# STRENGTH BEHAVIOUR OF CLAY-CEMENT CONCRETE AND QUALITY IMPLICATIONS FOR LOW- COST CONSTRUCTION MATERIALS

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**ABSTRACT**: Incorporation of clay soil into concrete mixtures may be one means of designing low- cost, low strength construction materials but its influence on material properties should be understood as it affects engineering performance. This paper argues that the use of concrete for low-cost cementitious building materials has special requirements. A significant demand exists for physical infrastructure in developing countries (DCs), and concrete or mortar blocks of sufficient integrity for low-cost housing, for instance 2 MPa, are often made from cement with clay-contaminated sand by artisanal builders.

The work presented is based on the experimental results of a laboratory study done for clay-cement concrete material. The clay-cement concrete studied was designed to be a low-strength material and its properties fall between those of soil and concrete. Four control concrete mixtures of 350 kg/m$^3$ CC (cementitious content) of w/cc (water – cementitious ratio) = 0.70, 0.75; 280 kg/m$^3$ CC of w/cc = 0.80, 0.85 were prepared. Further mixtures were made by substituting the OPC (ordinary Portland cement) in control mixes with 10, 20, 30, 40, and 60% local raw clay. Compressive strengths were measured at ages of 7, 28, 56, 270, and 365 days for all the mixtures. The laboratory test results show that clay-cement concrete 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 including housing, roads and dams which are current important social and economic issues of concern in DCs. Interestingly, clay-cement concretes gave higher strength performance factors at later ages than the corresponding plain cement concretes, suggesting a possible pozzolanic behavhiour, however minimal. Further investigations are being undertaken to determine the behavior of the clay-cement mixtures through study of drying shrinkage, creep, abrasion resistance, and fluid permeability.

## 1 INTRODUCTION

Building materials are often the single largest component of costs for housing construction in developing countries (DCs); accounting for up to 70% of standard low-cost housing unit (Erguden 2001).

A promising area of investigation for the future is the use of natural mineral deposites. Clays have been used as pozzolanic materials for thousands of years (Cook 1985). Inspite of heavy competition from industrial by-products, clays are still good alternatives as mineral additives or blendings for concrete in many places of the world. Several different clays exist in soils and their characteristics are likely to have an effect on the properties of concretes containing them. The main clays found in tropical regions are Kaolin and montmorillonite. Several sources of natural pozzolans are already used, but generally these are only available in certain localities. Other, minerals, notably Kaolin, can be activated by thermal treatment, but the cost of this process often makes them uncompetitive with the better established supplementary cementitous materials (SCMs). This situation is likely to change in the future as the imperative to reduce $CO_2$ emissions increase (e.g with introduction of carbon emission taxes) and as the source of traditional SCMs become fully utilized (Karen et al. 2007). In practice, the increased global use of traditional SCMs such as fly ash, ground granulated blast-furnace slag and natural pozzolans is limited by several factors, but mainly by transport costs (Damtoft et al. 2007) over relatively long distances (e.g 50Km) and at a considerable expense. Despite these factors, SCM`S are still favoured, although other natural resources may be available nearby that might be suitable for construction (Ferennandes et al., 2007). In the longer term, the price of energy may rise relative to that of the more abundant resources such as human labour or soils, and a far-sighted designer should be attempting to promote the use of resources in the longer term (Spence et al. 1983).

Local sands usually contain a significant clay fraction, unacceptable for use in normal concrete. However, the effects of clay on concrete /mortar performance are not fully understood and specifications restricting their use tend to be vague. Despite clay being considered deleterious in normal concrete production, previous work of experimental evidence to assess the use of clay-cement concrete suitable for constructions has been done (Solomon and Ekolu, 2010, Ljubomir 2005). The present work includes the compressive strength, workability, drying shrinkage and permeability of the material for use in building construction. One advantage of studying this construction material as compared to conventional concrete, is that direct water permeability tests can be conducted unlike conventional concrete of low w:cc ratio whose permeability can be too low for practical measurement of water permeability.

