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Mechanical, microstructure and rheological characteristics of high performance self-compacting cement pastes and concrete containing ground clay bricks

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HIGHLIGHTS

- ▶ Presence of SCC admixture, strength of concrete increases up to 28 days.
- ▶ Increase of powder content of GCB, the compressive strength of concrete increases.
- ▶ Pastes made with 12.5% and 37.5% GCB show higher strength with SCC at 28–1095 days.
- ▶ Increase of GCB content increases the shear stresses values in cement pastes.
- ▶ The microstructure of GCB–OPC displayed a more dense arrangement, enhances the compressive strength.

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ABSTRACT

The work aimed to utilize ground clay bricks (GCBs) in the production of self-compacting concrete. Physico-mechanical, rheological and microstructure of cement pastes and concrete were investigated. Total powder contents were 400 kg/m^3, the cement was replaced by GCB by 0.0, 50, 100 and 150 kg/m^3. The compressive strength of concrete decreased with GCB content in the absence of self-compacting concrete (SCC) admixture, whereas, increases in the presence of SCC admixture up to 28 days. Increase of GCB content up to 250 kg/m^3, the compressive strength of concrete increases. GCB enhances the compressive strength due to the pozzolanic reaction to produce additional CSH, which precipitated in some open pores. The compressive strength of OPC pastes increase with SCC admixture up to 1.5 mass%, whereas decreases with SCC admixture up to 2 mass%. On the other hand, cement pastes made with 12.5% and 37.5% GCB in the expanse of OPC cement show higher compressive strength with SCC admixture at 28–1095 days. The efficiency of SCC admixture decreases as GCB content increases up to 12.5%, whereas the efficiency increases with GCB content up to 37.5%. The presence of SCC superplasticizer, the microstructure displayed a more dense arrangement of microcrystalline C–S–H as the main hydration products with sheets of $Ca(OH)_2$ as shown in the micrograph. Useful conclusions and recommendations concerning use of 30–40 mass% of GCB in self-compacting concrete.

1. Introduction

Self-compacting concrete (SCC) is considered as a concrete that compacted under self-weight with little or no vibration effort and cohesive enough to be handled without segregation or bleeding. SCC used to facilitate and ensure proper filling and good structural performance of restricted areas and heavily reinforced structural [1,2]. So, SCC has been increasingly used in concrete construction. The principal reasons for the growing interest is because of the ease in placement in heavily reinforced areas which are otherwise difficult to access, the reduced effort in accomplishing some of the casting tasks and the significant reduction of the construction period. Additionally, the technology has improved the performance in terms of hardened material properties such as strength, durability, and surface quality [3].

SCC has many technical, social, and overall economical advantages; however its cost could be 2–3 times than normal concrete. To reduce the cost of SCC use of mineral admixtures such as fly ash, limestone filler, ground clay bricks (GCBs) and blast-furnace slag could be used to increase the slump of the concrete mix as well as improve the mechanical properties and durability of concrete. The incorporation of fly ash also reduces the need for viscosity modifying chemical admixtures and reduces cracking of concrete due to the low heat of hydration heat of hydration of the cement

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[4–8]. The excellent workability and flowability of super-flowing concrete containing 30–40% fly ash by weight of the total cementitious materials were reported [9,10].

Blended materials used in SCC with binary and ternary binder systems having complex hydration mechanisms. It has been shown that particle size, shape, morphology and internal porosity of secondary raw materials all have a very significant effect on the overall response of self-compacting systems [11]. This response is improved in the presence of limestone powder or fly ash with either silica fume or amorphous rice husk ash [12]. Hydration reaction of self-consolidating concrete gets accelerated and modified due to improved nucleation possibilities while the presence of fly ash makes interference in cement hydration and changes reaction kinetics in the sense that fly ashes tend to lengthen the dormant period [13].

The effect of blast-furnace slag and two types of superplasticizers namely, polycarboxylate and naphthalene sulphonate formaldehyde superplasticizers on the properties of SCC were discussed [14]. The results showed that polycarboxylate superplasticizer concrete mixes give more workability and higher compressive strength than those with naphthalene sulphonate superplasticizer. In cementitious systems, hydration reactions can perturb the behavior of suspensions [15,16]. Dispersion of agglomerated cement particles is recognized to constitute the main method by which superplasticizers improve the workability of concrete without increasing the water content. Dispersion forces, referred to as Van der Waals forces, are the main cause for agglomeration of cement particles in concrete and of the poor resulting flow properties. To counter these forces and improve flow of SCC, dispersants are added. Understanding these effects is a key aspect for predicting which combinations of cement and superplasticizers will lead to best workability [17]. Important factors are the length of graft chains, degree of polymerization, and the density of graft chains. The characteristics of superplasticizers depend on the raw materials and the synthesis conditions [17,18]. The fluidity of cement pastes containing naphthalene sulphonate depends on the molecular weight. Furthermore the retardation effect depends on its concentration and C_3A content of the cement. The operative mechanism of polycarboxylic ether type owing to electrostatic repulsive forces is based on the negative charge of polycarboxylate and steric repulsive forces on the cement particles based on long side strains. The mechanism of action of naphthalene sulphonate based superplasticizer is different from the one of a polycarboxylate superplasticizer. The first one acts by electrostatic repulsion, and the second one acts by steric hindrance effect [19].

