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Concrete mix design containing calcareous tuffs as a partial sand substitution

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HIGHLIGHTS

- This research investigates the effects of calcareous tuff on concrete properties.
- Two tuffs, distinct by their fines contents of 27% and 34% respectively, are studied.
- Sand is partially replaced by tuffs at the following proportions (5%, 15%, 25%, 35%).
- The compressive strength increase from 13% to 33% for 25% of tuff with superplasticizer.
- The durability of tuff concrete is reduced and therefore needs a protection against external aggressions.

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ABSTRACT

This paper reports results of the use of calcareous tuff in ordinary concrete as a partial sand substitution. The compressive and tensile strengths, water absorption (total and capillary) and resistance to acid environments of concretes produced with two tuffs using varying percentages (5–35%) are studied. The incorporation of calcareous tuff in concrete requires the use of a superplasticizer to overcome the workability loss resulting from the high fines content in tuffs. High concrete performances have been developed with the use of an optimum of 25% of tuff addition. The increase in compressive strength reaches 33%. However, absorption and chemical resistance were reduced probably due to the absorbing character and calcareous nature of tuffs.

1. Introduction

The increase in demand for sand in Algeria during this last decade, resulting from the significant development construction industry (large housing programmes and infrastructures) induced a huge material deficit. To overcome this problem, it is important to use materials of substitution such as crushed sand [1], dune sand [2–4], limestone fines, natural pozzolana, blast furnaces slag and different wastes [5–7]. However, even with these palliative materials, the expectations of the market are still far from being satisfied and the search for other alternatives remains necessary.

The work presented in this paper aims to valorise tuffs as a new material of replacement of sand in concrete because of its abundance in Algeria which covers a large area of about 300,000 km^2 [8–10].

A literature review revealed that there is a few or no research undertaken on the use of tuffs in structural concrete. However, only works on the stabilised cement calcareous tuffs used in road construction in some countries such as Argentina and Tunisia have been reported in the literature [11–13].

It should be noted that both calcareous tuffs and crushed sand are nearly similar because of the similarity of their mineralogical nature and high fines content. Thus it is very relevant to use tuffs as a material of substitution.

For the purpose of our investigation, tuffs of the different existing quarries of the North of Algeria have been analysed in order to determine their main characteristics.

Consequently and in order to study tuff addition effects on a fresh and hardened ordinary concrete respectively, several mixes containing tuffs have been considered.

2. Materials and methods

2.1. Materials used

A list of more than 80 calcareous tuff exploited deposits has been provided by the National Public Works Laboratory (LCTP) [14]. The examination of the data emphasises that tuffs differ mainly by their fines content and their geotechnical

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characteristic in particular the bearing capacity index CBR, the Proctor optimal density (Wopt) and the calcium carbonate percentage ($CaCO_3$). Within the framework of this research, it might be considered that only fines rate should constitute a selection measure because of its effect on the concrete performances.

Based on the existing geological data, it should be noted that calcareous tuffs in Algeria are mainly characterised by their different fine contents on the order of 10%, 15%, 25% and 35%. The last two proportion values are dominating (about 2/3) which helped to choose Boughezoul tuff (27% of fines) and that of Htattba (34% of fines). Their chemical compositions as well as the properties are presented in Table 1.

A 42.5 CEM II/A cement from Msila factory is the type of binder used for making concretes for the purpose of the work undertaken. Compressive and tensile strengths obtained for this type of cement at 28 days were 45.7 and 8.47 MPa respectively. Its fineness is around 300 m^2/kg. The chemical and mineralogical compositions are given in Table 2. The sand used is coarse river sand with a density of 2600 kg/m^3, a fineness modulus of 3, a water absorption capacity about 2.5% and a cleanliness level of 80%. Two fractions sizes (8/15 and 15/25) of calcareous crushed gravels have been used for the need of the study. The grading curves of the various aggregates are shown in Fig. 1.

Workability improvement of concretes was obtained thanks to the polycarboxylates superplasticizer (MEDAFLOW 30) used which is characterised by a chloride content lower than 0.1%, a density of 1.10 g/cm^3, a pH of 6 and a dry extract percentage of 30%.

2.2. Concrete mix-design

Dreux method [15] has been used in this study for the determination of the mix proportions of ordinary concretes on the basis of some specifications such as a slump greater than 10 cm and a compressive strength higher than 30 MPa. Considering these requirements, eight (08) concrete mixes with a constant water/cement (w/c) ratio and containing calcareous tuffs used as sand substitution, have been formulated. The objective of using a constant w/c ratio is to highlight the only effect of this addition on the workability and strength of concretes. The tuff has been incorporated in concretes at the following amounts: 5%, 15%, 25% and 35%. It should be noted that a concrete without tuff has been produced to be used as reference specimen for the need of comparison.

