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Effect of surface treatments on abrasion and permeation properties of clay concretes

Fitsum SOLOMON[1] and Stephen EKOLU
Department of Civil Engineering Science, University of Johannesburg, South Africa

Abstract. The resistance of concrete surfaces to various types of wear can be a defining performance characteristic in certain applications. Some concrete structures are required to be abrasion-resistant; among them are dams, canals, roads, floors, footpaths, parking lots, and paths in parks.

The work reported in this paper is based on a laboratory study of the concrete-surface treatments (CSTs) consisting of dry shake and screeding. Four control concrete mixtures were prepared with ordinary Portland cement (OPC), having a cement content (CC) of 350 kg/m^3 at water-cementitious ratio (w/cc) = 0.70, 0.75; and 280 kg/m^3 CC of w/cc = 0.80, 0.85. Other concrete mixtures were then prepared by substituting OPC in the control mixtures with 10, 20, 30, and 40% local raw clay.

Compressive strength, abrasion resistance, and air permeability of the surface-treated concretes were measured at the ages of six months, while drying shrinkage was monitored for up to year. Drying shrinkage of concrete reduced with decrease in w/cc ratio and increased with increase in raw clay content. Among all the mixtures, the control concrete of w/cm ratio = 0.70 and the clay-cement concrete containing w/cm=0.80 at 70% OPC/30% raw clay showed the least and highest shrinkage increments respectively. Abrasion resistance of concrete, measured by the rotating-cutter method, increased with increasing clay content and decreasing compressive strength. However, abrasion performance results of clay-cement concrete mixtures with CSTs were generally higher. Air permeability of the concretes was measured and its relationship with the depth of abrasion of the concrete was examined.

Keywords. Abrasion resistance, drying shrinkage, air permeability, dry shake, screed

Introduction

The use of clay in concrete as partial replacement for cement is not common. In spite of heavy competition from industrial by-products, clays may still be good alternatives as mineral additives or blending for concrete in many places of the world. Incorporation of clay soil into concrete mixtures is one means of designing low-cost, low-strength construction materials. However the influence of clay on material properties should be understood as it affects engineering performance. Previous laboratory experimental work showed that clay-cement mixtures with a maximum of w/cc = 0.80 and 20 to 30% clay replacement can be suited to fulfill the requirement of strength and workability for low-cost, low-strength applications [1].

[1]Corresponding author: Fitsummoa@gmail.com

In clay concretes, it is clear that the presence of more voids reduces the strength of clay concrete compared with ordinary concrete, but in many applications high strength is not essential. Light weight concrete, for example, provides very good thermal insulation and has satisfactory durability but is not highly resistant to abrasion. Researchers on abrasion resistance recommend that concrete can be made more abrasion resistant by several factors among them being surface treatments [2]. In the present work, the tests done include compressive strength, drying shrinkage, abrasion resistance and air permeability.

1. Background

Partial or complete substitution of cementing agents with clay binder can be done in sandy-clay and clay-mortar material. The use of such cementing materials is limited by availability, cost, susceptibility to local climatic conditions, mixing, placing, and densification with the available resources at the site of construction. This leaves large quantities of unutilized local sands usually containing a significant clay fraction exceeding the acceptable limits for use in normal concrete. The increased global use of traditional supplementary cementitous materials is still favoured over other natural resources that may be locally available for use in construction [3]. In general, clay concrete is cheaper than ordinary concrete. Also, direct water permeability tests can be conducted on clay concrete, unlike normal concrete of low w/cc whose permeability can be too low for practical measurement of water permeability. By using selected aggregates and fine mineral additives such as raw clay and concrete surface treatments, the properties of clay-cement concrete can be improved greatly.

Abrasion tests are destructive and will damage the test area permanently. For this reason, attempts have been made to predict non-destructively the abrasion resistance of concrete floors, with contradictory conclusions drawn [4]. There is an accepted view that the permeation properties of the 'cover' concrete are related to quality and hence performance, particularly durability [5]. The establishment of quantitative relationships between the permeation properties and the abrasion resistance of concrete, and how closely this type of durability can be established by means of permeation measurement would be of practical value. The aim of this investigation was to explore this possibility.

At present time, the intial surface absorption test (ISAT) is the best method of predicting the abrasion resistance of concrete non-destructively. Whilst the ISAT is somehow arbitrary, it does have acceptance by practising engineers [6].