Natural soil binder in a clay-bonded stabilized gravel produces clay concrete. Partial replacement leads to systems that possess properties intermediate between those of clay concrete and a PC concrete. Similarly, partial replacement of the soil binder by asphalt leads to water proofed granular soil stabilization, and complete replacement by bitumen and filler leads to bitumenious concrete. In a like manner, there exist a range of special concretes which include clay concrete, lime concrete, resin concrete, gypsum plaster concrete, and others.

Potentially all conceivable inorganic and organic cementing materials and thier combinations can be used to create concrete products as long as they adhere to or can be made to adhere to the soil mineral and particle surfaces. Partial or complete substitution of clay binder with other cementing agents can be done in sand-clay and clay-mortar systems also. The use of such cementing materials is limited by availablity, cost, susceptibility to local climatic conditions, mixing, placing, and densification with the available resources at the site of construction.

## 2 BACKGROUND

The need for cost effective construction materials is especially apparent in developing world. Strength is one of the main basic properties of hardened concrete. Concrete without adequate strength is of no use. With clay in the mix, the amount of water required for good workability can be considerably higher than that needed for hydration, to a greater extent than in normal concrete of say w:cc =0,60. Therefore, once the concrete is cured and a portion of the water is chemically bound by hydration, a greater remainder of it evaporates, leaving an increased content of voids (capillary porosity) in the hydrate assemblage, reducing the strength of the material (Neville, 1987).

In addition to the cementing reaction, the chemical interaction of cement and clay particles may have an effect on the properties of concrete and may explain why clay-contaminated concretes have different physical properties (Herzog and Mitchell, 1962). Not much research has been undertaken on clay-contaminated sand for use in concrete production, especially in the context of use in low-cost housing. Parsons. 1933 concluded that clay is much more detrimental to the strength of concrete if present as a surface coating surrounding the sand grains, than if evenly distributed throughout the mass. When the clay forms such a surface coating, it is bound only by weak electrostatic forces, which led researchers to suggest that clay particles interfere with the bond between the sand particles and cement paste matrix (Goldbeck 1932, Dolar-Mantuani 1983, Schmitt 1990, Forster 1994). If the bond between either the clay coating and the sand, or the clay and the cement paste, is weaker than the normal cement-sand bond (which is thought likely) then strength and durability problems may result (Forster 1994). However, although many have concluded that clay surface coatings weaken the sand/cement paste bond; there is little experimental evidence that this reduces concrete strength and durability. Moreover, Parsons suggested that if the clay is distributed evenly within the sand, there is no detrimental effect and it might increase the strength of the concrete by filling in the spaces between the larger particles. If both sand and clay could be regarded as chemically inert components, the cement would bind evenly-distributed sand and clay grains together during hardening, forming a roughly continuous matrix of a hard, strong material enclosing particles of sand and clay.

A significant demand exists for housing in Less Economically Developing Countries(LEDCs), where it has been estimated that more than 100 million people are homeless and about one billion people are inadequately housed (Erguden, 2001). Approximately twenty-one million new housing units are required each year (UNHCS, 2004).

## 3 EXPERMENTAL

### *3.1 Clays*

The research started by collecting undisturbed raw soil samples in Gauteng province guided by maps in the areas of Springs (RD) and Soweto (S2). 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 bentonite bought from the market were incorporated into concrete mixtures in various proportions Soils were not oven dried since an elevated temperature can permanently alter the properties of a clay soil. The two raw soil samples are rich in clay content being between 35 to 45%. By defintion, clay is a natural deposit of fine and mainly aluminous products of rock weathering, essentially a product of chemical action. In mechanical analysis, the clay fraction has a grain size less than 0,002 mm equivalent diameter. Generally, clay may contain material of larger grain size, such as silt and sand, provided that the clay fraction as defined above forms no less than 30% of the whole (A.M.I.C.E, 1950).

## 3.2 MIXTURES

Four control concrete mixtures having CC of 350 Kg/m$^3$ and w:cc = 0.70, 0.75; CC of 280 Kg/m$^3$ and w:cc = 0.80, 0.85 were made. Further concrete mixtures were prepared by substituting ordinary portland cement by 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 strengths of the hardened concretes were determined at ages of 7, 28, 56, 270 and 365 days.

Table 1. Mix proportions of the cement & clay- cement Concretes (kg/m3) used

| Mix | W:CC | Clay (%) | Density ( Kg/m3) | Cement | Clay | Water | Bld Sand | River sand | Local stone(19mm) |
|---|---|---|---|---|---|---|---|---|---|
| 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) used at limited high water-binder ratios onlydue to unworkable mixes.

