THE EFFECT OF METAKAOLIN ON CONCRETE PROPERTIES

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ABSTRACT. In this paper the effect of metakaolin addition on the concrete properties is investigated. Metakaolin, produced by controlled thermal treatment of kaolin, can be used as a concrete constituent, since it has pozzolanic properties. A poor Greek kaolin has been thermally treated at defined conditions and the produced metakaolin (MK) had been superfine ground. In addition, a commercial metakaolin (MKC) of high purity has been used. Five mixture proportions were used to produce high performance concrete, where metakaolin replaced an amount of the cement. The properties of the fresh concrete, the strength development and some properties concerning the concrete durability - chloride permeability, air permeability, sorptivity and porosity – have been studied. It is concluded that the produced metakaolin as well as the commercial one indicate a similar behavior concerning the strength development and the durability and lead to concrete production with an excellent performance.

Keywords: Concrete, Metakaolin, Strength, Chloride permeability, Gas permeability, Sorptivity, Porosity.

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INTRODUCTION

The most common cementitious materials that are used as concrete constituents are Fly Ash, GGBS and Silica Fume. They save energy, conserve resources and have many technical benefits [1]. Metakaolin, produced by controlled thermal treatment of kaolin, can be used as a concrete constituent, since it has pozzolanic properties [2-3].

According to the literature, the research work on metakaolin is focused on two main areas. The first one is the effect of the kaolin structure on the kaolinite to metakaolinite conversion and the use of thermoanalytical methods for the investigation of kaolin thermal treatment [4-12], while the second one concerns the pozzolanic behaviour of metakaolinite and its effect on concrete properties [2-3, 13-27]. Although there is a disagreement in many partial topics, the knowledge level is satisfactory and continuously extended.

The concrete performance depends mainly on the environmental conditions, the microstructure and the chemistry of the concrete. The two latter factors are strongly affected by the concrete components. It is obvious that the metakaolin presence affects the concrete performance. The present work deals with the effect of metakaolin on concrete properties and more specifically the comparison of a produced metakaolin to a commercial one is investigated. This work belongs to a research project aiming at the exploitation of Greek kaolins in concrete technology

EXPERIMENTAL

Materials

The chemical analysis of Ordinary Portland Cement (OPC: I/55) and characteristics of clinker are given in Table 1.

A poor Greek kaolin (K) has been thermally treated at 650°C for 3h and the produced metakaolin (MK) was ground to the appropriate fineness (20% residue at 13.6 micron). In addition, a commercial metakaolin (MKC) of high purity has been used. The chemical analyses of kaolins are given in Table 2, their mineralogical analysis in Table 3 and the fineness characteristics of the ground metakaolins in Table 4.

Table 1 Chemical analysis of OPC and characteristics of clinker

Cement		Clinker	
Chemical analysis (%)		Mineralogical composition (%)	
SiO_2	21.54	C_3S	65.6
Al_2O_3	4.83	C_2S	6.2
Fe_2O_3	3.89	C_3A	12.3
CaO	65.67	C_4AF	11.8
MgO	1.71	Moduli	
K_2O	0.60	LSF	0.949
Na_2O	0.07	SR	2.47
SO_3	2.74	AR	1.24
Cl^-	0.00	HM	2.17

Table 2 Chemical analysis of kaolins (%)

	SiO_2	Al_2O_3	CaO	MgO	Fe_2O_3	L.O.I.	SO_3
K	65.92	22.56	0.36	0.02	0.90	8.60	2.00
KC	47.85	38.20	0.03	0.04	1.29	12.30	0.00

Table 3 Mineralogical analysis of kaolins

	Kaolinite	Alunite	SiO_2	Illite
K	52	5	41	-
KC	96	-	-	3

Table 4. Metakolin fineness characteristics

	d_{20} (μm)	d_{50}(μm)	d_{80}(μm)
MK	13.6	7.5	3.4
MKC	10.3	5.1	1.9

Concrete Production and Properties

The concrete production was carried out in a mixer of 50l capacity. The mixture proportions of all concrete specimens are summarized in Table 5. Normal graded calcareous aggregates with maximum size 31.5 mm were used. A common superplasticizer was used at appropriate percentages in order to retain the slump of the fresh concrete between 50-90 mm (class S2 of EN 206). The dry materials were mixed for 2 min. Then the water was added, containing the plasticizer and the mixing was continued for a further 2 min.