2. Experimental`

2.1. Clays

The research started with collection of undisturbed raw soil samples within Gauteng province guided by maps in the areas of Springs (RD) and Soweto (S2M). The soil samples were tested to determine their engineering properties such as Atterberg limits, ASTM soil group classification, Casagrande`s soil classification systems and particle specific gravities. The two types of clays and commercially available bentonite were incorporated into concrete mixtures in various proportions. Soils were not oven-dried since an elevated temperature can permanently alter the properties of the clay. The two raw soil samples were rich in clay content, found to be between 35 to 45%.

2.2. Mixture proportions

Ordinary Portland cement (42,5N grade) was used. Four control concrete mixtures were prepared with ordinary Portland cement (OPC), having a cement content (CC) of 350 kg/m^3 at water-cementitious ratio (w/cc) = 0.70, 0.75; 280 kg/m^3 CC and w/cc = 0.80, 0.85. Further concrete mixtures were prepared by substituting ordinary Portland cement with 10, 20, 30, 40 and 60% raw clay in all control mixtures, as shown in Table 1. The workability of fresh concrete was measured for each mix and compressive strength of the hardened concretes was reported in the previous paper [1]. Further mixtures were prepared for the compressive strength and abrasion resistance testing at ages of six months, drying shrinkage monitoring for up to one year, and air permeability measurement for the selected mixtures and their concrete-surface treatments.

Table 1. Mix proportions of the cement, clay- cement Concretes (kg/m^3) and local stone (19mm) used

Mix	w/cc	Clay (%)	Density (Kg/m^3)	Cement (Kg)	Clay (Kg)	Water (Kg)	Bldg Sand (Kg)	River sand (Kg)	Local stone (Kg)
CM1	0.70	0	2235	350	0	245	380	380	880
CM2	0.75	0	2253	350	0	263	380	380	880
CM3	0.80	0	2144	280	0	224	380	380	880
CM4	0.85	0	2158	280	0	238	380	380	880
RD1	0.70	10	2235	315	35	245	380	380	880
RD2	0.70	20	2235	280	70	245	380	380	880
RD4	0.70	40	2235	210	140	245	380	380	880
RD7	0.75	20	2253	280	70	263	380	380	880
RD9	0.75	40	2253	210	140	263	380	380	880
RD12	0.80	20	2144	224	56	224	380	380	880
RD13	0.80	30	2151	196	84	224	380	380	880
RD14	0.80	40	2158	168	112	224	380	380	880
RD17	0.85	20	2158	224	56	238	380	380	880
RD19	0.85	40	2158	168	112	238	380	380	880
S2M2	0.70	20	2235	280	70	245	380	380	880
S2M4	0.70	40	2235	210	140	245	380	380	880
S2M5	0.70	60	2235	140	210	245	380	380	880
S2M7	0.75	20	2253	280	70	263	380	380	880
S2M9	0.75	40	2253	210	140	263	380	380	880
S2M12	0.80	20	2144	224	56	224	380	380	880
S2M14	0.80	40	2144	168	112	224	380	380	880
S2M17	0.85	20	2158	224	56	238	380	380	880
S2M18	0.85	30	2158	196	84	238	380	380	880
S2M19	0.85	40	2158	168	112	238	380	380	880
*BM 2	0.70	20	2235	280	70	245	380	380	880
BM17	0.85	20	2158	224	56	238	380	380	880

*BM-bentonite mixes.

2.3. Concrete-surface treatments (CSTs) preparation

Two types of surface treatments were applied namely, dry shake and screed. The surface treatments were prepared using OPC 42.5N. The dry shake finish consisted of the cement: crusher sand ratio of 1:2. The screed finish comprised a blend of 4 parts of crusher sand and 1 part building sand; in a mix of 3.5 blended sand and 1 part of cement by mass. Sufficient water was added to achieve a plastic and workable sand mix.

2.4. Specimens preparation and casting

100 mm concrete cubes were cast for compressive strength, 100 mm x 100 mm x 200 mm for drying shrinkage, 60 mm x 120 mm x 380 mm slabs for abrasion resistance. Cores were extracted from the slabs for air permeability testing. For surface abrasion test, core samples were extracted from the slab and surface treatments were applied. The treatments consists of screed surface finish of 15 mm and dry shake surface of 15 mm. This test was done to compare the permeation performance of surface finish treatments relative to plain concrete. Samples were cut and polished before transferring to a 50 ºC ventilated oven to be dried for 7 days before being tested.

