Concrete Beton, Volume 87, pp 16-23, November 1997

Laboratory Trials with Western Cape Metakaolin

Author: J R Mackechnie

Research Officer, University of Cape Town, South Africa

ABSTRACT:

Metakaolin is a highly reactive pozzolan that has been shown to enhance the strength development and durability characteristics of concrete. There is an increasing need for high quality cement extenders in the Western Cape due to the aggressive environment and reactive local aggregates. Extensive kaolinite reserves are located in the Western Cape and could be exploited to produce local metakaolin.

Preliminary laboratory trials were undertaken to assess the potential of local metakaolin together with imported material. Results indicated that the direct replacement of cement with metakaolin improved the strength development and potential durability of concrete. Further trials are still required to assess the viability of marketing metakaolin in South Africa.

Journal Contact Details:
PO Box 75364
Lynnwood Ridge
Pretoria, 0040
South Africa
+27 12 348 5305

admin@concretesociety.co.za
www.concretesociety.co.za

CONCRETE SOCIETY
OF SOUTHERN AFRICA

TECHNICAL PAPER

LABORATORY TRIALS WITH WESTERN CAPE METAKAOLIN

JR MACKECHNIE
Department of Civil Engineering, UCT

James Mackechnie

James Mackechnie was born and went to school in Zimbabwe. He studied at the University of Cape Town were he gained degrees in Civil Engineering (BSc 1985, MSc 1989 and PhD 1996). In between these periods at UCT he worked as a structural engineer in Zimbabwe and South Africa for six years. He is presently employed as a Research Officer in the Department of Civil Engineering at UCT involved in a wide range of concrete research activities. Current research is in the area of cement replacement materials, reinforcement corrosion and durability studies. Activities include contract research for cement companies and specialist material suppliers, consulting investigations of marine concrete structures and ongoing durability research.

SYNOPSIS

Metakaolin is a highly reactive pozzolan that has been shown to enhance the strength development and durability characteristics of concrete. There is an increasing need for high quality cement extenders in the Western Cape due to the aggressive environment and reactive local aggregates. Extensive kaolinite reserves are located in the Western Cape and could be exploited to produce local metakaolin. Preliminary laboratory trials were undertaken to assess the potential of local metakaolin together with an imported material. Results indicated that the direct replacement of cement with metakaolin improved the strength development and potential durability of concrete. Further trials are still required to assess the viability of marketing metakaolin in South Africa.

INTRODUCTION

Metakaolin is a reactive pozzalan produced by thermal activation (or calcining) of the mineral kaolin. The partial replacement of cement (typically 10 - 20 %) with metakaolin reduces calcium hydroxide levels, producing a dense and durable concrete. The pozzolanic reaction of metakaolin is extremely rapid being of a similar rate to that of silica fume and considerably faster than fly ash. Research indicates that metakaolin concrete improves the microstructure since pore sizes are reduced, calcium hydroxide levels are lower and the interfacial zone between cement paste and aggregate is improved[1,2]. These properties have been shown to improve the durability properties of concrete exposed to aggressive environments [2].

In the Western Cape with aggressive environments and reactive aggregates there is increasing need for cement extenders such as silica fume, fly ash and slag to improve the durability of local concretes. At present all of these materials must be transported considerable distances adding to their cost. In contrast many kaolin deposits which produce high quality kaolinite are located in the Western Cape region. The potential of using this material as a cement extender has been considered for several years with promising results being found many years ago [3].

With the increasing demand for a high quality, rapid acting cement extender, further testing of a local metakaolin was undertaken and compared to results with an imported metakaolin from the United States.

