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Significance of performance based specifications in the qualification and characterization of blended cement using volcanic ash

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HIGHLIGHTS

- Characterization of regionally available volcanic ash for use in blended cement.
- Effect of different percentages of VA on the properties of blended cement.
- Importance of accepting performance specifications for the qualification of VA.

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ABSTRACT

Blended cement has become an essential requirement for producing high-performance concrete as it promotes sustainability in construction by decreasing the carbon foot print and enhancing the durability of concrete structures in the aggressive environments. A systematic study for the qualification of volcanic ash (VA), and for the laboratory-scale preparation and characterization of blended cement according to international standards and specifications for evaluating the potential of using regionally available VA in blended cement is discussed in this paper. Binary cement blends were prepared in the laboratory by replacing cement with VA in four different percentages by mass of the blended cement, and its performance was evaluated. The physical and chemical properties of blends were investigated and were compared with the allowable limits prescribed in international standards. The compressive strength of the blends with the VA content varying from 10 to 30% satisfied the limits specified in ASTM C595 and ASTM C1157. Finally, guidelines were developed for using regionally available VA as a natural pozzolana for producing blended cement.

1. Introduction

The multiple challenges in the cement industry due to the scarcity of raw materials and growing environmental concern in the recent years have resulted in several changes in the cement production using alternative materials. One of the global effort is mainly concentrated towards the production of blended cement using locally or regionally available supplementary cementitious materials in order to contribute to sustainable development and for environmental protection [1,2]. Incorporation of artificial as well as natural pozzolanas in cement and concrete production results in saving energy, protecting environment, and enhancing the durability of concrete structures in the aggressive environment.

Scarcity of raw materials and deterioration of concrete structures in the marine environment are the greatest challenges facing the construction sector in Kuwait as well as in other Gulf countries. Kuwait accounts for roughly 10% of Gulf Cooperation Council's (GCC's) construction materials distribution market as it is in line to join the current construction boom in the GCC, with a projects worth of USD188 bn already underway including Kuwait City's USD 7 bn ongoing metro project, the USD 3.3 bn Kuwait International Airport terminal, and around USD 6.2 bn in a series of motorway construction projects. This huge infrastructure spending plan of Kuwait is reflected with a growing demand of cement [3]. Kuwait has no indigenous raw materials for cement production, and therefore, has to import all its requirements on long-term contracts from its neighbours, the United Arab Emirates and Iran [4]. In addition, Kuwait cement companies are producing only Portland cement of Type I and Type V, and the construction sector is still using Portland cement for majority of projects, even though blended cement is giving better performance in areas with

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aggressive environment where both chloride and sulphate attack are predominant. However, imported supplementary cementitious materials (SCM), like fly ash, slag and silica fume are extensively used in this region for concrete production, which affects the sustainability due to higher transportation cost, increasing the carbon foot print of these materials. This has driven the researchers' intentions to explore the potential of using natural Pozzolans (NP) such as volcanic ash (VA), regionally available in the Gulf countries for the production of blended cement and concrete [5,6]. It is reported that the volcanic scoria available in north western Saudi Arabia could be used as fine and coarse aggregate for producing light weight concrete satisfying the requirements of structural concrete [6]. Therefore, the significance of this research is to promote the production and use of blended cement by incorporating regionally available VA instead of imported SCMs.

The previous studies reported on blended cements containing VA are generally limited to testing the hydration behaviour and strength properties of cement paste, mortar, and concrete based on international standards [7–14]. These results cannot be applied in any region using different source of VA, as VA is a natural pozzolana and its properties changes with origin, mineralogical composition, particle characteristics and mode of formation [15,16]. Also, there are investigations on the optimum use of NP, and it is found that the properties like water demand, setting time and compressive strength depend on the percentage of replacement of Portland cement with natural pozzolana [1,17,18]. In addition, blending of Type I and Type II cement with VA had shown better resistance against seawater attack compared to Type V cement [9].

These studies indicated that the selection of the optimal percentage of VA depends on its type, and physical and chemical characteristics. To promote the use of regionally available VA to produce durable concrete structures suitable for the Gulf region, an attempt is made in this study to investigate the potential of using VA in blended cement by its characterization and studying its performance according to locally recognized standard specifications. The properties of paste mixtures with the VA blended cement, prepared in the laboratory scale, is studied against the adopted international specifications in Kuwait.