2.5. Testing

Tests for compressive strength and drying shrinkage were conducted in accordance with SABS 863: 1976 and SABS 0100: 1992 respectively. Abrasion resistance test was performed as per ASTM C944-99:2005 [7]. The intrinsic air permeability was measured on specimens (cored from the test slabs) by using Blight apparatus [8].

Abrasion test samples were removed after 6 months of water curing then oven dried for 7 days. The abrasion mass loss or depths measurements were made by using a laboratory balance (mass loss) to the nearest 0.01 g or by vernier calliper to the nearest 0.01mm depth of wear, following 2 minutes abrasive wear for plain concretes and 8 minutes for surface finish treatments. A constant 100 N spindle load and 200 rpm speed of rotation were applied in abrasion test.

3. Results and discussion

3.1. Compressive strength

The strength results obtained are shown in Table 2. It was required that the substrate concrete on which the screed or dry shake is to be laid should be hard and strong. Weak, friable concrete is not suitable as the substrate for a screed or topping may fail [9]. For this reason, the surface finishes were applied on the limited samples of CM1, S2M2, CM2, and S2M7.

Table 2. Compressive strength of 6 months samples

Type of concrete	CM1	RD1	S2M2	S2M4	CM2	S2M7	CM3	S2M14	CM4	S2M18
Compressive Strength (MPa)	37.6	30.7	23.6	17.8	33.0	22.8	32.3	15.0	31.0	14.6

3.2. Drying shrinkage

Drying shrinkage can be defined as the volumetric change due to drying of the concrete. Normal concrete usually shrinks between 300 – 600 micro-strains in one year of drying [10] but the cement concrete made from control mixes CM1 to CM4 gave shrinkage of 711, 855, 919, and 1135 micro-strains respectively, as shown in Figures 1 to 4. This drying shrinkage levels were larger, probably due to high water content in the clay-concrete mixes as they contained relatively high fines. This is not necessarily a problem in itself since concrete in compression can with stand up to 2000 micro-strains. So when determining whether this material is suitable for applications of concrete, these shrinkage movements need to be considered. For pre-made concrete blocks, provided the drying shrinkage has already occurred, it is expected that these concrete blocks can be used.

Figures 1 to 4 show that shrinkage of the clay-cement concretes is significantly greater than shrinkage of normal concretes. Clay concrete shrinkage of samples RD13, RD14, RD17, RD19 and S2M19 are extremely high, giving 2015, 2095, 2159, 2328 and 2094 micro-strains respectively, as shown in Figures 3&4. This would lead to unacceptably high tensile strains at the interface with the substrate, with the consequence of potential cracking and adhesion failures.

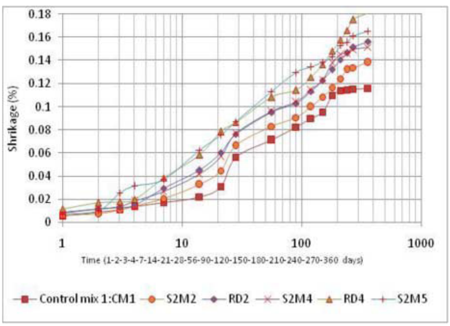

Figure 1. Drying shrinkage of clay concretes of w/cc = 0.70 and cementitious content 350 Kg/m^3.

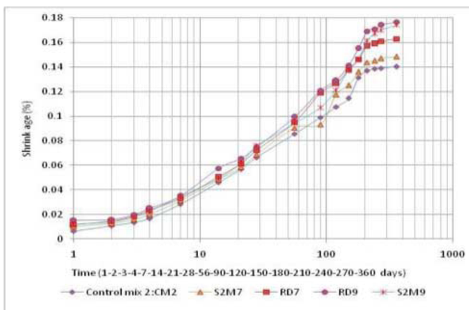

Figure 2. Drying shrinkage of clay concretes of w/cc = 0.75 and cementitious content 350 Kg/m^3.

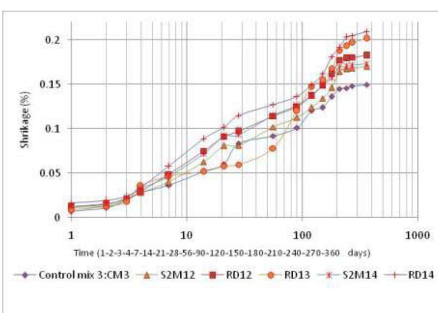

Figure 3. Drying shrinkage of clay concretes of w/cc = 0.80 and cementitious content 280 Kg/m^3.

