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Research paper

Effects of fly ash, blast furnace slag and metakaolin on mechanical properties and durability of coral sand concrete

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ABSTRACT

This paper investigates the effects of fly ash (FA), blast furnace slag (BFS) and metakaolin (MK) on the mechanical properties, drying shrinkage, carbonation and chloride permeability of coral sand concretes (CSC), in which the replacement levels of supplementary cementitious materials (SCMs) below 35% by weight are compared. The control mixture contain only ordinary Portland cement (OPC) as the binder and nature aggregate concrete (NAC) while the remaining mixtures include binary and ternary blends of FA, BFS, and MK addition. Test results indicate that CSC show slightly lower compressive strength, higher drying shrinkage and carbonation depths compared to that of NAC due to high porosity of coral sand aggregate. Moreover, CSC exhibit better chloride penetration than that of NAC. The incorporating of MK has efficient pozzolanic reaction in improving the development of compressive strength and chloride permeability performance, and reducing drying shrinkage values of CSC than that of modified CSC with FA and BFS addition. Furthermore, the incorporation of MK manifests better carbonation resistance than that of control group and CSC containing FA and BFS.

1. Introduction

The exploitations of open seas islands consume a large amount of construction resources and labor, which cause that it is difficult to meet the economic requirements of engineering activities. Therefore, it is important to search substituted source of building materials in exploitation of open seas islands.

In the open seas, most islands are made up of coral reef. There are a mass of loose deposits containing bone and clear debris of coralline algae and other marine creatures of in those islands (Yu et al., 2006). Coral reefs provide abundant resources, such as coral itself contains calcium carbonate by >95%, which is essential solvent for smelting the nonferrous metals in industry (Fu et al., 2009). However, these deposits on these islands are usually considered as waste reef which occupy a lot of precious land space. Under the condition that the local ecological environment is not affected, it is simultaneously important to make full use of the waste reef and reduce land resources, in addition decrease the construction cost and environment load in the process of transportation.

Over the past few decades, some studies considered the using of coral aggregates as available aggregate in concrete. Howdyshell (1974) thought that the utilizing of coral aggregate was feasible. However, the chloride ion erosion, protective layer thickness and chlorine salt content in water were necessary considered. Rick (1991) investigated that the compressive strength of coral aggregate concrete was over 20 MPa at 28 day. Wanchai et al. (2003) reported that low W/C did not much affect the strength of coral aggregate concrete. Due to the fact that coral aggregates have higher porosity, water absorption, and contaminant content than that of natural aggregates. The using of coral aggregates will decrease the mechanical properties, increases permeability performance of concrete compared to those of natural aggregate concrete (NAC). Li (2012) study found that coral aggregate and lightweight aggregate had similar internal curing properties which were important for strength development. In addition, some material such as polypropylene fiber (Wang et al., 2014) and silica fume (Sun, 2014) can be used to mechanical properties of coral aggregate concrete. However, there is less literature about durability of coral sand concrete. The investigation of using coral sand aggregate is insufficient and needs further study.

The addition of supplementary cementitious materials (SCMs) have led to new trends which improve the strength and durability in concrete. These SCMs including industrial by-products (fly ash, blast furnace slag, silica fume and so on) as well as natural materials (red clay, metakaolin) are also widely used (Taylor-Lange et al., 2015; Zhang et al., 2014, 2016). Metakaolin is from kaolinite clay through a calcining process which has high pozzolanic activity (Sabir et al., 2001). The

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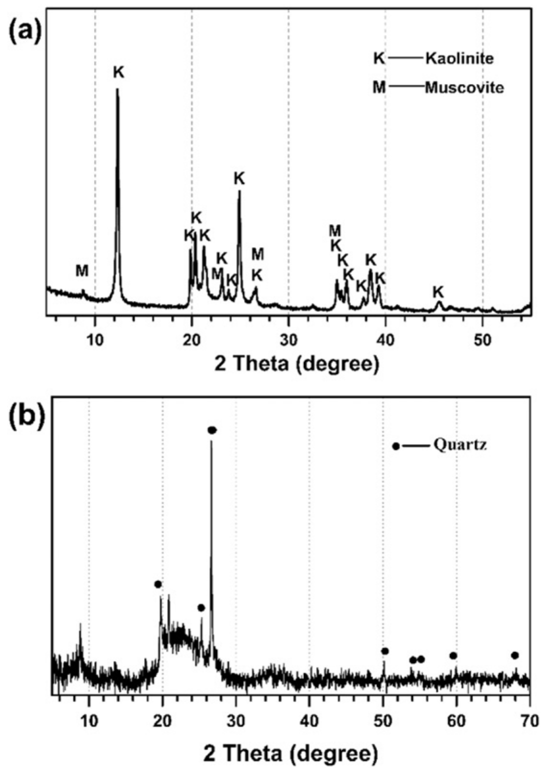

Fig. 1. XRD pattern of used kaolin and metakaolin (a) kaolin; (b) metakaolin.

different temperatures, heating rate, calcining scheme and thermal treatment affected structure of MK which lead to different reaction activity (Kakali et al., 2001; Siddique and Klaus, 2009; Vizcayno et al., 2010). Brooks and Megat Johari (2001) investigated that the incorporation of MK decreased the early autogenous shrinkage and drying shrinkage with a reducing trend at higher replacement levels in concrete. Poon et al. (2006) found that the strength development of MK modified concrete was better than that of silica fume modified concrete. Erhan Güneyisi et al. (2012) suggested that the replacement level of MK had significant effects on the mechanical, chloride permeability and shrinkage characteristics of high performance concretes. Moreover, some studies shown that MK blended self-compact concrete (SCC) reduced permeability and exhibited large positive effect by reducing the CO_2 emission and consume less thermal energy (Kavitha et al., 2016). It is well known that the large production of Portland cement and construction consume a huge amount of energy and generate a lot of CO_2. Thus, the utilization of appropriate mix design methodology with the incorporation of SCMs not only reduces the cost of construction but also improves the properties and durability of concrete. Despite some studies about the using of coral sand as construction material have been published, the mechanical properties and durability of coral sand concrete with metakaolin are limited.