MATERIALS

A series of concrete mixes was cast using a local metakaolin produced from Serina kaolin (denoted MKS) and an imported metakaolin, Metamax (denoted MKM). The local metakaolin was produced in the laboratory by calcining a processed kaolin from Serina Mine, Noordhoek. From recommendations made in previous work, calcining was done at 700 °C for two hours, being the optimal level to ensure satisfactory dehydration while minimizing negative side-effects such as ettringite formation [3]. The calcined material was then crushed, pulverized and ball-milled for 24 hours to achieve a fineness superior to that of normal cement (chemical analysis and fineness are given in Table 1). Cement used in the work was a type II/A-L (portland composite cement - PCC containing limestone) with 20 % replacement levels of cement with metakaolin (direct replacement with cement). Two grades of concrete were designed with target strengths of 20 MPa for low grade concrete and 40 MPa for high grade concrete. Typical Western Cape aggregates were used throughout, namely 19mm greywacke coarse aggregate and Cape Flats dune sand and mixes were designed for a slump of 50mm. Details of the concrete mixes are given in Table 2. Concrete was cast into 100mm cube moulds and compacted for 30 seconds on a vibrating table. After demoulding at 24 hours the samples were either wet cured (in water at 23 °C) or dry cured in an environment controlled room (23 °C and 60 % R.H.).

LABORATORY TESTING

The strength and potential durability of concrete was tested in the laboratory at ages between 7 and 28 days using standard tests for compressive strength and durability index tests. Details of the compressive strength and durability index tests (oxygen permeability, water sorptivity and chloride conductivity) are given below.

Compressive Strength Testing

Standard compressive strength testing was done by crushing 100 mm concrete cubes in an Amsler compression tester in accordance with SABS method 863. Strength development of the concrete was monitored by crushing wet cured concrete cubes at 7, 14 and 28 days. Dry cured concrete was tested only at 28 days.

Oxygen Permeability Testing

Testing for permeability has been widely regarded as a method of defining the degree of durability of concrete. A falling head permeameter, which measures the pressure decay with time as oxygen diffuses through concrete was used[4]. Figure 1 gives details of the apparatus and shows how the oven-dried concrete core samples are sealed into the permeameter using a rubber collar. From the pressure decay curve, the Darcy coefficient of permeability was determined and results expressed in terms of the oxygen permeability index (defined as the negative log of the coefficient of permeability).

Water Sorptivity Testing

Movement of water into concrete is generally associated with wetting and drying action rather than permeation. The dominant mechanism controlling water ingress is therefore absorption caused by capillary action. Sorptivity is defined as the rate of movement of a water front through a porous material under capillary action. Sorptivity testing was done using oven-dried concrete core samples exposed to water on their bottom face and the mass of water absorbed was measured at regular intervals (see figure 2) [4]. From the slope of the line produced when the mass of water absorbed is plotted against the square root of time, the sorptivity of the concrete could be determined.

Chloride Conductivity Testing

The physical resistance of concrete to chloride ingress was assessed using the chloride conductivity test where concrete samples were tested in a two cell conduction rig[5]. The oven-dried concrete core samples were initially vacuum-saturated in a 5M NaCl solution to standardize the pore solution.The concrete samples were then clamped in the two cell conduction rig and a 10 V potential difference applied across the sample (see Figure 3). The chloride conductivity was determined by measuring the current flowing through the concrete under the applied potential difference.

DISCUSSION OF RESULTS

The workability of metakaolin concrete mixes was poorer than equivalent PCC concrete and some allowance (ie. use of superplastericers) needs to be made for this phenomenon as with silica fume concrete. The variable workability of the concrete mixes would have some implications on the hardened properties of the material and should be considered when making comparisons between different concretes. Slumps recorded for the six mixes are shown in Table 2 while a summary of all laboratory results is shown in Table 3. Clear trends are apparent with respect to grade of concrete, curing regime and binder type. These trends are discussed in more detail below where results from each test method are analyzed.

Compressive Strength Results

Control PCC concrete had lower than expected compressive strengths due to the poorer performance of PCC compared with OPC material. The use of metakaolin in concrete resulted in faster strength development that PCC concrete when wet cured. Even dry cured metakaolin concrete was found to have higher 28 day strengths than similar PCC concrete. The negative effect of dry curing was more noticeable on metakaolin concretes compared with PCC concrete. Concrete containing imported metakaolin (MKM) consistently outperformed with strengths on average 48 % better than PCC concrete. A comparison of 28 day compressive strengths is shown in Figure 4.