Table 5 Concrete mix proportions

Sample	Content (Kg/m^3)					Superpl. (%)	W/C	W/B
	C	MKC	MK	Aggregates	W			
OPC	350	-	-	Fine: 720 Medium: 400 Coarse: 800	175	0.057	0.50	0.50
MKC-10	315	35	-			0.140	0.56	
MKC-20	280	70	-			0.170	0.63	
MK-10	315	-	35			0.181	0.56	
MK-20	280	-	70			0.400	0.63	

The slump (ASTM C 143-90a), the density (BS 1881-103/1993) and the air content (ASTM C 138-92) of the fresh concrete were tested. Concerning the hardened concrete, the compressive strength after 2, 7, 28 and 90 days (ASTM C 39) was measured.

The specimens for the durability tests were cast in steel cylinders of 100 mm diameter and 200 mm height. The molds were stripped after 24 h and the specimens placed under lime-saturated water at 20°C for 90 days. This long-term curing period under water ensures an advanced degree of both Portland cement hydration and pozzolanic activity.

The AASHTO T277 rapid test method was followed to rank the chloride penetration resistance of concrete by applying a potential of 60 V DC and measuring the charge passed through the specimen. The tested concrete cores were slices 51 mm thick, cut from the middle of the initially 200 mm specimens and coated with watertight tape on the cylindrical surface.

The air permeability tests were applied to a concrete cylinder of 100mm diameter and height varied between 45mm and 50mm. The samples were oven-dried at 105^{o}C, until a weight change of less than 0.1% over 24h is observed [28]. The drying period of these specimens was 4-6 days. A modified commercial triaxial cell for 100mm diameter samples, operating to maximum cell pressure of 1.7 N/mm^2, was used for the determination of the gas (N_2) permeability of the specimens. The used equipment as well as the detailed procedure is described in a previous work [29].

The sorptivity test was applied to a concrete cylinder of 100mm diameter and 125mm height, oven-dried at 105^{o}C for 24h. The used equipment as well as the detailed procedure is described in a previous work [29].

The concrete pore structure was studied using mercury intrusion porosimetry. More specifically, the porosity of the specimen as well as its pore size distribution were measured with a Carlo Erba 2000 Hg porosimeter.

RESULTS AND DISCUSSION

Table 6 presents the properties of the fresh concrete. The slump of the mixes was in the range 50-95 mm (class S2 of EN 206) with the appropriate use of superplasticizers (Table 5). The density of the fresh concrete varies from 2427 to 2453 kg/m^3. The concrete is well compacted as it is shown from the air content values.

Table 6 Properties of Fresh concrete

Sample	Slump (mm)	Unit weight (Kg/m^3)	Air content (%)
OPC	70	2453	1.4
MKC-10	95	2434	1.5
MKC-20	60	2440	1.0
MK-10	50	2433	1.5
MK-20	75	2427	1.0

Figure 1 presents the compressive strength of the tested samples. It is generally observed that when metakaolin substitutes cement, higher strengths than the OPC concrete are succeeded. More specifically, it is seen that the metakaolin concrete shows lower 2 days strength (with the exception of MK-10), but it has a very positive effect on the strength after 2 days and specifically at 28 days and 90 days. As far as the metakaolin type is concerned, it is observed that MK has a more considerable effect on strength development than MKC. Concrete with 10% MK showed the best results. The strength increase is attributed to the higher content of calcium silicate hydrate in the metakaolin specimens, due to the reaction of the calcium hydroxide produced from cement hydration with the active silica of the metakaolin.

