011
Received in revised form 23 October 2013
Accepted 31 October 2013
Available online 5 December 2013

Keywords:
Bugholes
Image analysis
Precast concrete
Release agent
Self-compacting concrete

ABSTRACT

This paper investigates bughole minimization techniques in self-compacting concrete in a precast concrete plant in Brazil. Specifically, the objective of this study was to improve the final surface appearance of self-compacting concrete precast elements with respect to the presence of bugholes. Bugholes are imperfections that appear on a concrete surface after demoulding. The experimental study was based on the modification of concrete composition and the use of two types of release agents. In particular, ethyl-alcohol and biodegradable-oil-based admixtures were applied on laminated plywood formwork. By using a specific image analysis method, the concrete surface was analyzed using digital images taken from concrete board plates with dimensions of $1.00 \times 0.30 \times 0.08$ m. The results indicate that a reduction in the concrete shear stress ratio contributed to reduce the percentage of bugholes, whereas no significant difference in the concrete surface appearance was observed as a function of the investigated release agents.

1. Introduction

Self-compacting concrete (SCC) is a high-performance concrete that can flow under its own weight so as to completely fill the formwork and self consolidate without any mechanical vibration [1,2]. SCC is specifically designed to achieve excellent deformability, a low risk of blockage, and good stability, ensuring a high formwork filling capacity. Because of the ability of the SCC to easily flow in highly congested areas, it is now being considered to be a suitable material for the construction of structural members with high volumes of steel reinforcement [3,4].

The use of SCC in precasting is rapidly developing in the construction industry. This trend is likely due to the production process costs and the advantageous organizational nature of the SCC [4]. Nonetheless, it is important to consider that the production of SCC is more difficult than that of conventional concrete, and many parameters have to be considered in order to obtain a final product that has an acceptable quality for the intended purpose.

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http://dx.doi.org/10.1016/j.conbuildmat.2013.10.102

One of the primary problems that is associated with precast concrete plants relates to the presence of bugholes on the concrete surface. Bugholes are imperfections or voids that appear on the concrete surface after demoulding. According to the European guidelines for SCC [5], the occurrence of bugholes is related to the presence of entrapped air, entrapped form oil, and entrapped water in the contact surface with the formwork. In addition, the appearance of bugholes is more pronounced in concrete mixtures with poor filling ability, high viscosity, low slump-flow, and rapid slump-flow reduction.

Even with the advanced construction methods [6] and chemical admixtures of today, surface voids still persist [7]. Although bugholes do not affect the structural integrity of concrete, their presence causes delays in the production schedule. These delays are due to the need for proper surface treatment before the structure is considered to be finished.

The first methods used to classify concrete surface quality were based on the manual counting and measuring of the bugholes' diameter, followed by the calculation of the percentage of holed areas on the surface [8–10]. Because this technique was considerably laborious, it has been replaced with the one suggested by Thomson [8]. Specifically, the concrete surface analysis is based on the comparison of the actual surface to photographs of reference samples (see Fig. 1) with different degrees of bughole coverage [11]. This method is considered to be acceptable by the industry. While simple in principle, this classification can be problematic due to the variability between different printed scales of the reference samples and the subjectivity of the human eye. Moreover, one surface can group several types of bugholes such that the use of reference samples becomes difficult and subjective [7,12]. Therefore, it is likely that a more objective evaluation can be obtained by using digital images and image processing methods in order to compute the percentage and size of bugholes on a concrete surface.

The final goal of this work is to improve the final surface appearance of SCC precast elements by modifying the concrete composition and using two different types of release agents. The concrete surface analysis that was conducted in this study was based on an image analysis tool specifically developed for this application. The details of the experimental program and the image analysis tool are presented in the following sections.

2. Experimental program

The tests that were conducted in this study were carried out using SCC mixtures. In order to produce these mixtures, cement CP V ARI [13] was used together with limestone filler (LMF), two types of fine aggregate (FN – natural sand from dunes and FM – manufactured sand), and coarse aggregate (CA). In addition, a polycarboxylate-based high-range water-reducing admixture (HRWRA) with 30% solid content was used. The physical properties of the aggregates were assessed based on the instructions from [14–16]. The obtained results are shown in Table 1.

The compositions of the SCC mixtures that were produced in this study are listed in Table 2. The definition of these compositions was based on concrete composition C_1, which was the composition that the precast concrete plant has been using in its production process.