Oxygen Permeability Results

Results from oxygen permability testing showed consistent trends which would indicate that increasing grade, wet curing and the use of metakaolin reduced the permeability of concrete (see Figure 5). Metakaolin concrete had consistently lower permeability than similar PCC concrete even when dry cured. The imported metakaolin (MKM) consistently out performed the local material (MKS) for both concrete grades and curing regimes. Interestingly the effect of curing was more marked with PCC concrete than metakaolin concrete which suggests that the pozzolanic reaction was rapid and not as significantly affected by drying.

Water Sorptivity Results

Water sorptivity was found to reduce with increasing grade of concrete, wet curing and addition of metakaolin. Metakaolin concrete had consistently lower sorptivity than PCC concrete (roughly 40%

lower when moist cured and over 100% lower when dry cured). The difference in results between the two metakaolin types was not marked but was still consistent (see Figure 6). The results would indicate that metakaolin produces a dense surface layer with low absorption characteristics.

Chloride Conductivity Results

Trends observed in other tests were also apparent, but were more obvious when chloride conductivity results were compared as shown in Figure 7. Chloride conductivity values of metakaolin concrete were extremely low particularly when the concrete was wet cured. Grade 40 wet cured metakaolin concrete had chloride conductivity values of 0.61 and 0.15 mS/cm (for MKS and MKM respectively) which compare favorable with typical results for silica fume concrete (grade 40, 10% CSF produced chloride conductivity of 0.54 mS/cm). From marine exposure trials, chloride conductivity values below 1.00 mS/cm should produce concrete with high chloride resistance (6).

CONCLUSIONS

Results from these limited trials showed that the replacement of 20% cement with metakaolin produced concrete with rapid strength development and good durability potential. The effect of metakaolin on concrete appears to be very similar to that of silica fume and shows tremendous potential. Local metakaolin was less effective than the imported material but was still found to be very effective despite the limited optimization of the laboratory processing. Further development particularly with regard to finer grinding could well enhance the performance of the locally sourced metakaolins and help determine the potential for commercial utilization.

Metakaolin appears to be an extremely useful cement replacement material which could help solve many of the durability problems in the Western Cape. The material has great potential since it promotes rapid strength development and has inherently good durability characteristics. The rapid strength development means that cementitious contents do not need to be increased when using metakaolin and no additional cuing is necessary. The presence of alumina phases in particular, which are almost entirely absent in silica fume, should assist in increasing chloride binding and produce durable concretes for marine applications.

REFERENCES

(1) Calderone, M A, Gruber, KA and Burg, R G. 'High reactivity metakaolin: a new generation mineral admixture', *ACI Concrete International,* Vol 16 No 11, 1994, pp 37-40.

(2) Asbridge, A H, Jones, T R and Osborne, G J. 'High performance metakaolin concrete: results of large scale trials in aggressive environments' *Proc . of Int. Congress - Concrete in the Serivce of Mankind: Radical Concrete Technology,* E and FN Spon, London, 1996, pp 13-24.

(3) Clark, I H and Heckroodt, R O. 'Evaluation of Western Cape clay materials as artificial pozzolans', *Transactions of the Journal of South African Institution of Civil Engineers,* Vol 29 No 7, 1987, pp 347-350

(4) Ballin, Y. 'Curing and the durability of OP C, fly ash, and blast furnace slag concretes', *Materials and Structures,* Vol 26 No 158, 1993, pp 238-244.

(5) Streicher, P E and Alexander, MG. 'A chloride conduction test for concrete', *Cement and Concrete Research,* Vol 25 No 6, 1995, pp 1284-1294.

(6) Mackechnie, J R and Alexander, M G, ' A rational design approach for durable marine concrete structures', *Journal of the South African Institution of Civil Engineers,* Vol 39 No 1, 1997, pp 11-15.

Table 1: Chemical and Physical Analysis of Metakaolin

Compound/ Property	MKS (Serina)	MKM (Metamax)
Al_2O_3	41.0	46.0
SiO_2	55.0	54.0
Fe_2O_3	1.3	0.7
CaO	-	-
MgO	0.4	0.1
K_2O	1.2	0.1
TiO_2	0.5	1.0
P_2O_5	0.2	0.1
SO_3	-	-
Blaine Fineness *(m^2/g)	1.35	2.50

** Estimates based on previous work (UCT & CTL)*

Table 2: Concrete Mix Designs (Standard 1 m^3 Mixes)