To facilitate the readings, mixes with letter A refer to concretes made of tuff of Htattba and mixes with letter B refer to concretes containing tuff of Boughezoul whereas the reference concrete is referred as CO. For further investigation, similar concretes containing a superplasticizer have been formulated. The Polycarboxylate superplasticizer has been used, at different amounts varying from 0.8 to 1.2 by weight of cement, in order to compensate the workability loss induced by the high tuff fines content. To describe the new concrete mixes, the same letters have been used to which a letter S (for superplasticizer) is added. The mix proportions of the different concretes are listed in Tables 3 and 4. It should be emphasised that the quantities of water and superplasticizer have been adjusted in order to reach the required workability on the order of 9 cm slump, the same as that of concrete CO and to ovoid segregation.

2.3. Preparation of concrete test specimens

Concrete specimens have been batched, moulded and cured according to AFNOR standard [16]. All the moulds were covered by plastic sheets and stored for 24 h in the laboratory prior to demoulding, afterwards, they were cured in water at 20 °C and at relative humidity (RH) on the order of 50–60%.

Table 1
Physical and chemical characteristics of the calcareous tuffs.

Physical characteristics	Htattba tuff	Boughezoul tuff
Apparent density ρa (kg/m^3)	1100	1120
Absolute density ρs (kg/m^3)	2100	1950
Fineness modulus FM	1.24	1.78
Absorption Abs (%)	11	6
Blue value Vb	0.9	0.5
Fines content <63 μm (%)	34	27
Chemical composition		
SiO_2	26.69	21.16
Al_2O_3	2.54	1.43
Fe_2O_3	2.14	0.68
CaO	36.68	39.97
MgO	0.61	1.34
SO_3	0.13	0.56
K_2O	0.38	0.10
Na_2O	0.08	0.15
P_2O_5	0.07	0.04
TiO_2	0.12	0.09
PF	30.56	34.01

A testing programme has been elaborated and consisted of determining the essential mechanical, physical and chemical properties of fresh and hardened concretes. The necessary test specimens have been cast in different moulds and three tests were carried out to assess each required characteristic.

For the determination of compressive strength, concrete cubes of $150 \times 150 \times 150$ mm^3 [17] were used. It was measured at 28 days old using a testing machine with a maximum load capacity of 3000 KN. The tensile strength was measured on $70 \times 70 \times 280$ mm^3 prismatic specimens [18] at 28 days old applying a three-point bending test, using a testing machine with a maximum load capacity of 30 KN.

An investigation on the durability of the elaborated concretes was carried out. Thus, the capillary test [19] and total absorption test [20] were determined on $100 \times 100 \times 100$ mm^3 concrete test specimen cubes.

The rate of capillary absorption of water was evaluated on mature concrete at 28 days old. The lower side of the sample was placed into water (h = 5 mm) for 24 h. Specimens were left to cool in an air-tight container. In order to ensure that water flows in a single direction, specimens were sealed on the side.

Water total absorption was estimated by measuring the increase in specimen mass after 24 h of total immersion in water.

For the last part of the testing programme, prismatic concrete specimen bars of $70 \times 70 \times 280$ mm^3 were immersed in different acid solutions, notably in hydrochloric and sulphuric acids, in order to appreciate the durability problems that occur with concrete. Relative chemical resistance has been determined after 3 months of immersion in solution at 5% of acid at ambient temperature. The affected parts of the concrete specimens have been washed with water then the chemical resistance has been determined by measuring the concrete specimen mass loss percentage.

3. Mechanical performances and physical properties of the elaborated concretes

3.1. Workability (concrete with constant water content)

Slump measures of all concretes containing superplasticizer are similar to that of the reference concrete (CO), so the analysis of workability, in this section, is focused only on concrete without superplasticizer. The results obtained on ordinary concretes containing tuff and without chemical admixtures show a loss in workability. The slump that was 9 cm for the reference concrete dropped until 3 cm for concretes A35 and B35 as shown in Fig. 2. The workability loss is significant in the case of Htattba tuff which revealed the highest fines content. Increasing tuff addition percentage acts negatively on concrete rheology. This is obviously due to the presence of fines in this material and also to its absorbing character. Indeed, both Htattba and Boughouzoul tuffs are characterised by water absorptions of 11% and 6% respectively, which are significantly higher than water absorption of used coarse river sand which is about 2.5%.

Similar loss in workability is observed with several additives used in concrete or even in cement mortars as limestone fine [21,1], marble waste [7] or recycled aggregate waste [6]. Workability drops of concretes with constant water content are similar and also important and can reach 66%. This may be attributed to the particle size or grading, the smoothness and the form of the fines [7].

In a cement-based filler-added material, without any superplasticizer, the amount of free water is reduced, and more of the water is adsorbed on the surface of the filler particles or entrapped inside flocks of particles [22]. Therefore, depending on the fineness and morphology of the filler, the water need may vary from 1 to 4. As reported by Baron in [23], filler addition is positive provided fillers contribute to lessen the water need. The presence of mineral fillers also modifies the concrete consistency (or workability).

The adsorbed water at the filler particle surface does not only fill in voids, it also provides greater thickness to the water layer around particles, which reduces viscosity, and, hence, flow properties and workability in particular [21].

3.2. Compressive strength

The observed compressive strength of calcareous tuff concretes without chemical admixture is lower than that of the reference