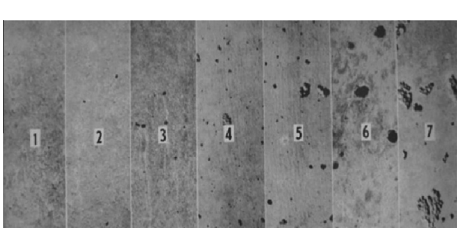

Fig. 1. Concrete Industry Board (CIB) bughole scale: surface 1 has the lowest percentage of bugholes and surface 7 has the largest percentage of bugholes [11].

Table 1
Physical properties of the aggregates.

Fineness modulus (–)	1.28	2.5	4.81
Dusty material content [a], (%)	1.6	15.3	6.7
Density (kg/dm^3)	2.653	2.685	2.780
Max. grain size (mm)	1.20	> 2.40	9.50
Min. grain size (mm)	0.075	< 0.075	< 0.075

[a] Materials finer than a 75 μm sieve [15].

Table 2
SCC compositions tested in the experimental study.

Materials	Composition (kg/m^3)					
	C_1	C_2	C_3	C_4	C_5	C_6
Cement	430.8	428.4	425.9	440.0	494.1	431.4
LMF	84.61	53.2	–	57.6	–	48.4
FN	501.8	564.2	585.7	556.4	558.3	545.6
FM	507.9	571.0	592.7	563.0	564.9	552.0
CA	669.7	544.0	540.7	540.8	542.6	530.2
HRWRA[a]	3.95	3.00	3.20	3.50	3.50	2.40
Water	207.2	217.3	222.1	219.0	219.3	237.1

[a] Polycarboxylate-based admixture.

The following were considered to be design parameters for the SCC mixtures: (i) mortar content in volume – α_{vol} (%); (ii) volume of fine material (i.e. materials with a maximum grain size that was smaller than 75 μm) – V_f (%); (iii) water to volume of fine material ratio – w/V_f; iv) water to cement ratio – w/c; and (v) admixture dosage (percentage of the cement mass) – A_d (%).

The values of the design parameters for each of the SCC mixtures are listed in Table 3. The slump-flow of the mixtures was held constant at 80.0 ± 1.0 cm. The mixing procedure was also held constant. Specifically, dry materials were mixed for 30s. Next, water was added for 30s followed by a 60s mixing interval. After that, the mixer was stopped for 30s to allow for edge shovel cleaning. Finally, HRWRA was added over a period of 30s and the mortar was then mixed for 90s.

The definition of the initial concrete composition modification for the reference mixture, i.e. from C_1 to C_2, was based on the in situ observation of the concrete surface. As shown in Fig. 2, the surface of the concrete plates presented honeycombs, which were likely caused by the lack of mortar to cover the aggregates [17]. Therefore, the mortar content (α_{vol}) of the reference mixture (C_1) was increased from 69.6% to 75.0% (C_2).

Next, the concrete compositions, starting from C_2 to C_6, were modified in order to adjust the concrete rheological properties, i.e. shear stress ratio and plastic viscosity, and evaluate their effect on the final appearance of the concrete surface. These modifications were based on the European guidelines for SCC [5] and previous research [18–20] that identified the effect of composition modification on SCC rheology; hence, the rheological properties of the concrete were not measured in this research. Nonetheless, qualitative assumptions with regard to these properties could be made based on visual analysis in the laboratory when the SCC mixtures were mixed and tested.

To evaluate the final appearance of the concrete surface, boards that were $1.00 \times 0.30 \times 0.08$ m (length × width × thickness) were moulded in a laminated plywood formwork. To simulate precast concrete plant production conditions, the SCC was poured from a height of 1.00 m into a single point of the formwork such that the SCC could flow along the mould. The details of the formwork and the moulding procedure of the concrete boards are presented in Fig. 3a.

Two release agent types were used in this study. The first type, namely A_1, consists of an ethyl-alcohol-based admixture with density of 0.860 ± 0.01 g/cm^3. Whereas the second type, namely A_2, is a biodegradable-oil-based admixture with density of 0.830 ± 0.02 g/cm^3. The details of the concrete board and use of the release agents are presented in Fig. 3b.

Table 3
Design parameters of the SCC mixtures (C_1 to C_6).

Parameters	C_1	C_2	C_3	C_4	C_5	C_6
α_{vol} (%)	69.6	75.0	75.0	75.0	75.0	75.0
V_f, (m^3)	221.8	210.8	192.3	215.6	213.4	208.5
w/V_f(l/m^3]	0.93	1.03	1.15	1.02	1.03	1.14
A_d (%)	0.90	0.70	0.70	0.80	0.70	0.60
w/c (–)	0.48	0.51	0.52	0.50	0.44	0.55