Concrete Type	Material/ Property	Grade 20 MPa Concrete	Grade 40 MPa Concrete
PCC Only	Cement	240	360
	Sand	815	740
	Stone	1100	1100
	Water	200	200
	w/c ratio	0.83	0.56
	Slump	25 mm	40 mm
Metakaolin (20% Serina)	Cement	192	288
	MKS	48	72
	Sand	800	725
	Stone	1100	1100
	Water	200	200
	w/c ratio	0.83	0.56
	Slump	15 mm	10 mm
Metakaolin (20% Metamax)	Cement	192	288
	MKM	48	72
	Sand	800	725
	Stone	1100	1100
	Water	200	200
	w/c ratio	0.83	0.56
	Slump	10 mm	5 mm

Table 3: Summary of Laboratory Results for Concrete Types

Test Method	Age days	Cure	20MPa PCC	20MPa MKS	20MPa MKM	40MPa PCC	40MPa MKS	40MPa MKM
Cube f_{cu} (MPa)	7 14 28 28	Wet Wet Wet Dry	13.2 14.6 16.0 17.2	23.0 24.8 28.9 22.5	23.8 28.1 31.5 24.7	27.8 32.9 36.8 32.7	31.7 44.5 48.2 36.2	38.2 50.9 56.2 44.7
Oxygen Perm. Index	28 28	Wet Dry	8.85 8.07	9.22 8.71	9.56 9.18	9.80 8.82	9.90 9.51	10.36 9.80
Sorp-tivity ($mm/hr^{1/2}$)	28 28	Wet Dry	14.2 23.0	8.5 11.8	6.3 9.2	8.9 15.7	6.3 7.2	4.9 6.5
Chlor. Cond. (mS/cm)	28 28	Wet Dry	2.94 4.52	1.24 2.23	0.87 1.20	1.69 2.50	0.61 1.25	0.15 0.54

