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Influence of Metakaolin on the Performance of Mortars and Concretes

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***Abstract*—**The use of additions in cement in manufacturing, mortar and concrete offers economic and ecological advantages. Cements with additions such as limestone, slag and natural pouzzolana are produced in cement factories in Algeria. Several studies analyzed the effect of these additions on the physical and mechanical properties as well as the durability of concrete. However, few studies were conducted on the effect of local metakaolin on mechanical properties and durability of concrete. The main purpose of this paper is to analyze the performance of mortar and concrete with local metakaolin. The preparation of the metakaolin was carried out by calcination of kaolin at a temperature of 850 °C for a period of 3 hours. The experimental results have shown that the rates of substitutions of 10 and 15% metakaolin increases the compressive strength and flexural strength at both early age and long term. The durability and the permeability were also improved by reducing the coefficient of sorptivity.

***Keywords*—**Metakaolin, calcination, compressive strength, durability.

I. Introduction

THE impact of Portland cement on the environment is of concern, as the manufacture of cement is responsible for about 2.5% of total global emissions from industrial sources [1]. An effective way to reduce the impact on the environment is to use supplementary cementitious materials (SCM) as a partial substitute for cement. This strategy has the potential to reduce costs, save energy and reduce waste volumes. Metakaolin (MK), produced by controlled thermal treatment of kaolin, is also one of the mineral additions in cement and concrete. The use of MK for mortar and concrete has received considerable attention in recent years due to its high pozzolanic reactivity [1].

This study proposes to analyze the mechanical strength as well as the durability by means of capillary absorption test, water permeability and gas permeability of concrete made with a local metakaolin.

II. Experiments and Methods

A. Materials Used

The cement used in this study is CEMI 42.5 type. Kaolin was originated from the region of Chlef (Algeria), the sand is siliceous sand from Baghlia River and the gravel is a crushed stone from a quarry in the region of Setif. To get a constant workability of mortar and concrete, a superplasticizer called MEDAFLOW 30 and manufactured by the company Granitex was added. Table I summarizes the chemical composition of the cement and metakaolin used whereas Tables II and III summarized the sand and gravel properties.

TABLE I
Chemical Composition of the Cement and Metakaolin Used

Chemical analysis (%)	Cement	MK
SiO_2	21.06	50.08
CaO	63.4	0.08
MgO	1.85	0.41
Al_2O_3	3.6	34.03
Fe_2O_3	4.47	1.62
SO_3	2.0	0.2
K_2O	0.57	2.79
Na_2O	0.13	0.09
Loss of Ignition	2.53	2.53
Specific density	3.05	--
Fineness (m²/kg)	300	--

TABLE II
Characteristics of Sand

ρ_{abs} (kg/m^3)	Absorption coefficient (%)	Humidity (%)	Fineness Modulus	Sand equivalent
2560	1.10	1.67	3.32	83

TABLE III
Characteristics of Gravel

Granular class (mm)	Specific gravity	Density (kg/m^3)	Absorption coefficient (%)	Moisture (%)
3/8	2.715	1465	0.50	0.13
8/15	2.715	1475	0.50	0.30

III. Results and Analyses

A. Effect of MK on the Workability of Mortar

Fig. 1 shows the effect of MK on the demand for superplasticizer for a constant workability for different percentages of cement substitution with MK. We note that the dosage of superplasticizer increases with increasing MK content. This is probably due to the greater fineness of the MK compared to that of cement.

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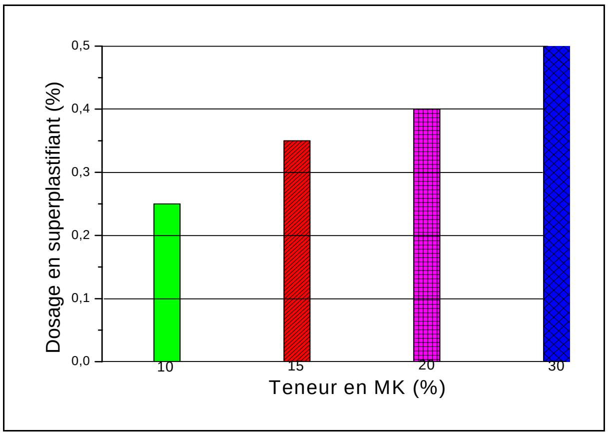

Fig. 1 Effect of MK content on superplasticizer demand

B. Effect of MK on the Compressive Strength of Mortar

Fig. 2 shows that MK plays a positive role in the development of compressive strength but it remains less than the strength of the reference mortar for 10, 20, and 30% of substitution of cement by MK. We note that 15¨% of MK gives a mortar of a compressive strength that is lower than the one for cement without MK up to 28 days after which the pozzolanic effect of metakaolin improves the strength of the mortar which reaches and exceeds the strength of the reference mortar.