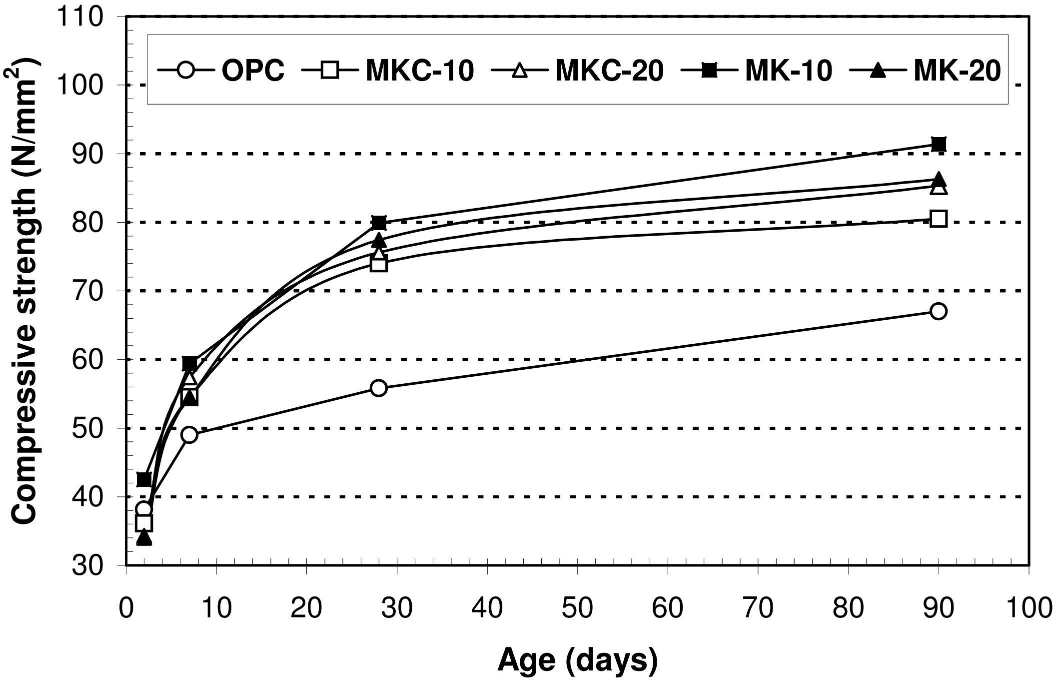

Figure 1 Compressive strength development for metakaolin concrete

Table 7 presents the chloride permeability, the gas permeability, the sorptivity and the mean pore size of the tested specimens. The results given in Table 7 are the average values of three different specimens.

Table 7 Chloride permeability, gas permeability, sorptivity and mean pore size of metakaolin concrete

Sample	Chloride permeability (C)	Gas permeability (m^2 x 10^{-16})	Sorptivity (mm x $min^{0.5}$)	Mean pore size (nm)
OPC	2460	2.94	0.114	96
MKC-10	730	1.68	0.097	70
MKC-20	240	1.45	0.089	55
MK-10	690	1.35	0.080	74
MK-20	760	1.60	0.067	62

The addition of metakaolin causes a significant decrease of concrete chloride permeability. The chloride permeability of metakaolin concrete varies from 240 to 760 C, while the OPC concrete presents a chloride permeability of 2460 C. The concrete with 20% MKC has the lower chloride permeability.

Concrete with metakaolin exhibits lower gas permeability values compared with the OPC concrete. The gas permeability of the metakaolin concrete varies from 1.35 to $1.68 \cdot 10^{-16}$ m^2, while the OPC concrete presents a gas permeability of $2.94 \cdot 10^{-17}$ m^2. The concrete with 10% MK shows the lower gas permeability.

