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Effect of quaternary cementitious systems containing limestone, blast furnace slag and natural pozzolan on mechanical behavior of limestone mortars

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HIGHLIGHTS

- Mineral additions have a benefic effect vis-a-vis to the mechanical properties of mortars.
- Simultaneous incorporation of BFS, NP and LF reduces the compromising effect of this one.
- Mechanical, thermal and chemical methods are the methods for activate BFS and NP.
- Activation of LF, BFS and NP affected the mechanical properties of hardened mortars.

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ABSTRACT

This paper describes an experimental research on the study of mechanical behavior of crushed limestone mortars of the Algerian Central Saharan Atlas made from a mixture of three mineral additions. Namely; Portland cement, limestone filler, blast furnace slag and natural pozzolan which were simultaneously used to obtain blended cements that contain 50% mineral additions. Mortars have been the subject of a series of normative tests, in order to achieve a characterization, more or less detailed, which allows assessing the quality of these mortars in terms of standards. Three methods for activation of pozzolanic reactivity of BFS and NP were used, namely; mechanical, thermal and chemical methods to activate the pozzolanic reaction of slag and pozzolan at an early age.

Three activation methods of pozzolanic reactivity of mineral admixtures were used. Mineral additions were activated mechanically by grinding to 3800 cm^2/g, and 6000 cm^2/g Blaine surface area (mechanical method), elevated temperature by curing mortar specimens at 8 °C, 20 °C and 40 °C (thermal method), and chemically by mixing the mixture with 1% of alkaline activator (NaOH) based on the mass of binder (chemical method).

Tests were carried out to characterize the mechanical behavior of binary, ternary and quaternary binders of hardened limestone mortars at 2, 7, 28, 90, 180 and 365 days. Test results showed that the simultaneous incorporation of LF, BFS and NP in partial replacement to the OPC where the role of the mechanical, thermal and chemical activation of these mineral additions slightly affected the mechanical properties of hardened mortars based on crushed limestone sand at short and long terms (from 2 days to 90 days).

1. Introduction

Massive rocks laminated in metric and decametric benches of limestone lithological nature of the Cretaceous Turonian of the Mesozoic age, outcrop on the level of the mounts of the Central Saharian Atlas (C.S.A.) and its piedmont until the North of the Saharan platform in Algeria [1,2]. For many years, limestone has been increasingly used in concrete as coarse aggregate, filler or as a main cement constituent [3,4]. It is applied in high performance concrete as well as in normal or low performance concrete [5–7].

The use of ternary cements (limestone filler + natural pozzolan) contributes in a positive way to improve the mechanical strength

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of cements. Durability is also improved manifesting itself by a best resistance to permeability to chloride ions [8].

The mixture of 70% OPC and 20% pozzolan and 10% limestone develops a very comparable strength to that of a control mortar. This mortar presented, at 90 days, better resistance to chloride ions [9].

The combination of pozzolan and slag in an OPC has resulted in an optimal amount of 35%, which is more resistant, so the cement with pozzolan and slag shows an improved durability thanks to its resistance to the aggressive environment [10].

Pozzolanic and cementitious materials, when mixed with Portland clinker and water, produce C–S–H similar to that generated from the hydration of calcium silicate of clinker (ACI 225R-85) [11].

The replacement of a part of clinker by slag has led to the improvement of the compressive strength at 28 days, but with a slight decrease at 7 days [12].

The combination of limestone filler and blast-furnace slag is complementary: the limestone filler improves the early strength of cement while the BFS improves the later strength by the cementing reaction that refines the pore systems. It is proved that the ternary cementitious blend of limestone filler offers an advantage over the binary blended cements and plain Portland cements [13]. At all ages, there is a ternary blend of LF, BFS and PC that present an optimum strength, better than binary LF or BFS cements and plain Portland cements. It is attributable to the complementary behavior of both admixtures: LF improves the early strength while BFS improves the later by its cementing reaction [14].

A maximum pozzolan amount can be used with an optimum productivity and an efficiency to achieve a maximum strength. The optimum pozzolan/cement ratio to obtain the maximum strength is approximately 0.28. This optimization method can be used for the production of blended cements [15].

