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Waste ceramic powder incorporated alkali activated mortars exposed to elevated Temperatures: Performance evaluation

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HIGHLIGHTS

- High volume waste ceramic powder incorporated AAMs were prepared and characterized.
- Performance of such AAMs were assessed under elevated temperature exposure.
- Microstructure of AAMs were sensitive to the variation of WCP contents.

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ABSTRACT

This paper reports the effects of high volume waste ceramic powder (WCP) inclusion on the mechanical and microstructure properties of alkali activated mortars (AAMs) exposed to elevated temperatures. Such ternary mixes were designed by blending the abandoned waste materials from Malaysian agro and construction industries including WCP, ground blast furnace slag (GBFS), and fly ash (FA) with low concentration of alkaline activators. The as-prepared mortar specimens were heated up to 900 °C to determine their temperature dependent residual compressive strength, weight loss, and microstructures. The deterioration of the AAMs at elevated temperatures was evaluated by X-ray diffraction measurement, thermo-gravimetry analyser (TGA), Fourier transformed infrared (FTIR) spectroscopy, and field emission scanning electron microscopy (FESEM). The resistance of the proposed AAMs to elevated temperatures was enhanced with the increase WCP contents from 50 to 70%. Furthermore, the replacement of GBFS by FA in the ternary blends led to the reduction of the mortar deterioration up to 900 °C.

1. Introduction

Since ages, Ordinary Portland Cement (OPC) has been serving as the primary structural material in the construction sector and widely used as concrete binder worldwide [1–3]. Although it is well known that large scale manufacturing of OPC causes serious environmental pollution in terms of considerable amount of greenhouse gases emission but right substitute to OPC has not been emerged [4,5]. The OPC production alone is accountable for nearly 6 to 7% of total CO_2 emissions [6]. In recent times, alkali activated mortars (AAMs)/concretes have been introduced as a new construction material to replace the traditional concrete in the construction industry [7–9]. Several notable merits of AAMs such as cheap production from abundant industrial wastes via recycling, reduction of the environmental pollution, enhanced durability, energy saving attributes, high early strength, and great non-combustibility make them advantageous over other construction materials [10–12].

Members of concrete structures used in the buildings must satisfy appropriate fire safety requirements specified to building codes [13,14].This is because fire represents one of the most severe environmental conditions to which structures may be subjected. Therefore, provision of appropriate fire safety measures for structural members is an important aspect of building design. Fire safety measures to structural members are measured in terms of fire resistance which is the duration during which a structural member exhibits resistance with respect to structural integrity,

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stability, and temperature transmission [15,16]. Generally, AAMs provide the best fire resistance properties when applied as building material [17]. This excellent fire resistance attribute of AAMs is due to chemical combination of the constituent materials that are essentially inert and have low thermal conductivity, high heat capacity, and slow strength degradation with temperature [18]. It is this slow rate of heat transfer and strength loss that enables concrete to act as an effective fire shield not only between adjacent spaces but also to protect itself from fire damage [19].

It is worth noting that millions of tons of natural, industrial and agriculture wastes such as fly ash (FA), coal and oil-burning by-products, bottom ash, palm oil fuel ash (POFA), bagasse ash (BA), used tires, cement dust, marble and crushed stone, waste ceramic powders (WCP) are dumped every year in Malaysia [20–23]. These waste materials cause severe ecological setbacks such as air contamination and leaching out of hazardous substances. Several studies [24–28] revealed that many of these wastes may be potentially recycled in the form of innovative concrete materials as an alternative to OPC (often as much as 70%). Besides, these newly developed concretes, owing to their green chemical nature, are environmental friendly, durable and inexpensive building materials.

Yet, the development of different AAMs as environmental friendly construction materials by blending WCPs has rarely been explored. The ceramic powder is the principal waste of the ceramic industry which is generated as unwanted dust during the process of dressing and polishing. It has been estimated that 15–30% of the ceramic wastes are produced from the total raw material used [22,29,30]. A portion of this waste is often utilized on-site for the excavation pit refilling. Ceramic wastes are not only non-biodegradable but also consume much space in landfill. Thus, finding a new way to recycle this waste and subsequently using in the construction of infrastructures can be useful to preserve natural resources and the environment. Previous research [24] revealed that ceramic wastes have pozzolanic properties, which can be used to make concrete with improved strength and durability. According to Pacheco et al. [31], concrete combined with WCP have increased durability performance because of its pozzolanic properties. It was realized that by replacing the conventional sand with WCP, it is possible to produce mortars with superior strength and durability performance. This WCP substituted conventional fine aggregates containing AAMs were effective with a bit lower water absorption performance. This water permeability of the AAMs implied that the substitution of conventional sand by WCP is an excellent option. The durability of WCP against sulfuric acid attack and sulphate attack were not evaluated.