The addition of metakaolin causes a relative decrease of concrete sorptivity. The sorptivity varies from 0.067 to 0.097 $m/min^{0.5}$, while the OPC concrete presents a sorptivity of 0.114 $m/min^{0.5}$. The concrete with 20% MKC has the lower sorptivity.

Concrete with metakaolin exhibits lower gas permeability values compared with the OPC concrete. The mean pore size of the metakaolin concrete varies from 55 to 74 nm, while the OPC concrete has a mean pore size of 96 nm. The concrete with 20% MKC shows the lower mean pore size.

In order to indicate more clearly the contribution of the metakaolin to the concrete properties the ratio (p/p_0) has been used, where p is the value of a specific property of metakaolin concrete and p_0 is the value of the same property in OPC concrete. Therefore, (p/p_0) values less than 1 indicate that metakaolin favors the concrete properties and improves the concrete performance. The (p/p_0) values presented in figure 2, show that the metakaolin addition has a positive effect on all the studied concrete properties. It is also concluded that metakaolin affects in a more considerable way the chloride permeability and the gas permeability of the concrete.

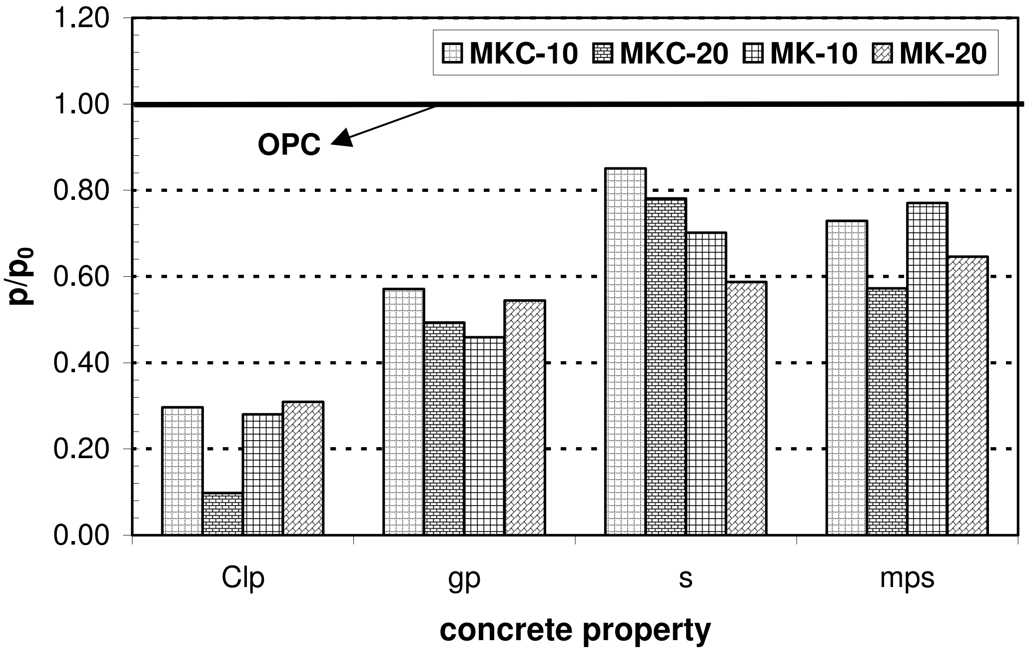

Figure 2 The effect of metakaolin on concrete properties (p: value of a specific property of metakaolin concrete, p_0: value of the same property in OPC concrete, Clp: chloride permeability, gp: gas permeability, S: sorptivity, mps: mean pore size)

CONCLUSIONS

The following conclusions can be drawn from the present study:

- The produced metakaolin as well as the commercial one indicate a similar behavior concerning the strength development and the durability of concrete and lead to concrete production with an excellent performance.

- Metakaolin has a very positive effect on the concrete strength after 2 days and specifically at 28 days and 90 days.

- Metakaolin concrete exhibits significantly lower chloride permeability, gas permeability, sorptivity and pore size compared with OPC concrete.

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