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Effect of granular urea on the properties of self-consolidating concrete incorporating untreated rice husk ash: Flowability, compressive strength and temperature rise

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HIGHLIGHTS

- Effect of urea on high performance self-consolidating concrete was studied.
- RHA replacing in Portland Cement Type 1 (OPC) by 20%wt.
- Urea-powder materials ratios were augmented by 0, 5, 10, and 20%wt.
- Flow through obstacles is likely to decrease as the amount of urea increased.
- When urea is included, internal temperature of concrete is likely to decrease.

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ABSTRACT

This article presents the effect of granular urea on the flowability, compressive strength and temperature rise of self-consolidating concrete (SCC) that includes untreated rice husk ash (RHA) with granular urea (urea) in its composition. The slump flow test was used to assess the horizontal free flow of the concrete in the absence of obstructions. Powder materials were used in the amounts of 450, 550, and 650 kg/m^3. Ordinary Portland cement (OPC) was replaced with RHA at a percentage replacement of 20%wt. The granular urea-powder materials (OPC + RHA + urea) ratios were augmented by 0, 5, 10, and 20%wt of the powder materials. Moreover, the water-powder materials ratio (w/p) was 30%. The unit weight, setting time, slump flow and loss, J-ring flow, V-funnel, temperature rise, and compressive strength of the samples were measured for up to 120 days. The results show that when urea is mixed with SCC, the temperature rises less, which has the effect of producing high flowability without segregation when the appropriate percentage of urea is also used. However, this composition also produces SCC with a longer setting time and lower compressive strength than those of conventional SCC. A longer setting time can be beneficial when it is necessary to delay this process in practice. It should be noted, too, that the effect of urea on the compressive strength depends on the concrete age—that is, for a concrete age of 91 days, the effect is very similar to that achieved when only water (as opposed to both water and urea) is included in the mixture. These findings suggest that adding granular urea and RHA to SCC can reduce the concrete temperature and improve the flowability, especially in mass concrete construction or in hot tropical areas.

1. Introduction

Developed over the past 30 years to produce durable reinforced concrete structures in the face of a shortage of skilled labor, self-consolidating concrete (SCC) is a highly innovative concrete technology with multiple applications [1–3]. SCC has become very popular in the construction industry, given that it has a number of important advantages over normal-slump concrete. Unlike normal-slump concrete, SCC has the ability to flow and compact within formwork. Additionally, there is no need to vibrate SCC, unlike normal-slump concrete: SCC settles evenly under its own weight with no segregation or bleeding, which, in turn, reduces labor costs. It is practical to use SCC for large concrete structures including those with congested reinforcing steel, which are difficult or even impossible to negotiate using standard vibration methods [4]. In this context, SCC has the advantage over

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normal-slump concrete in that the former can flow through very dense reinforced steel without any segregation. Additionally, when removed from formwork, SCC does not have a honeycomb structure. However, in practice, it is necessary to understand the properties and behaviors of SCC in regard to the specifications associated with it. For example, SCC requires a very high amount of OPC in its composition, which affects the heat generated in the concrete via the hydration reaction. For this reason, SCC can be used successfully in very large, very deep structures. However, SCC can have a negative effect on the integrity of a structure by inducing thermal cracking, which, in turn, results in higher thermal stresses between the core and the surface of the concrete. However, through several studies, this cracking tendency has been fully addressed and obviated. Similarly, the problem of the internal restraint and external restraint of concrete has also been addressed. A number of research studies have shown that replacing a proportion of the OPC content in SCC with pozzolanic materials, of which RHA [5–11] is one option, can reduce the heat of the hydration reaction [12].

As the most abundant agricultural by-product in Thailand, rice husk is most effectively used to produce electricity. By burning the rice husk under a controlled temperature and atmosphere, a highly reactive rice husk ash (RHA) is obtained. After the appropriate combustion, ground rice husk ash is suitable for use as a pozzolanic material [6,7]; the pozzolanic reactivity of amorphous RHA was higher than that of partial crystalline and crystalline RHA [8]. On the other hand, Sua-iam and Makul [9–11] found that by incorporating untreated RHA in various mixtures, it is possible to use as-received residual RHA as a partial cement and fine aggregate replacement in SCC. The elimination of grinding costs increases the feasibility of using RHA in concrete production, reduces land-filling costs and provides a cleaner sustainable environmental solution, saving energy and reducing carbon dioxide generation by cement consumption [12]. Generally, SCC incorporating RHA as cement replacement has a lower maximum temperature rise and a later timing of peak temperature. However, the peak temperature of the internal concrete is still high, which means that it is necessary to determine the other material in the concrete mixtures in order to decrease the temperature. Urea is a material that can be used to address this problem.

