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The use of the volcanic powders as supplementary cementitious materials for environmental-friendly durable concrete

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HIGHLIGHTS

- The powders of the volcanic rocks tested present a very high pozzolanic activity.
- Relationships between SAI index and chemical components were established.
- Energy consumption for the production of volcanic powder cements was calculated.
- Volcanic powders can be used up to 15% as a partial substitute for Portland cement.
- Mortars with the volcanic powder withstand much better chemical attacks.

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ABSTRACT

This study is part of a sustainable development policy that is dictated by the growing needs of material resources and the requirements of environmental protection. It addresses an investigation on the possibility of using volcanic powders as supplementary cementitious materials for environmental-friendly durable concrete. For this purpose, an experimental investigation was carried out to evaluate the mechanical resistances and the durability of mortars containing an amount of volcanic powders. Firstly, the work attempts to characterize several volcanic rocks (basalt, olivine andesite, amphibole-biotite andesite, amphibole andesite, hyodacite and scoria) from the mineral and chemical viewpoint and evaluate their pozzolanic activity. Relationships between chemical components of volcanic rocks and strength activity index were established. Secondly, it considers the mechanical strengths of the Portland cement mortars containing a variable percentage of volcanic powders (10, 15, 20, 25, and 30%). Performance energy for the production of volcanic powder cements was evaluated. At the end, the effects of aggressive chemical environments were investigated in terms of miscellaneous acidic attacks (H_2SO_4, HCl, HNO_3 and CH_3COOH). Furthermore, a supplementary cementitious material, used by many cement plants in Algeria, has been included in order to establish a comparative study.

1. Introduction

To lighten the economic and environmental impacts of cement industry, supplementary cementitious materials (SCMs), including limestone powder, fly ash, slag, silica fume, and natural pozzolans, can be used as partial replacement of cement in concrete [1–4]. Apart from the immediate reduction consequence of the concrete manufacturing costs, the partial replacement of cement will make it possible substantially to decrease the gas emissions for purpose of greenhouse (0.89t CO_2/t clinker), minimize the harmful environmental impacts, and reduce the consumption of natural resources and the energy. Due to the rush towards sustainability, nowadays, many countries have adopted a sustainable development program based on the use of the SCMs materials, namely natural pozzolanic materials. This subject has become of interest to the scientific community; several researchers have focused their research efforts on using natural pozzolan as an additive or substitute for cement in concrete mixtures [5–8]. In fact, natural pozzolan would react with calcium hydroxide to form more cementitious calcium silicate hydrate. In addition, mortars which contain pozzolanic materials

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would exhibit considerable enhancement in durability properties [9–11].

For this purpose, the aim of this investigation is to determine the validity of volcanic powders used as supplementary cementitious materials (SCMs). This step will make it possible to develop materials available locally and will contribute to the social development of the area. It is important to note here that the results of this research are of special importance not only for studied region but also for other regions with similar geology, such as: Ougarta, Yetti-Eglab and Edough (Algeria); Massif Central and Alpes (France); Calabre (Italy); Sierra Nevada (Spain); Anti Atlas, Ouarzazat, Ougnat and Siroua (Morocco); Harrat Al-Shaam (Syria, Jordan and Saudi Arabia); Djebel Dokhan (Egypt) etc. The choice of this kind of materials has been recommended by their interesting mechanical properties, abundance and economic exploitation with lower environmental impact [12–14]. Indeed, from an energy performance standpoint, the total energy required to produce cement was evaluated to be in the range 800–1200 kW h per ton of cement, including around 50 kW h/t for the finish grinding of the clinker. In the case of volcanic powder, the energy needed for the grinding of this material was evaluated at 75 kWh/t [15]. This process energy was assumed to be zero kWh/t if the volcanic powder is a by-product.

2. Location and geologic setting

In this investigation, representative samples of volcanic rocks were shortlisted from natural deposits in the southwest of Algeria (massif of Boukais). The massif of Boukaïs is located in the southwest of Algeria, specifically, at 50 km southwest of the Bechar city. Its latitude and longitude are 31°90′–32°00′N and 2°40′–2°60′W. The dimensions of this volcanic massif are approximately 12 km long by 6 km wide (Fig. 1).

This massif displays a wide variety of magmatic products, such as andesitic basalt flows, doleritic dykes and dacitic intrusions (Fig. 2) [16–18]. The reserve of the volcanic rocks is a great potential for the cement industry; it is estimated at more than 150.10^6 m^3 [19,20].

The geological investigation in situ has directed us to choose five representative samples (Fig. 3) showing separate textural characters (samples A, B, C, D and E). In addition to our investigation, we also established a comparative study by using supplementary cementitious material (Sample F). This material is used as pozzolans by local cement factories in the manufacture of composite Portland cement CPJ. A visual description of these tested samples is summarized in Table 1.