Since cement is the most expensive component of concrete, reducing cement content is an economical solution. Mineral admixtures can improve particle packing and decrease the permeability of concrete. Besides the economical benefits, such uses of by-products or waste materials in concrete reduce environmental pollution. Therefore, the durability of concrete is also increased [20–25]. The development of SCC is considered as a milestone achievement in concrete technology due to several advantages. Self-compactable the fresh concrete must show high fluidity besides good cohesiveness [26].

One of the disadvantages of SCC is its cost, associated with the use of chemical admixtures and use of high volumes of Portland cement. One alternative to reduce the cost of SCC is the utilization of mineral admixtures [27–30]. In addition, the incorporation of these fine materials can enhance the grain size distribution and the particle packing, thus ensuring greater cohesiveness [30,31].

The present work aimed to utilize Homra, which is the crushed portion of ground clay bricks (GCBs) from the Misr Brick (Helwan, Egypt) to produced self-compacting concrete. The physico-mechanical, rheological and microstructure of cement pastes and concrete were investigated.

2. Experimental technique

2.1. Materials

2.1.1. Cement

Ordinary Portland Cement (OPC) is used in all test specimens, the tests carried out on the used cement to determine its physical properties according Egyptian Code of Practice [32]. The chemical analysis of material was given in Table 1.

2.1.2. Ground clay bricks

A ground clay brick (Homra; GCB) is a solid waste materials produced from the manufacture of clay bricks. These crushed portions of Homra are not of commercial use and even may be considered as a solid waste to the environment. The mineralogical composition of the ground clay bricks is seen from the XRD pattern in Fig. 1.

The ground clay bricks sample constitutes mainly of SiO_2, Al_2O_3, Fe_2O_3, CaO, SO_3, MgO, and Na_2O, K_2O as traces and chemical properties were given in Tables 1. GCB sample constitutes mainly of free silica quartz from added sand and from clays and amorphous aluminosilicate from the decomposition of clay minerals as well as albite and hematite.

2.1.3. Aggregates

Locally available continuously graded crushed dolomite aggregates (magnesium carbonate and calcium carbonate) with a normal maximum size of 20 mm and well graded natural sand free from impurities with a fineness modulus of 2.75 were employed. The relative density of the coarse aggregate and sand were 2.66 and 2.56 and their absorption rates were 1.9% and 1% respectively.

2.1.4. Admixtures

In this study, polycarboxylate self-compacting admixture is used to increase the flow capability of the concrete and improve the viscosity. It is turbid liquid, with a specific gravity of 1.11 and pH value was 8.0 ± 0.5. The used dosages of polycarboxylate self-compacting admixture were 0.0, 0.5, 1.0, 1.5 and 2.0 mass% of concrete.

2.2. Mix proportions

Fifteen concrete mixes were made, which had total powder content of 400, 500 and 600 kg/m^3 (cement and ground clay bricks), coarse aggregate, fine aggregate content w/p ratio and polycarboxylic ether based superplasticizer (Viscocret 5-400) were given in Table 2. The cement was replaced by ground clay bricks as shown in Table 2.

2.3. Mixing and casting

For these mix proportions, required quantities of materials were weighed. Cement and GCB were mixed in dry state as well as coarse and fine aggregates were mixed dry separately. After adding water, all materials were mixed together to obtain the homogeneous mix. The casting of the mixes was done immediately. After casting, test specimens were left in the casting room for 24 h at a temperature of about 20 °C ± 0.5, in 100% relative humidity. The specimens were removed from mold after 24 h, and then immersed in water-curing tank until the time of the test. The cubes of size 150 × 150 × 150 mm were cast for determination of compressive strength after 28 days.

For pastes specimens, OPC has been partially substituted by GCB with ratio of 0, 12.5 and 37.5 mass%. The ingredients of each mix were blended in a porcelain ball mill for 1 h using a mechanical roller mill to ensure complete homogeneity. The superplasticizer was added in different amounts to the mixing water. The solid mix of each paste was mixed with a sufficient amount of water to form a paste of standard consistency according to ASTM specifications [33]. The pastes were molded in 2 × 2 × 2 cm cubes for studying compressive strength and scanning electron microscopy.

Table 1
Chemical oxide composition of the starting materials mass%.

Oxides	OPC	GCB
SiO_2	20.39	75.06
Al_2O_3	5.60	14.25
Fe_2O_3	3.43	5.61
CaO	63.07	1.30
MgO	2.91	1.35
Na_2O	0.38	0.19
K_2O	0.35	0.08
SO_3	2.42	0.70
L.O.I	3.21	0.00