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Dune sand and pumice impact on mechanical and thermal lightweight concrete properties

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HIGHLIGHTS

- A lightweight concrete was manufactured with dune sand.
- Mechanical and thermal properties of lightweight concrete were studies.
- The replacement of alluvial sand by dune sand improves the concrete density and thermal performance.

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ABSTRACT

This paper consists of substituting an appropriate fraction of natural aggregates with lightweight ones composite concrete development such as pumice which is found in volcanic sediments, the advantage of using lightweight concrete is to reduce the dead-weight; its light weight gives a better thermal insulating power in comparison to traditional materials, given the volume of air they contain. This work comes also within an economic framework, given the abundance of sand dunes, particularly in the Sahara to possibly replace the coastal sand dunes. High cement proportion is required to obtain high resistance levels, hence lightweight concrete performance can be dramatically improved through a consistent dosing of fines. Workability is improved by increasing Water/Cement ratio; it also relies on fine nature and dosing when W/C ratio is fixed. On that point, the substitution of dune sand in lightweight concrete could obviously be of great benefit. This advantage allows us to exploit natural resources and gives us the ability to produce at lower costs and provide concrete with rheology and long term strength. The simplest approach consists of measuring each parameter impact: collapse, mechanical resistance and heat transfer properties, through 16×32 cm cylindrical probes. Pumice has a major influence on fresh lightweight concrete; it should stay damp before use to avoid quick slump loss. Mixture's workability was affected by a substantial sand content. The dune sand substitution with the quarry sand increased the resistance by the filling of the voids within the aggregates, thus compressive strength of concrete type has spectacularly increased. The testing behaviour and simulations performed on cylindrical probes of 16×32 cm have shown that dehydration of the heated concrete causes a decrease of Young's modulus (softening) and mechanic resistance drop (decohesion) in compression causing degradation of the paste aggregate interface, and may cause cement matrix micro-cracks.

1. Introduction

The current concern is to promote composite products able to perform several purposes. Currently, we do not only look for the mechanical performance but we are also trying to improve the thermal and economic qualities. The development of lightweight concrete can play a role as an insulator, retaining sufficient performance levels, these materials are then studied simultaneously on two themes: mechanical/thermal or mechanical/acoustic [1]. Lightweight concrete is characterized by its density generally less than 2000 kg/m^3 and its thermal conductivity is less than 1.0 W/m °C [2]. Therefore, lightweight concrete can be used instead of the normal weight concrete, especially when light and economic solutions are required [3].

Considering that the desert regions dispose of important and renewable natural resources as fine-grained dune sand, which have silicon-rich chemical and mineralogical composition,

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nevertheless, significant problems related to fresh and hardened concrete have been encountered, such as endogenous and exogenous shrinkage, early cracks, loss of rigidity, resistance loss, etc. [4,5].

A huge quantity of research [6–10] was undertaken on using waste as substitution material of fine aggregate. Research revealed that the substitution of alternative materials in concrete could improve durability and mechanical properties, leading to the elaboration of sustainable concrete. Some researchers studied the effects of river estuaries fine-grained dune on concrete mixtures, it was found that when the sand content increases, the water content needed for the normal workability is not higher than in coarse sand concrete [11]. Others have compared the mortar mixtures strength properties based on conventional sands and sand dunes and the development of resistance, it was also found that the development of resistance and elasticity are not different from that of conventional concrete [12].

Due to the production variations of concrete material, the difficulties of mastering the dosage are important to achieve the desired objectives. The composition of concrete must be controlled in some cases, in order to be corrected. To this end, the work was divided into two succinct parts, to improve the lightweight concrete properties and reduce the error factor.

The first part suggests the substitution of different percentages of sand dune in the manufacture of lightweight concrete, the second part was designed to study the mechanical and thermal properties of lightweight concrete, the materials needed for lightweight concrete have been predefined and fixed upstream in part 1.