The compressive strength of mortars made with blended cements containing large amounts of natural pozzolan was lower than that of the Portland cement at all tested ages up to 90 days. Specifically, the early strength of blended cements decrease significantly as a result of combined effects of low Portland cement content and relatively high water-to-Portland-cement ratio in blended cement mortars [16,17].

The blend with a composition of 80% Portland cement and 20% natural pozzolan and 1% superplasticizer provides superior strength and durability characteristics in comparison to the counterparts without superplasticizer and to the blends with a high proportion of natural pozzolan [18].

The activation process is influenced by the chemical composition of slag and pozzolan, the chemical activator used and the glass phase (glass content). The activator is not a simple catalyst for the course of reactions, but also a reactive that enters in the reactions of hydrate formation. Its role is to accelerate the solubility of the components of slag, promotes the formation of some hydrates and favors the formation of the structure system of hydrates [19–21].

This paper presents an experimental study carried out on limestone mortars in order to quantify the effect of the influence of the simultaneous incorporation of limestone filler, blast furnace slag and natural pozzolan in a partial replacement to Portland cement. The role of the mechanical, thermal and chemical activation of these mineral additions on the mechanical properties of hardened mortars containing crushed limestone sand was studied.

The objective of this study is to investigate the influence of the simultaneous incorporation of limestone filler, blast furnace slag and natural pozzolan in partial replacement to the Portland cement and the role of the mechanical, thermal and chemical activation of these mineral additions on the physical and mechanical properties of fresh and hardened mortars containing crushed limestone sand.

2. Geology of the study area

In this research, the geological study was initiated to clarify the different types of limestone rocks (geological formations) that exist in the study area belonging to the Algerian Central Saharan Atlas.

There are limestones of the superior Kimmeridgian, limestones of the inferior Kimmeridgian, limestones of the Portlandian, limestones of the Turonian, limestones of the Senonian etc.

Each type of limestone is distinguished by its physical, chemical and mechanical properties and consequently the concrete or mortar made from these limestones differs from other concretes and mortars by its physicomechanical characteristics. That is why it is necessary to do the study case by case. The aggregates used in this study originated from the Turonian limestone of Mesozoic (secondary era).

Algeria is divided from north to south into four zones (Fig. 1a) [2,22]:

- The Tellian Atlas (or the Tell) is made up of the northernmost steep relief flanked by rich coastal plains such as the Mitidja in the center, the Chlef to the west and the Seybouse plains in the east.
- The high plateaus.
- The Saharan Atlas as a succession of NE-SW oriented reliefs spreading from the Moroccan border to Tunisia.
- The Sahara desert, south of the Saharan Atlas, yields most of Algeria's hydrocarbon resources. The desert is composed of large sand dunes (East and West Erg) and gravel plains (regs) with dispersed oases such as El-Oued, Ghardaia and Djanet.

The geological history of the sedimentary basins (Fig. 1b) is part of the global geodynamic process of plate tectonics, which contributed to the division of Algeria into two distinct domains:

- Alpine Algeria in the north.
- The Saharan platform in the south.

The Saharan Atlas was formed from an elongated pinched trough between the high plateaus and the Saharan platform.

During the Mesozoic times, the trough was filled-in by thick (7000–9000 m) sedimentary deposits. Later, the tertiary compressive tectonic stresses modified the former extension trough into a number of reverse structures, which led to the reaction of the mountain range. The main target of this area is the Jurassic [2]. The sedimentary sequences of the Central Saharan Atlas consist essentially of Mesozoic formations was deposited originally in a subsiding furrow. The mesozoic formations can be divided into four main sets:

- Inferior Jurassic, with the gyspo-saline clays, accompanied by volcanic rocks assigned to the Triassic, it should be noted the existence of Cenozoic and Quaternary.
- Superior Jurassic characterized by an alternation of limestone, sandstone and marl-limestone, a top oolitic carbonate series with a few layers of sandstone, marls and clays.
- Lower Cretaceous, known by the powerful detrital series of sandstone-clay with the carbonate pasts, Barremian–Aptian–Albian. These series occupy large areas of depression between anticlines and synclines.
- The Upper Cretaceous, are clays at gypsum and dolomtic benches (Cenomanian–Turonian–Senonian), they constitute the perched synclines (Fig. 2) [23,24].

The Cenomanian includes a first term clay-gypsiferous with some carbonate or anhydrite intercalations, surmounted by a