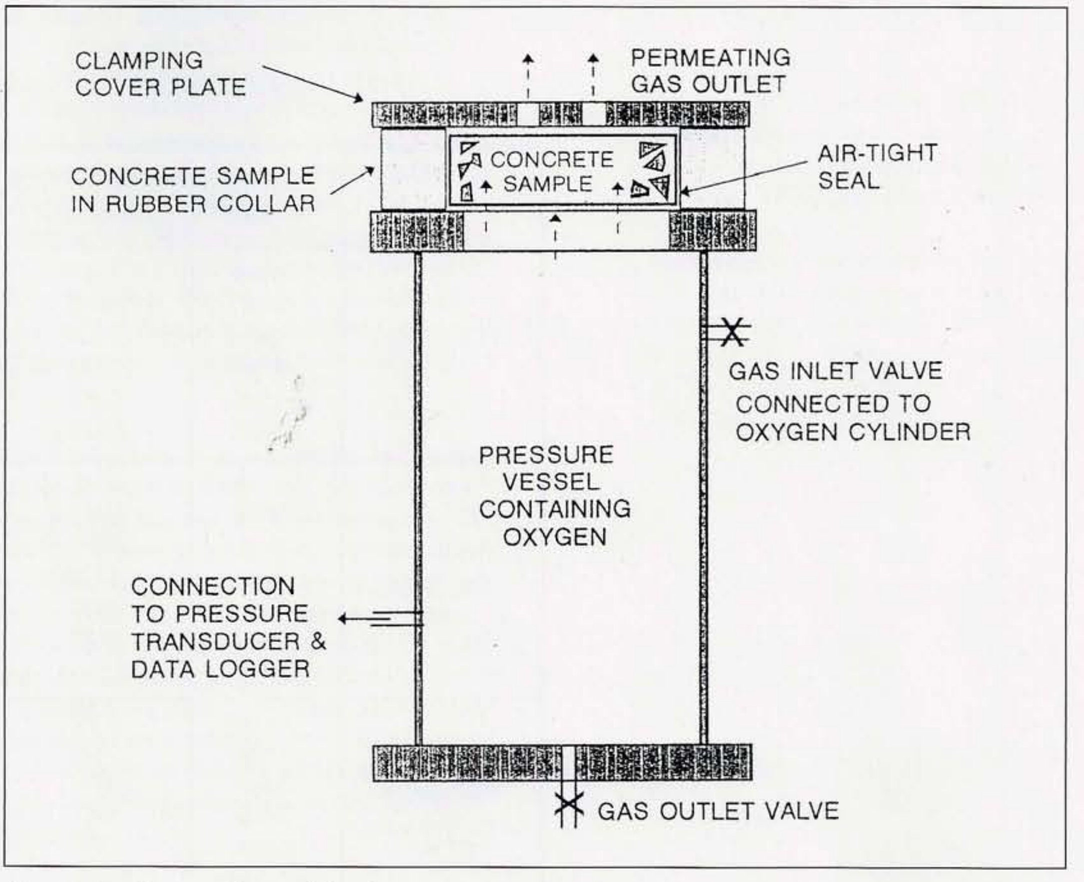

Figure 1: Oxygen Permeability Apparatus

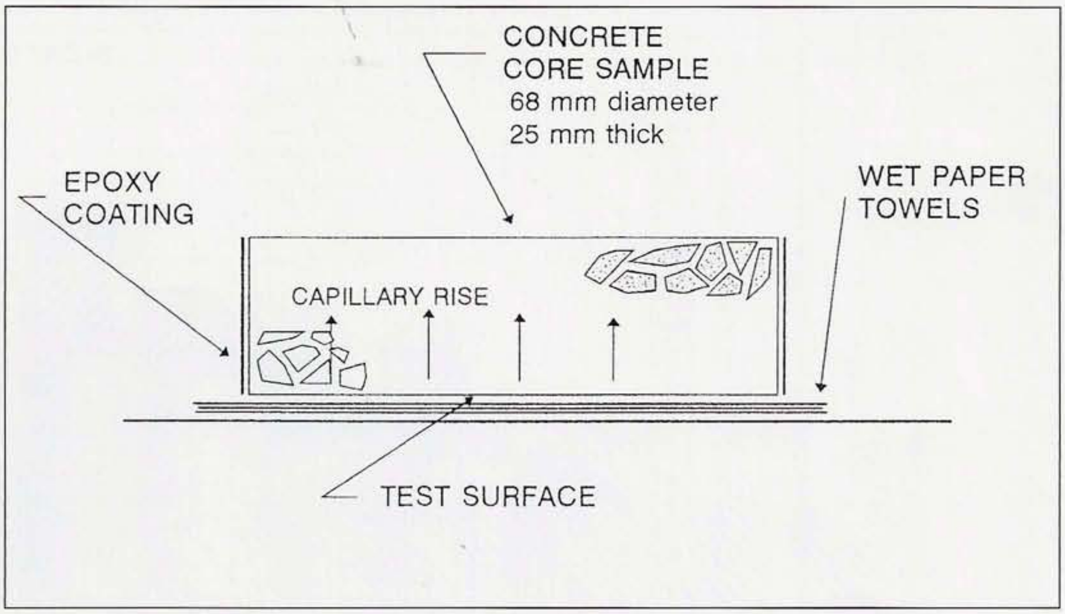