2. Lightweight concrete formulation

2.1. Fundamental principle

To prevent aggregates not to fully absorb the water needed for cement hydration and thus modify the rheology of the concrete, it is necessary to pre-wet aggregates (dry). This amount of water corresponds with the water absorbed by the dry aggregates 5 min after the immersion. The amount of water depends on the aggregates moisture content.

At the stage of kneading, when a certain amount of water is added, it will help to humidify the cement. To realize this step, the cement reaction depends on the amount of water absorbed by the lightweight aggregate.

The water absorption capacity is important for lightweight aggregates, since the pumice material depends on its size, its initial density, the distribution of vesicles according to their dimensions, and the way they are connected, this amount of water can be very important, this feature gives concrete uniqueness [13].

In some cases, lightweight aggregates are used dry, in others completely saturated, depending on the objectives [14]. In particular, worked on the effect of this parameter with pretty amazing results. For example, the use of dry aggregates improved compressive strength for a type of lightweight aggregate; however, workability has decreased [14,13]. Henceforth, there is no absolute rule in the formulation of a lightweight concrete [13].

In practice, the authors seem to agree on the following point [13]: in the case where the lightweight aggregates are dampened before being used for the concrete manufacture, distinctions must be performed in the description of the amounts of water involved. Indeed, two quantities of water are to be taken into account: on the one hand, the water absorbed or inner water which is not considered in the mixing water, on the other hand, water absorbed on the surface of lightweight aggregates, also named surface water which takes part of the mixing water [14,15].

2.2. Holm's method

The approach proposed by Holm [15] forms the basis of the study presented in this article. Specifically, it aims to estimate the amount of water from dampened or saturated lightweight aggregates that will intervene in the mixing water with a lightweight concrete. The assumption made by Holm is: Only the water adsorbed at the surface of the lightweight aggregate is found in mixing water and influence on the W/C ratio (Water/Cement ratio).

Henceforth, a protocol was developed to estimate this amount of water. It revolves around two water content measurements of lightweight aggregates in order to have the following final estimate:

$$\mathbf{MAD} = \mathbf{MT} - \mathbf{MAB}$$

MAD = Free water in the Water/Cement ratio (% mass);
MT = Effective water content of aggregates at the time of lightweight concrete manufacture (%), according to ASTMC 566-97 [16];
MAB = Water content of lightweight aggregates according to ASTM 566-97 [16] standard, after towel-dried surface.

This assumption will be used in the context of this article to obtain the required effective W/C.

3. The formulation

The principle in the formulation of the studied lightweight concrete is to replace the same volume of coarse aggregate by the lightweight aggregates. For quality concrete, we applied curing to the lightweight concrete probes with the objective to keep the concrete saturated, or as saturated as possible until filling the water-filled pores with the hydration products [13–15].

4. Used materials

4.1. Used sand

The sand used in the lightweight concrete was taken from three major sites:

1. Quarry sand from northern area (A1).
2. Sand dunes from southern area (A2).
3. Sand dunes from southern area (A3).

Sieve analysis was performed according to NF 18-560 with an adjustable frequency sieve shaker, the frequency used was 50 Hz. Results are summarized in the graph in Fig. 1, the test of Sand Equivalent (SE) was performed according to NF P 18-598 standard [17,18] (See Table 1).

Fig. 1 shows the corresponding percentages of the three types of sand (A1, A2 and A3) in terms of the sieve diameter. This study shows the presence of three different granulometry types, from which it is possible to infer the physical characteristics of the three types of sand.

The sands collected in the southern area have a fineness modulus lower than 2.1 while the sand collected in the northern area (A3), show a sand of coefficient f uniformity of Cu = 2.4 and a fineness modulus corresponding to 2.70, this allows us to conclude that the A1 sand complies with the NF P 18-598 standard [18]. There is a tight granulometry, the use of washed aggregates in the manufacture of concretes often induces a deficiency in fines (<to 80 μm) in the granulometric curve continuity. The sand dunes will be used for the correction of the granular structure of the sand because it is advisable to use fillers or very fine sand grain (Sablon),