In view of this, the effect of three supplementary cementitious materials, namely, blast furnace slag (BFS), fly ash (FA) and metakaolin (MK) on the compressive strength, shrinkage and durability of CSC are investigated. A total of nine different concrete mixtures are proportioned. Then, the effects of FA, BFS and MK addition on mechanical properties and durability of coral sand concrete (CSC) are discussed.

Table 1
Chemical analysis and physical properties of raw materials.

Item	OPC	FA	BFS	MK
CaO (%)	59.81	4.24	38.83	0.03
SiO_2 (%)	21.52	56.12	33.82	57.37
Al_2O_3 (%)	5.86	24.35	15.02	38.63
MgO (%)	2.23	0.38	7.14	0.07
Fe_2O_3 (%)	2.85	6.78	0.44	0.77
K_2O (%)	0.67	2.21	0.57	0.49
Na_2O (%)	0.22	0.39	0.29	0.39
SO_3 (%)	2.06	1.05	2.34	0.15
TiO_2 (%)	–	1.51	0.91	0.41
P_2O_5 (%)	–	0.42	0.02	0.61
Loss of ignition (%)	3.65	2.55	0.73	1.04
Specific gravity	3.13	2.38	2.96	0.68
Specific surface (m^2/kg)	339	287	399	>2000

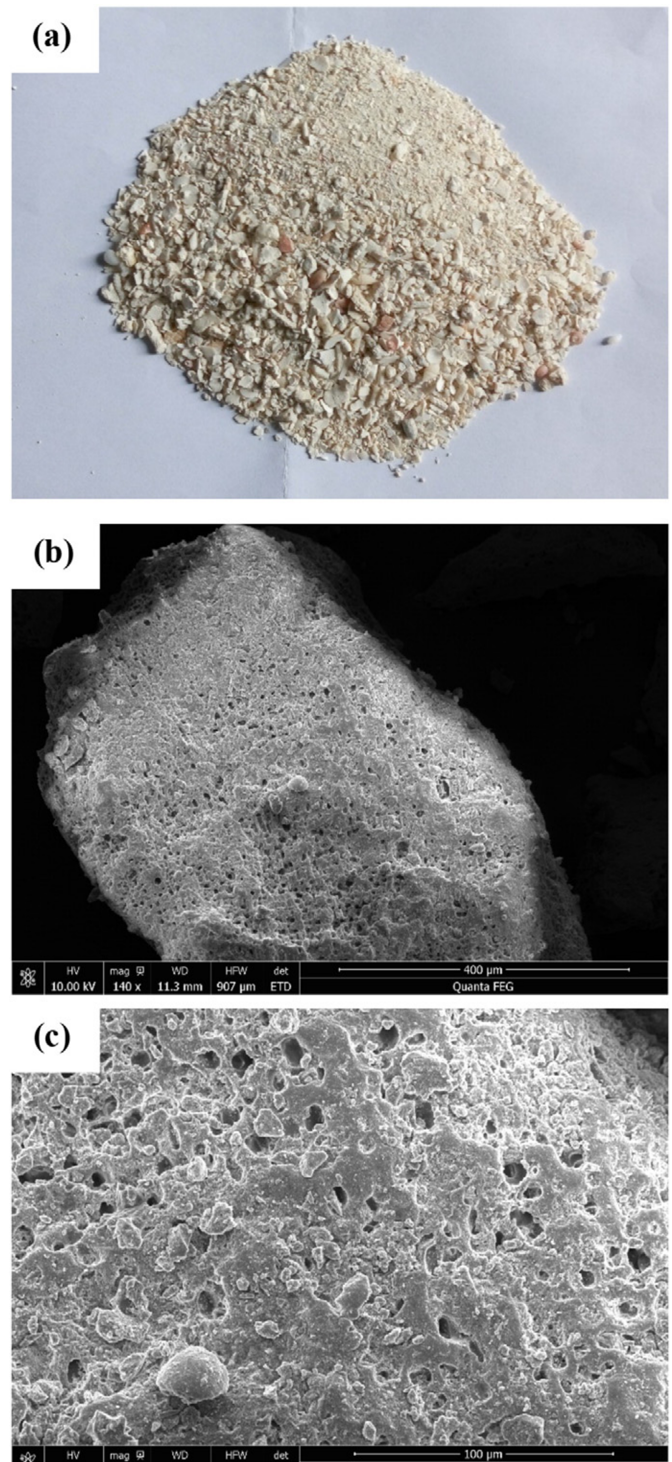

Fig. 2. Photograph and SEM micrograph of coral sand (a) photograph; (b) SEM of coral sand surface (140×); (c) SEM of coral sand surface (500×).