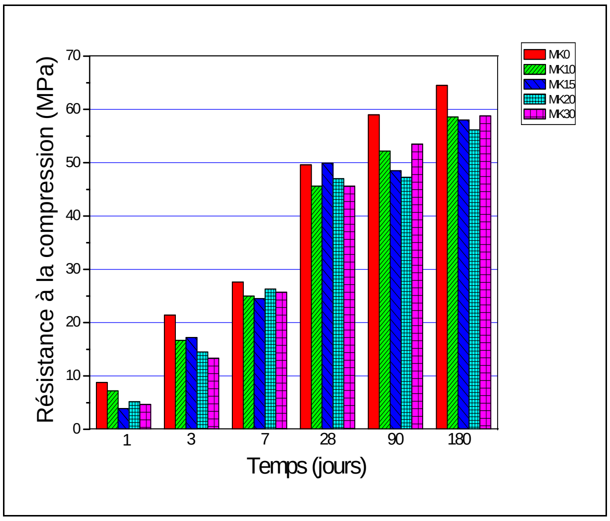

Fig. 2 Development of the compressive strength of mortars with time

C. Effect of MK on the Flexural Strength of Mortar

Fig. 3 shows that MK plays a very positive role in the development of flexural strength for mortars incorporating 10, 20, and 30 % cement substitution by metakaolin especially for MK20 which develops a strength of 120 % compared to the long term reference mortar. Mixed to the cement, metakaolin has a pozzolanic effect. The pozzolanic reaction leads to a densification of the cementitious matrix [2].

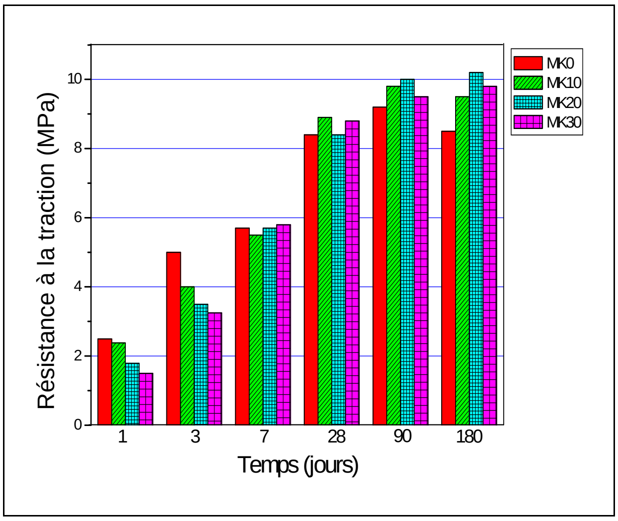

Fig. 3 Development of the flexural strength of mortar with time

D. Effect of MK on the Workability of Concrete

Fig. 4 shows that of the need for superplasticizer increases with increasing MK content to compensate for the loss of workability of concrete.

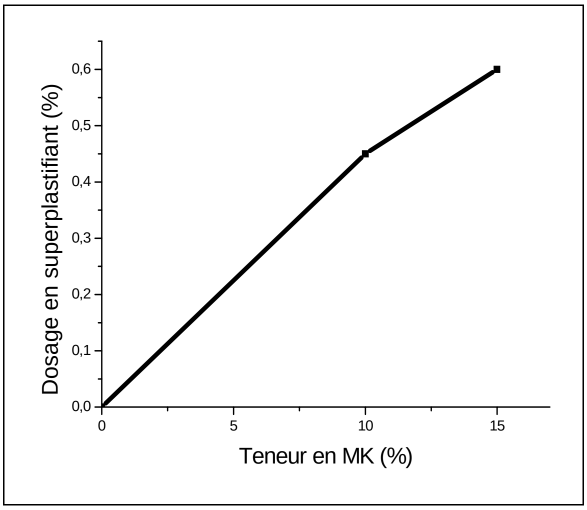

Fig. 4 Effect of MK content on demand for superplasticizer

E. Effect of MK on the Compressive Strength of Concrete

MK plays an important role in increasing the compressive strength of concrete (Fig. 5), especially at 10% of MK where a compressive strength of 41.5 MPa at 60 days is achieved compared to 34.50 for concrete mix without Mk (MK0).