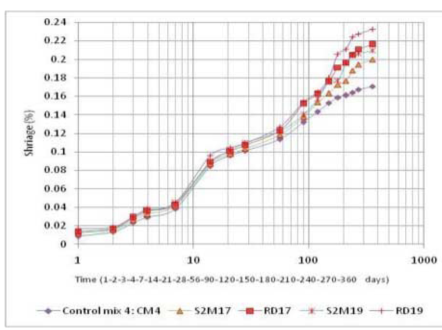

Figure 4. Drying shrinkage of clay concretes of w/cc = 0.85 and cementitious content 280 Kg/m^3.

3.3. Abrasion resistance of normal concretes

The results for abrasion resistance of normal concretes are shown in Table 3 and Figure 5. The abrasion mass loss, wear depth, the rate of mass loss and rate of wear depth is highest for S2M18 (w/cc=0.85 with mass loss 2.2 g (1.14 g/min), 1.11 mm) followed by S2M14. The lowest abrasion value was shown by CM1 (w/cc=0.70 with 0.57 g abrasion loss and 0.46 mm wear depth), followed by CM2, CM3 and CM4.

Table 3. Abrasive mass loss and depth rate of normal (non-treated surface) concretes

Type of concrete	CM1	RD1	S2M2	S2M4	CM2	S2M7	CM3	S2M14	CM4	S2M18
Abrasive mass loss rate (g/min)	0.28	0.33	0.40	0.77	0.30	0.66	0.40	0.95	0.58	1.14
Abrasive depth rate (mm/min)	0.23	0.26	0.35	0.39	0.28	0.39	0.35	0.49	0.40	0.55

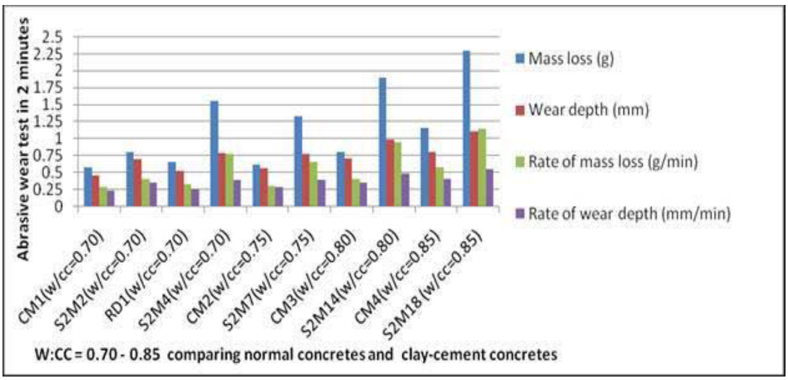

Figure 5. Abrassive wear of depth and mass loss of plain concretes

3.4. Abrasion of treated surface finishes

The results of abrasion (mass loss in g/min and wear depth) of treated surfaces are shown on Table 4 and Figure 6. The highest rate of mass loss and wear depth was given by S2M7 dry shake (DS) and screed (SCR) finish. The lowest rate of mass loss occurred on CM1 dry shake topping which gave 0.05 g/min. The lowest rate of wear depth was exhibited by screed surface finishes CM1, S2M2 screed giving 0.05mm/min.

Table 4. Abrasion of surface treatment finishes

Abrasion 2&8 mins	CM1 NIL	CM1 DS	CM1 SCR	S2M2 NIL	SM2 DS	S2M2 SCR	CM2 NIL	CM2 DS	CM2 SCR	S2M7 NIL	SM7 DS	S2M7 SCR
RML* (g/min)	0.28	0.05	0.11	0.4	0.07	0.11	0.3	0.10	0.13	0.66	0.18	0.15
RWD** (mm/min)	0.23	0.07	0.05	0.35	0.07	0.05	0.28	0.06	0.05	0.39	0.05	0.05

*RML-Rate of mass loss, **RWD= Rate of wear depth. DS= Dry Shake. SCR= Screed

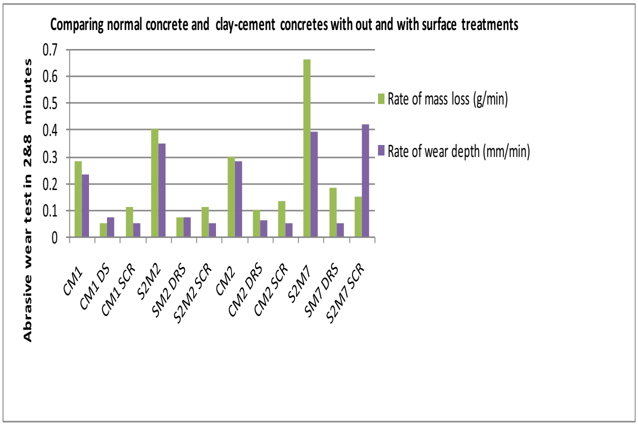

Figure 6. Abrasive wear of on plain and surface-treated concretes

3.5. Intrinsic permeability and relationship with abrasion

The intrinsic permeability was measured on specimens cored from the slabs. Air was used as a flow gas. The intrinsic permeability was obtained using the equation (1) given below. The coefficient of permeability values obtained are shown in Table 5.

