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Heat of hydration of concrete containing powdered scoria rock as a natural pozzolanic material

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HIGHLIGHTS

- A semi-adiabatic system was used for the evaluation of scoria rocks as a new source of pozzolanic materials.
- Scoria rocks can be used as a source of natural pozzolan for mass concrete applications.
- Scoria rocks can be used as effective as FA in reducing the peak temperature rise.
- There is a slight difference in the rate of heat evolution of SRs due to the difference in their properties.

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ABSTRACT

Specifications for mass concrete constructions typically mandate the use of pozzolanic materials with a low heat of hydration. In this paper, the influence of different powdered scoria rocks on reducing the heat of hydration and the associated temperature rise in mass concrete was investigated. Six paste mixtures, including a control and mixtures containing three sources of powdered scoria rocks (SR1, SR2, SR3), fly ash (FA) and ground silica flour (GS), were investigated using isothermal calorimetry. Also, the temperature rise due to the heat of hydration of their corresponding concrete mixtures cast in a semi-adiabatic block was recorded. The compressive strength development and microstructure of concrete mixtures were examined. The results show that powdered scoria rocks were as effective as FA in reducing the heat of hydration and peak temperature rise and can be used as a source of natural pozzolan for mass concrete applications.

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1. Introduction

Cement hydration with water is an exothermic reaction liberating heat during the early age of hydration [1–3]. The evolved heat dissipates rapidly when the dimensions of the cast concrete element are relatively small (e.g., beams, columns, slabs). However, for massive concrete constructions, such as raft foundations, dams and bridges, heat dissipation becomes slow resulting in significant build-up of internal temperature. As a result, a large difference in temperature between the center and surface of concrete is created. This temperature gradient usually induces thermal stress, which may exceed the tensile stress capacity of concrete and lead to the formation of thermal cracks [4–6]. The formed cracks reduce the integrity of concrete and provide paths for various substances to penetrate into concrete leading to deterioration and corrosion of the reinforcing bars and reducing the service life of the concrete structure [1–3,7].

Several methods have been documented to minimize the temperature rise and the risk of thermal crack in mass concrete. These methods include the use of cement of low heat of hydration; low cement content; placement at low temperature; the use of artificial cooling systems during placement and early curing [5–8]. Many specifications limit the maximum differential temperature between the interior and exterior surface of concrete to 20 °C to avoid thermal cracking and the maximum internal temperature during hardening to 70 °C in order to avoid the formation of delayed ettringite [4,6]. The Portland Cement Association (PCA) estimates the maximum temperature rise in concrete to be 12 °C for every 100 kg of Portland cement (PC) [6]. Therefore, reducing PC content in concrete mixture can be considered as the most effective way of reducing the temperature rise in concrete. This necessitates the introduction of a high volume of low reactivity supplementary cementitious materials (SCMs). SCMs such as fly

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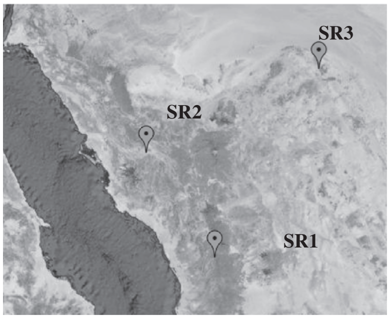

Fig. 1. Actual satellite image showing the three selected regions of SR.

Table 1
Location of the collected SR samples.

Region	Sample ID	GPS coordinates	
		Latitude (N)	Longitude (E)
1	SR1	23° 11.9103′	39° 56.9014′
2	SR2	25° 37.7778′	37° 73.1667′
3	SR3	26° 91.7778′	42° 35.1389′

ash (FA) and ground granulated blast furnace slag (GGBS) have been used effectively to lower the rate of heat evolution in concrete [9–12]. Nili and Salehi [13] investigated the effects of FA, silica fume (SF) and natural pozzolan (NP) on the temperature rise, heat evolution and early-age strength development of medium- and high-strength concrete. They concluded that FA was the best pozzolanic material for massive high-strength concrete as it reduces the peak temperature without resulting in a considerable decrease in compressive strength.