3. Materials and mix designs

According to ASTM Standard C 311-98 [21], the volcanic rocks were dried at a temperature of 105 °C to eliminate free water and they were ground in a laboratory ball mill to a particle size of 100% less than 70 µm. The ordinary Portland cement type CEM I 42.5 obtained from cement factory of Ain Touta was used as cementitious material. It had a Blaine specific area of 435 m^2/kg and a specific density of 3100 kg/m^3. Standard sand of 2 mm maximum particle size was employed for the formulation of mortars. The distilled water was used in all mortar mixtures and in the curing of all the tests specimens. The mix designs of mortars used for the experimentation are given in Table 2. After mixing, all mortars were cast into 4 × 4 × 16 cm molds and they were kept in laboratory conditions for 24 h. Then, the specimens were

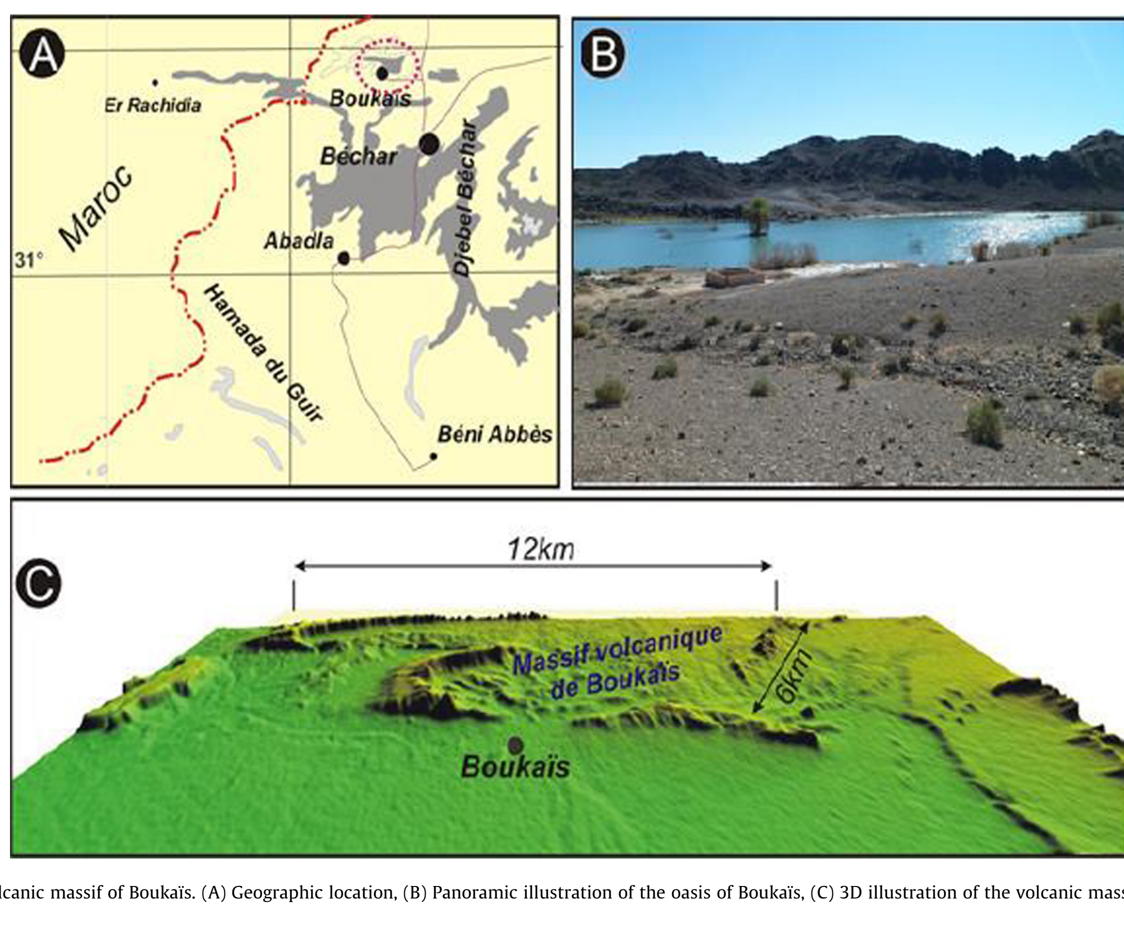

Fig. 1. Volcanic massif of Boukaïs. (A) Geographic location, (B) Panoramic illustration of the oasis of Boukaïs, (C) 3D illustration of the volcanic massif of Boukaïs.