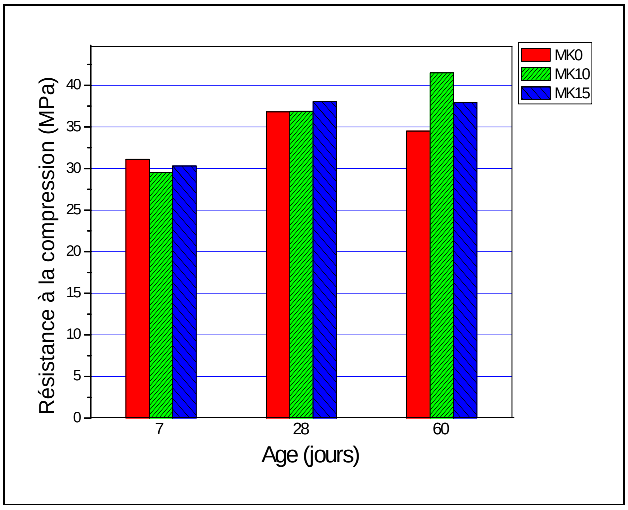

Fig. 5 Development of compressive strength of concrete with time

Three basic factors affect the contribution of MK to the compressive strength of concrete when it partially replaces cement in concrete. These are the filler effect, accelerating the hydration of CEM I and the pozzolanic reaction of MK with CH. The effect of filler results in a more efficient packaging of the paste is immediate, the acceleration of the hydration of CEM I has maximum impact within the first 24 hours and the pozzolanic reaction provides the largest contribution to the compressive strength between 7 and 14 days [3].

F. Effect of MK on Water Absorption by Capillarity

Fig. 6 shows that the water absorption decreases with increasing the dosage of metakaolin. This means that the incorporation of metakaolin has a very positive effect on the absorption of water. It may also be noted that the capillary absorption coefficient decreases with the increase in the percentage of metakaolin. Concrete mixes with 10 and 15% of MK reduce the absorption coefficient with respect to reference concrete respectively by 25 and 30 %. The incorporation of metakaolin reduces the sorptivity as seen in Fig. 6. Ramezanianpour et al. [4] found that the increase of the content of MK reduces the water absorption of concrete. This reduction in absorption was explained by the finer pore structure.

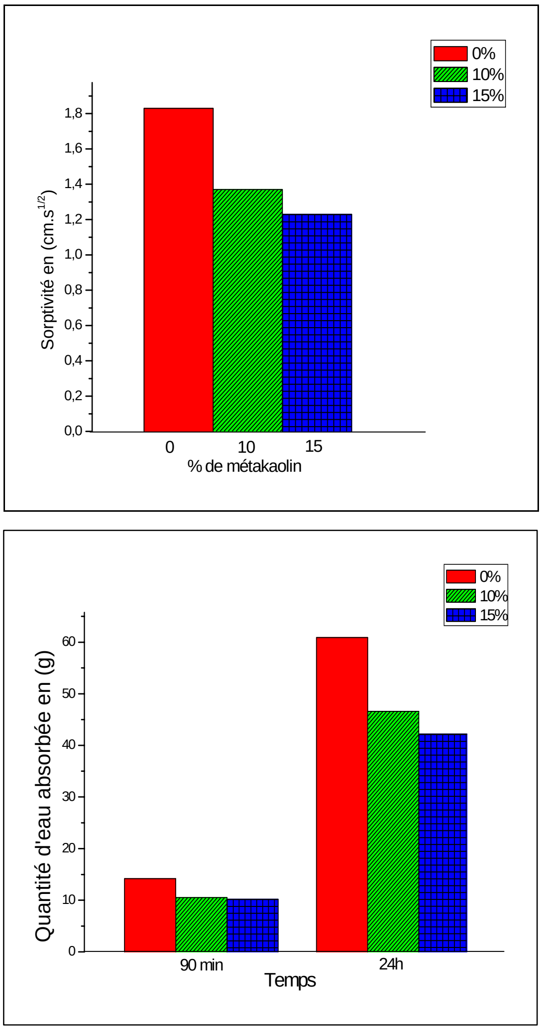

Fig. 6 Effect of MK on the absorption of water by capillarity and the concrete sorptivity