The coefficient of permeability (m/s) is calculated using the equation [11]:

$$K = WVg/RA\ (d/(\theta.t))In(Po/P) \quad (1)$$

Where
k = coefficient of permeability (m/s)
W = molecular mass of air = 28.97g/mol
V = volume of air under pressure in permeameter (m^3)
g = acceleration due to gravity ($9.81m/s^2$)
R = Universal gas constant = 8.313 (Nm/kmol)
A = superficial cross-sectional area of sample (m^2)
θ = absolute temperature (K)
t = time (s) for pressure to decrease from Po to P
Po = Pressure at the beginning of test (KPa)
P = Pressure at the end of test

Table 5. Intrinsic permeability (m^2) plain concretes and concrete surface-treatments

Sample	($K*10E\text{-}17m^2$) Plain	($K*10E\text{-}17m^2$) Dry shake	($K*10E\text{-}17m^2$) Screed finish
CM1	21.3	16.2	16.0
S2M2	38.1	28.8	28.5
CM2	23.2	17.6	17.4
S2M7	22.1	16.8	16.5

Figures 7 and 8 show an attempt to relate abrasion mass loss rate and intrinsic permeability. There is a general trend showing a significant linear relationship between the two parameters. The close relationship between the abrasion resistance and intrinsic permeability can be attributed to the fact that both parameters are influenced largely by the quality of surface matrix. The practical implication of these results is that fluid permeability has the potential of being used to non-destructively assess the abrasion resistance of concrete slabs. For testing in situ slabs, an air-drying method can be adopted for pre-conditioning purposes.

It was anticipated that a significant relationship would be found between abrasion resistance and the absolute properties of intrinsic permeability. While there exists a general linear relationship, there is wide data scatter (Figures 7&8) which shows that the correlation between abrasion depth and permeation characteristics may be weak. The reasons for these differences are however not clear.

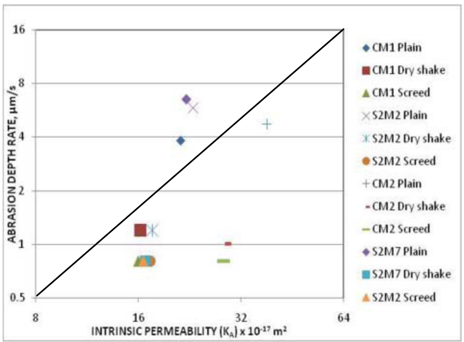

Figure 7. Relationship between abrasion depth rate and permeability.

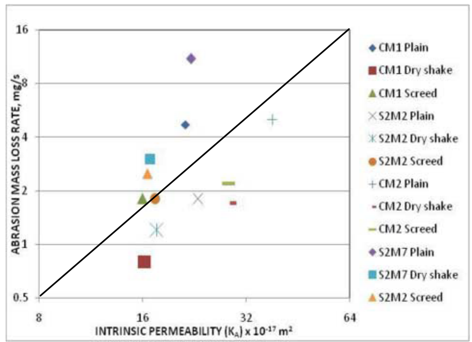

Figure 8. Relationship between abrasion mass loss rate and permeability.

4. Conclusions

The following conclusions are based on the experimental results reported in this paper. Drying shrinkage is greater for clay concretes which contain RD raw clay. In all cases, most of the shrinkage occurs within the first 56/90 days and remains relatively stable beyond that age.

Abrasion resistance was found to be influenced by the water-cement ratio and strength of concrete. The concrete having the highest water-cement ratio showed lower abrasion resistance [1]. The use of concrete surface treatment was found to be effective in offsetting this problem. Concrete surface treatment with dry shake was found to have a reduced abrasion resistance than screed finish. The abrasion resistance of the normal concretes was found be similar to that of surface treated clay-cement concretes. A relationship between intrinsic permeability and abrasion test was found to exist.

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