In many parts of the world, the traditional SCMs are unavailable. Thus, searching for local alternative materials that can be used as SCMs is crucial. The wide availability of NP in many countries, its low cost and the drive toward more sustainable construction have resulted in renewed interest in NP as SCMs for concrete [14,15]. Historically, various types of NP were successfully used in dams and aqueducts, where the strength demand is not high but the durability and thermal cracking control are of major concern [16]. Recently, several studies on the potential use of natural scoria rocks of the Arabian Peninsula in concrete have been reported [15,17]. It has been demonstrated that the use of scoria rocks and limestone powders in concrete as a partial cement replacement material has very good potential for self-compacting concrete [18]. The aim of this research was to assess the performance of powdered scoria rock (SR) for structural mass concrete applications. SRs from different sources were investigated for their effect on the heat of hydration and temperature rise in a system simulating mass concrete. The performance of SR concrete mixtures was benchmarked against FA and ground silica flour as pozzolan and inert materials, respectively. In addition, the development of compressive strength and the microstructure were examined for all concrete mixtures. The successful utilization of SRs for structural mass concrete applications is expected to have significant sustainability and economic impacts in countries where conventional SCMs such as FA and slag are not available.

2. Experimental program

2.1. Materials

Ordinary Portland cement (PC) complying with the ASTM C150 specification for Type I cement was used in this investigation. Scoria rocks samples were procured from different locations along the Arabian shield, Saudi Arabia. A satellite image showing the three selected sources is shown in Fig. 1, while the GPS international coordinates for the procured SR samples (SR1, SR2 and SR3) are presented in Table 1. The volcanic cones, typical grain size and stereomicroscopic images of the procured samples (SR1, SR2 and SR3) are shown in Fig. 2. The stereomicroscopic investigation reveals that the SR1 and SR2 grains have sintered and dense structures of variable porosity, while SR3 is much less dense and features a porous networked structure.

The collected scoria rock samples were ground using a Fritsch planetary mono mill PULVERISETTE 6 instrument (320 RPM) for 60–90 min such that approximately 90% of the particles passed through ASTM sieve no. 200 (75 Microns). The grinding of SRs is performed at the industrial level by several local suppliers. The availability of SRs and their elevated grindability render their powder production feasible and cost effective compared with imported SCMs.

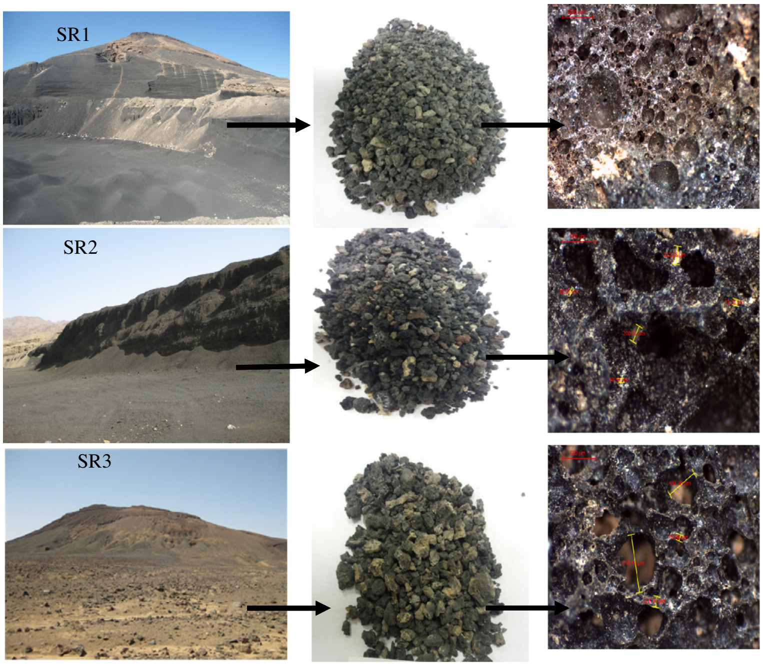

Fig. 2. The volcanic cone, typical grain size and stereomicroscopic images of SR1, SR2 and SR3.

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