2. Research significance based on locally recognized cement standard specifications

Portland cement is specified in Kuwait standard specifications "Portland cement" KWS GSO1914-10 [19], while the expansive hydraulic cement is specified by adopting ASTM C845-12 [20]. As there is no specific Kuwaiti standard for blended hydraulic cements, it is specified by adopting ASTM C595-14 [21], "Standard specification for blended hydraulic cements" as GSO ASTM C595-14 [22]. ASTM C1157-11 [23] is also adopted regionally by the Gulf standardization organization under the name GSO ASTM C1157-14 [24]. This performance specification covers hydraulic cements for both general and special applications with no restrictions on the composition of the cement or its constituents. Therefore, to meet the challenges faced by the construction industry in Kuwait due to the scarcity of materials, it is required to understand the importance of relying on performance specifications for the optimal use of locally and regionally available construction materials for the production of blended cement.

3. Experimental program

3.1. Material characterization

Natural pozzolana (NP) in the form of VA is abundantly available in Saudi Arabia, the neighbouring country of Kuwait in the Gulf region. Two different sizes of VA collected from Saudi Arabia were used in this study. A detailed investigation was conducted to understand the physical and chemical characteristics of the collected samples of both 20-μm and 40-μm VA according to ASTM C595-14 [21] to find its suitability to use as a natural pozzolana for the production of blended cement. Type 1 ordinary Portland cement (OPC) complying with ASTM C150/150M-12 [25] was used in this experimental investigation. The chemical characteristics of OPC and VA were determined using X-ray fluorescence spectroscopy (XRF). Mineralogical analysis of VA was carried out using X-ray diffraction (XRD). The XRD analysis was performed with a Bruker D8 Discover powder diffractometer. In this apparatus, the Cu K_α (λ = 1.5418 Å) radiation was generated in a copper (Cu) tube at 40 kV, 40 mA. The tests were performed over a Bragg angle (2θ) range of 5–70° with a scan speed of 1 s per step on the samples. Also, particle size distribution analysis of VA was conducted using laser granulometer in wet condition with isopropyl alcohol as solvent.

3.2. Blends preparation and test methods

The study was carried out on control samples and blends prepared using ordinary Portland cement acquired from a local manufacturing company, satisfying the specifications of KWS GSO1914-10 [19] and ASTM C150-12 [25]. Blends were prepared by replacing cement with 10–40% VA by mass of the blended cement. Similar weights of blended cement in all blends were mixed using a mechanical mixer to assure a uniform quality of blending. The chemical composition of blends was analyzed by XRF method and the loss of ignition was determined according to ASTM C114-13 [26]. The physical properties of fresh and hardened states of cement blends were investigated according to the ASTM international standard methods, as detailed in Table 1.

In addition, the influence of VA on the hydration characteristics was studied as per ASTM C1679-09 [33], using an isothermal calorimeter for the studied blends. Cement paste was prepared with different blends at a water-cement (w/c) ratio of 0.4 according to ASTM C186-15 [34]. Mixing was done externally in a vortex mixer and then transferred to the vial in the isothermal calorimeter. The temperature of isothermal calorimeter was kept at 23 °C for 24 h to stabilize the temperature. Test was conducted for a period of 48 h. The isothermal calorimeter measured the heat flow from the sample, which was maintained at a constant temperature sink, to a heat sensor and recorded with the help of the software.

4. Results and discussion

4.1. Physical properties of VA

The physical properties of the VA was determined and compared to the requirements of NP for use in the blended cement, according to ASTM C595-14 [21], as given in Table 2. The Blaine's fineness test showed that the fineness of VA (396 m^2/kg) was comparable with that of OPC (367 m^2/kg). The test results also showed that the VA of 20-μm satisfied the requirement of fineness accord-

Table 1
Test methods for the determination of physical properties of cement blends.

Physical Property	Applicable Test Methods
Air content of mortar (Volume %)	ASTM C185 (2008) [27]
Time of initial setting (min)	ASTM C191 (2013) [28]
Fineness (m^2/kg)	ASTM C204 (2011) [29]
Compressive strength (Mpa)	ASTM C109 (2013) [30]
Autoclave length change, (%)	ASTM C151 (2009) [31]
Mortar bar expansion, 14 days (%)	ASTM C1038 (2014) [32]