This study was intended to determine the effects of WCPs on the thermal properties of the ternary AAMs containing FA and GBFS. Mortar properties such as residual compressive strength, weight loss and appearance colour are evaluated at various temperatures (400, 700 and 900 °C). Microstructure tests including XRD, SEM, EDX, FTIR and TGA were used to explain the changes in physical and chemical properties of alkali activated mortars.

2. Materials and methods

2.1. Materials

Three types of wastes materials, ceramic, GBFS and fly ash, were obtained from a single source for each one and used to prepare the ternary blended alkali activated mortars. In the present study, the ceramic wastes were collected from the construction industry located in Johor (Malaysia). As received materials were first crushed, grinded using Los Angeles grinding machine (LAAM) and sieved through 600 μm to isolate the large particles. The sieved ceramic was again ground for 6 h and the finesse of particles was checked after every hour interval. Next, the powder was collected and used in the mixing process (Fig. 1). The cement-free binder was made using pure GBFS (collected from Ipoh, Malaysia) as one of the resource materials, which was further utilized without any laboratory treatment. This slag possessed both cementitious and pozzolanic properties. GBFS shows off-white colour due to the development of hydraulic reaction during mixing with water. Low calcium FA was acquired from Tanjung bin power station (Malaysia) as resource aluminosilicate materials for preparing AAMs. It satisfies the ASTM C618 [32] requirements and appears grey in colour. From the Brunauer, Emmett and Teller (BET) test, it was observed that the specific surface area of FA showed the highest value of 18.1 m^2/g compared to GBFS and WCP which were 13.6 and 12.2 m^2/g, respectively. The fine size and light specific gravity of FA have influenced on the surface area test which showed the highest value. The low specific surface area was observed with WCP 12.2 m^2/g and its particle size was 35 μm.

X-Ray fluorescence (XRF) spectroscopy was used to detect the chemical compositions of WCP, GBFS and FA as summarized in Table 1. The main oxides composition were silica and aluminium in the presence of 84.8% GBFS, 41.7% GBFS, 86% FA. GBFS presented very high content of calcium oxide (51.8%) compared to other

Table 1
Chemical compositions of WCP, GBFS and FA obtained from XRF analysis.

Material	WCP	GBFS	FA
SiO_2	72.6	30.8	57.20
Al_2O_3	12.2	10.9	28.81
Fe_2O_3	0.56	0.64	3.67
CaO	0.02	51.8	5.16
MgO	0.99	4.57	1.48
K_2O	0.03	0.36	0.94
Na_2O	13.46	0.45	0.08
SO_3	0.01	0.06	0.10
SiO_2: Al_2O_3	5.95	2.82	1.98

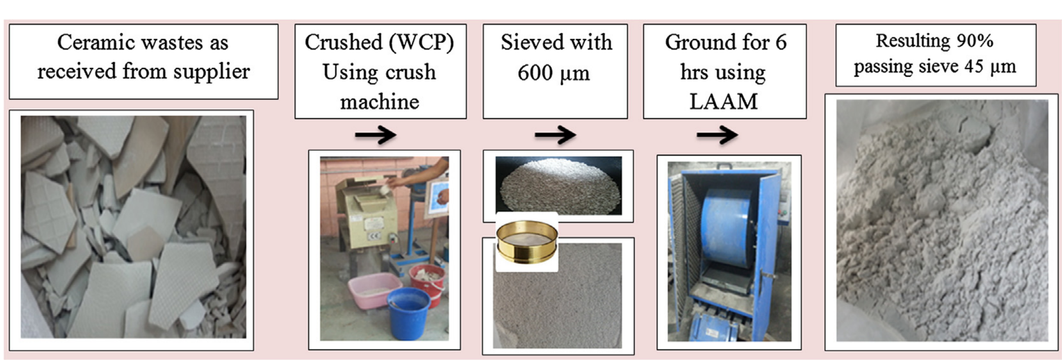

Fig. 1. Processing steps of WCP.