When concrete is mixed with granular urea, the urea can reduce the temperature of the concrete due to the endothermic reaction between water and urea. This property reduces the temperature of the concrete during the casting stage and during the hydration reaction. This property is useful in mass concrete applications and under high-temperature conditions such as during the summer and during hot-weather concreting [13]. All concretes generate heat as the cementitious materials hydrate. For thicker concrete sections (mass concrete), heat dissipates more slowly than it is generated. The net result is that the mass concrete can become hot, but specifications generally limit temperatures in mass concrete to prevent cracking and durability problems [14]. Concrete that includes urea in its composition is useful for mass concrete construction in the early stages of the building process, such as placing the concrete in the inner parts of the construction. In addition, urea also has the effect of improving the flowability of concrete [15,16].

In the present study, we investigate the effect of urea on the flowability and temperature rise of SCC that includes RHA as a partial replacement for OPC. In terms of the advantages of using SCC with RHA in comparison with conventional SCC, the former can reduce the burden of handling RHA, reduce its environmental impact, and increase its economic value in sustainable development contexts. In addition, urea used in the production of SCC can also provide a basis for acquiring new knowledge in regard to reducing the temperature of other kinds of concrete and improving the flowability of SCC.

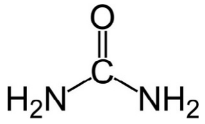
2. Materials and methods

2.1. Materials

The chemical composition and physical properties of the constituent materials are presented in Table 1. OPC with a density of 3.14 g/cm^3 in compliance with ASTM C150 [17] was used. RHA, a material with a high SiO_2 content, which is not in compliance with ASTM C618 [18], with a density of 2.20 g/cm^3 was used. The RHA used in this experiment is a main by-product from a biomass thermal power plant in Thailand.

As shown in Table 1, calcium oxide (CaO) is a main constituent of OPC, at 67.97%. The secondary constituents of SiO_2, Al_2O_3, and Fe_2O_3 were 16.23, 3.42 and 3.67% of the OPC, respectively; also, the sulfur trioxide (SO_3) content of the OPC was 1.89%. Silicon dioxide (SiO_2) is the main constituent of RHA, at 92.33%. The summation of the SiO_2, Al_2O_3, and Fe_2O_3 contents was 92.84%.

Table 1
Chemical composition and physical properties of OPC, RHA, and urea.

Chemical composition (% by mass)	OPC	RHA
SiO_2	16.23 ± 1.25	92.33 ± 2.92
Al_2O_3	3.42 ± 0.28	0.31 ± 0.10
Fe_2O_3	3.67 ± 0.12	0.20 ± 0.04
MgO	0.64 ± 0.05	0.36 ± 0.12
CaO	67.97 ± 3.57	1.29 ± 0.03
Na_2O	0.07 ± 0.01	0.16 ± 0.01
K_2O	0.49 ± 0.06	1.54 ± 0.21
SO_3	1.89 ± 0.42	0.01 ± 0.01
Loss on Ignition (LOI)	1.65 ± 0.05	1.89 ± 0.01
Physical properties		
Particle size at 50% cumulative passing (μm)	10.90 ± 0.34	53.60 ± 1.79
Density (g/cm^3)	3.24 ± 0.07	2.23 ± 0.04
Specific surface area(BET method) (m^2/kg)	615 ± 13.22	850 ± 17.11
Urea (CH_4N_2O)		
Total nitrogen content (%)	45.83 ± 2.43	
Moisture content (%)	0.21 ± 0.05	
Biuret (%)	0.14 ± 0.01	
Bulk density (g/cm^3)	1.29 ± 0.22	
Mean particle size (mm)	2.91 ± 0.68	
pH	8.53 ± 0.96	
Color	Pure white	