Figure 2: Water Sorptivity Apparatus

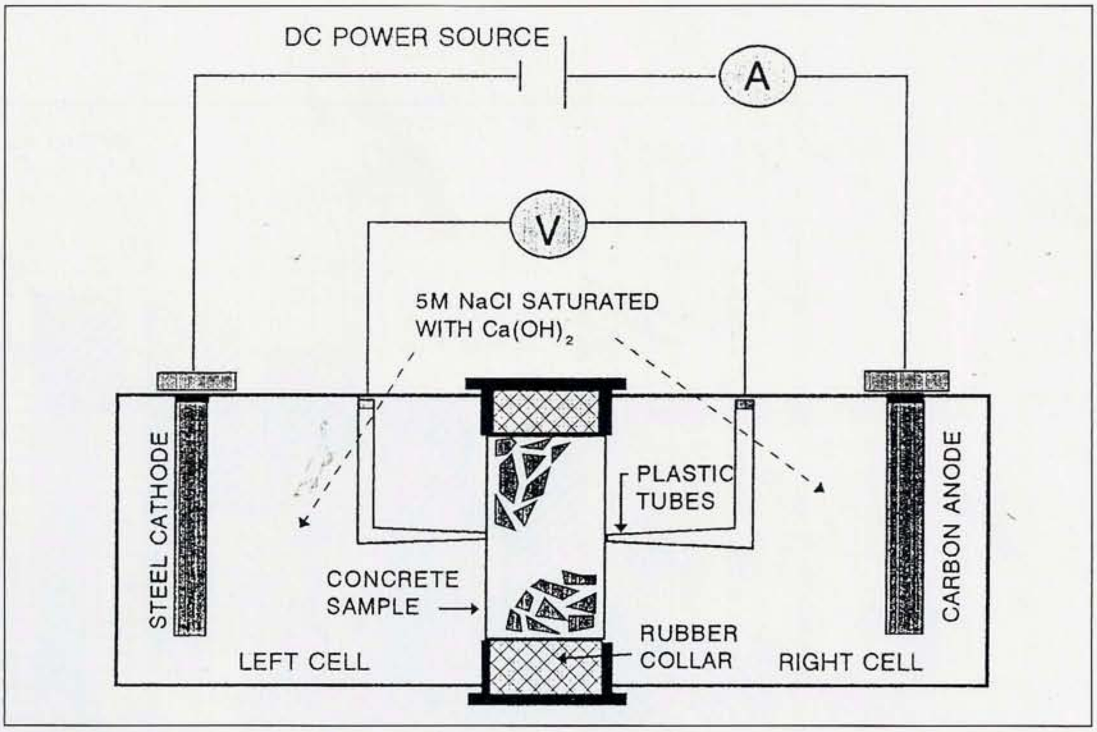

Figure 3: Chloride Conductivity Apparatus

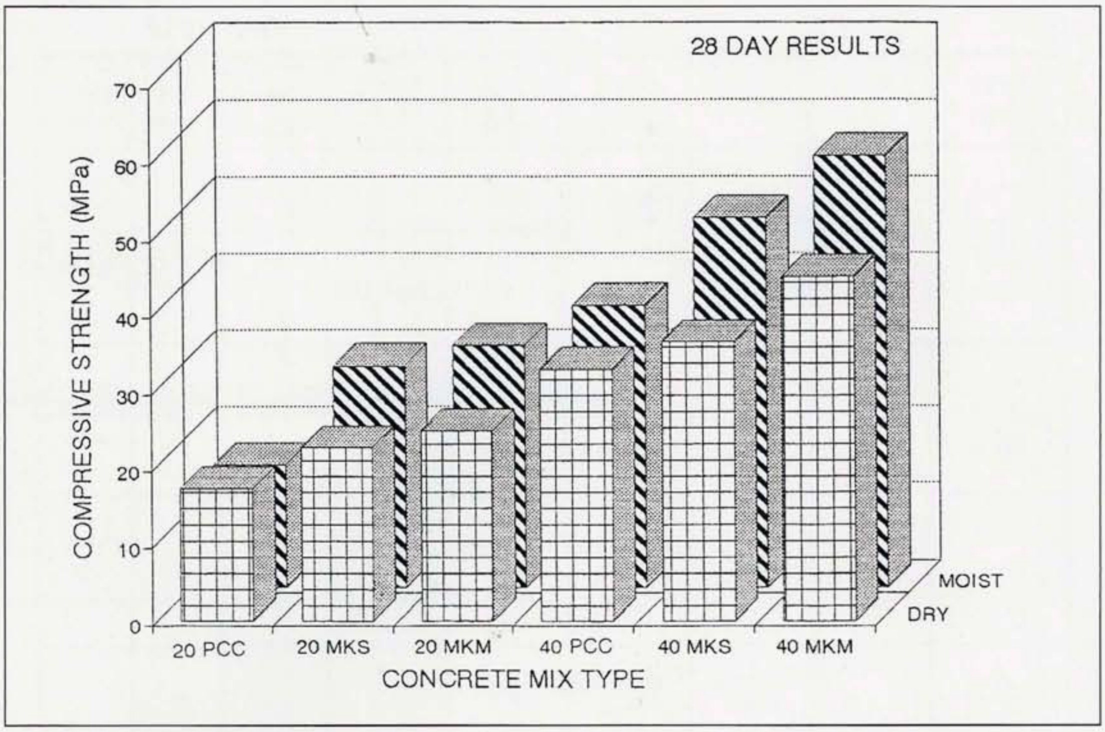