G. Effect of MK on the Penetration of Water

One of the main factors of the durability of concrete is permeability. Concrete with lower permeability provides better resistance against chemical attack, because when water penetrates concrete along with soluble salts it causes corrosion of steel [5]. We note from Figs. 7 and 8 that the incorporation of metakaolin has a very positive effect on the permeability of water under pressure. Mixes with 10% MK have the best results with a decrease of water permeability of about 25%. However, the mix with 15% MK decreases the permeability by about 15%.

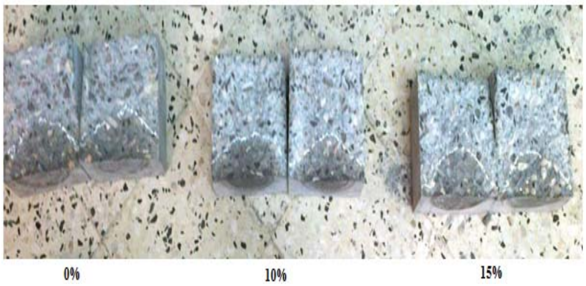

Fig. 7 Depth of penetration of water

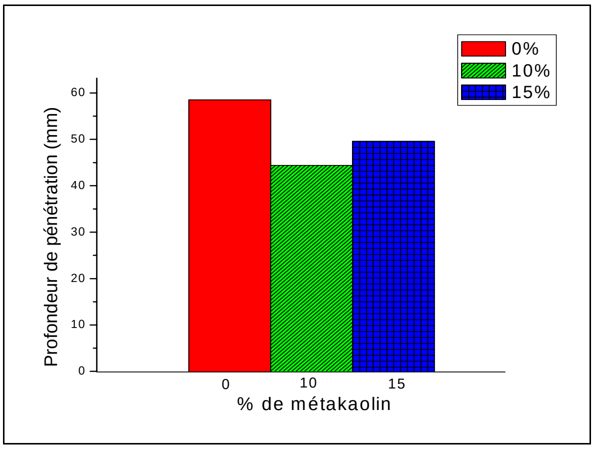

Fig. 8 Effect of metakaolin on the depth of water penetration

H. Effect of MK on Gas Permeability

Fig. 9 show that metakaolin plays a less important role in the permeability to gas. The higher is the level of cement substitution by MK, the higher the coefficient of gas permeability. The values of the measured coefficients of gas permeability are respectively 3.27 × 10 17 m², 4.37 x10-17m ² and 17m ²-x10 6.80 for MK0, MK10 and MK15.

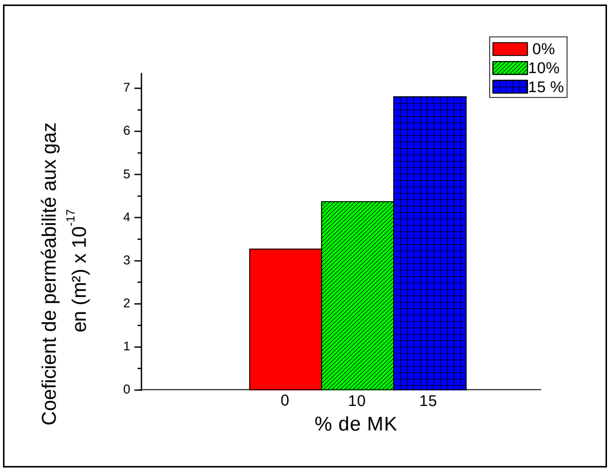

Fig. 9 Effect of metakaolin on gas permeability

IV. Conclusion

The importance of incorporating metakaolin in concrete and mortar was demonstrated. Concrete and mortar suffer a loss of workability due to the incorporation of metakaolin hence the need to add a superlasticizer. Compressive and flexural strengths were improved both at 7 days of age and at long term. All durability parameters were improved after the incorporation of 10 and 15% metakaolin except gas permeability.

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