Figure 4: Compressive Strength Results

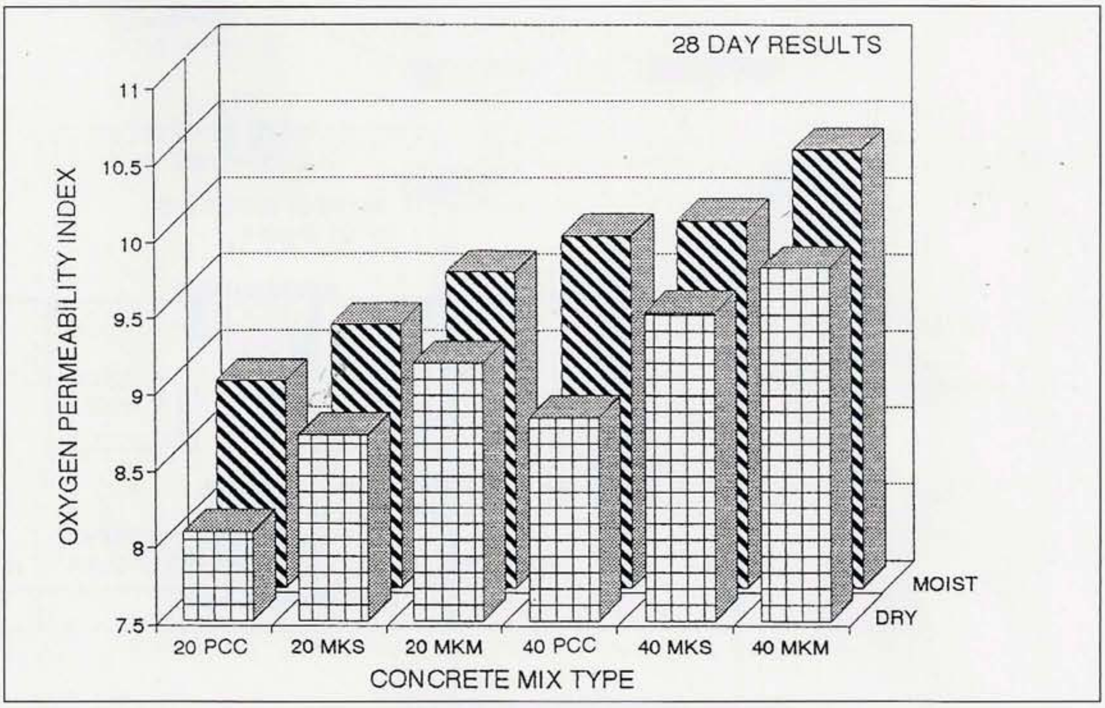

Figure 5: Oxygen Permeability Results

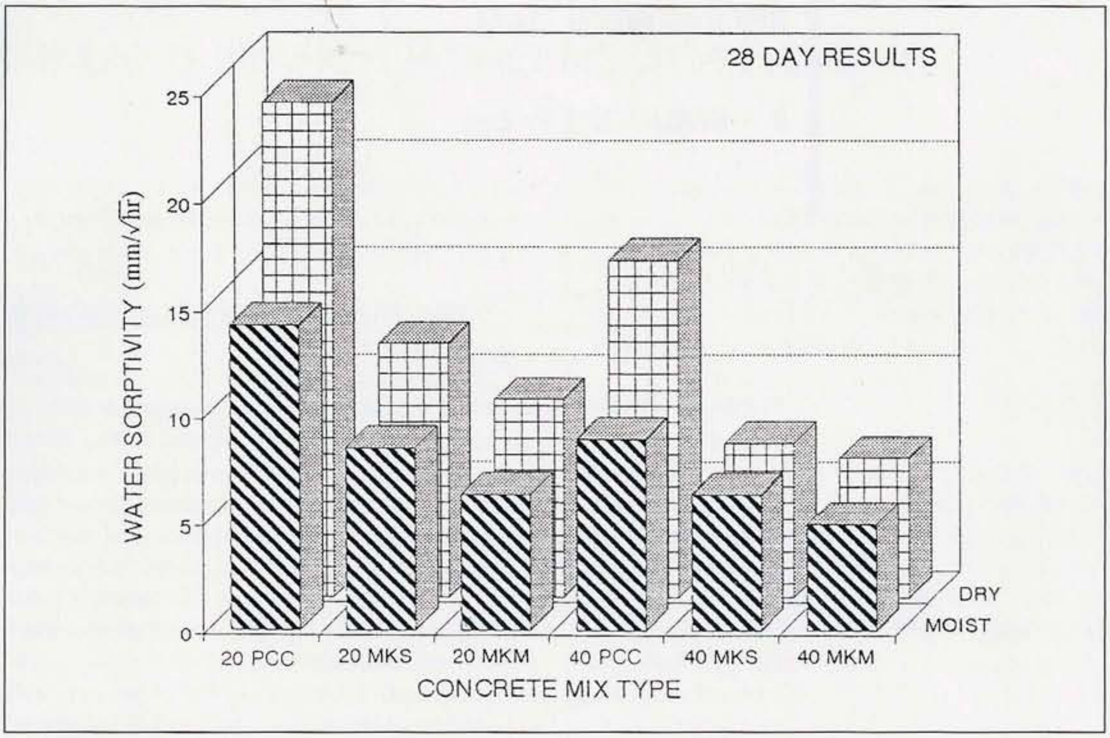

Figure 6: Water Sorptivity Results

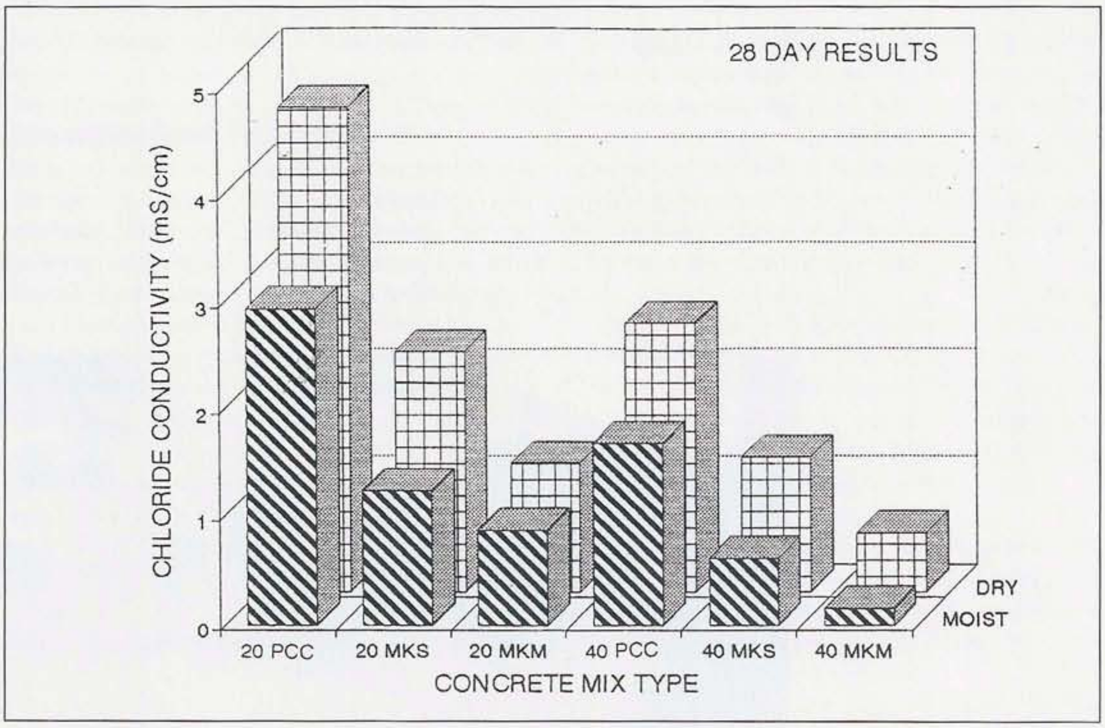

Figure 7: Chloride Conductivity Results