# 4 RESULTS
## 4.1 SOIL TYPES

The soils obtained from Springs/Brakpan and from Soweto were tested and their properties are given Table 2 in terms of Atterberg limits, particle size distribution and soil classification.

According to the international society of soil science, the soils can be classified as:

Soil- I (RD) - Reddish sandy silty clay
Soil- II (S2) - Deep red sandy silty clay

Table 2. Atterberg limits, gradation and soil classification of soil samples

| Soil Samples | Atterberg limits | | | ASTM Soil group classification | Casgrande`s soil classification system | | Particle specific gravity. |
|---|---|---|---|---|---|---|---|
| | PL | LL | PI | | Group Symbol | Soil classification | |
| S2 | 13 | 22 | 9 | A-2-4 | CL ML | Clay&Silt of low compressibility | 2,66 |
| RD | 25 | 37 | 12 | A-6 | CI | Clay of medium compressibility | 2,73 |

S2 – clay soil from Springs; RD – clay soil from Soweto

### 4.2 WORKABILITY

Figures 1 and 2 show the influence of the clays on slump measurements for the mixtures of various w:cc ratios. Interestingly, the RD clay significantly reduces the workability of the concretes with increase in clay content. On the other hand, the S2 clay generally increased the workability of the mixtures as the clay content was increased from 0 to 40%. These opposite effects of the clays may presumably be attributed to the different moisture contents of the soils as well as the differences in their soil structures.

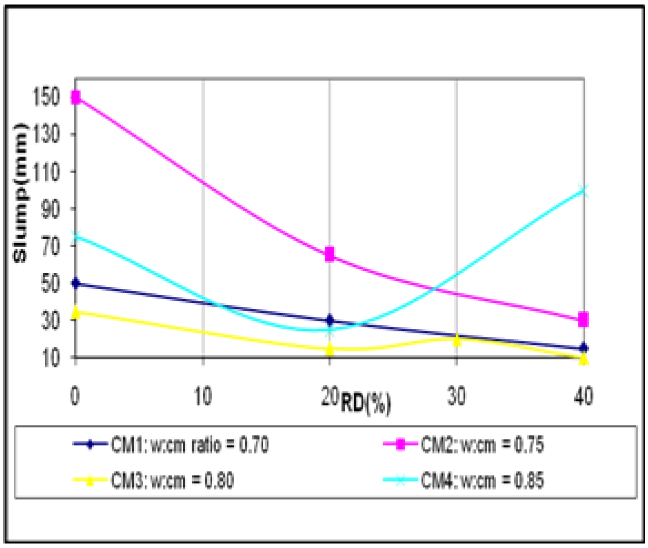


Figure 1: Workability of RD - clay mixes of varied w:cc raios

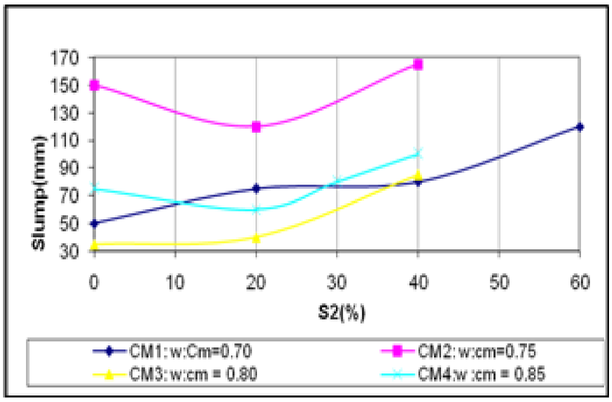


Figure 2: Workability of S2 – clay mixes of varied w:cc ratios

### 4.3 COMPRESSIVE STRENGTH

The strength results of the clay concrete mixtures are summarized in Figures 3-6. It can be seen that in general, mixtures containing clay soils show a reduced rate of strength gain at the early ages relative to the control. At the later ages, the clay concretes show lower compressive strengths in proportion to the clay content incorporated. This implies that the clays affect cement hydration through dilution effect and/or chemical reaction. An investigation of the actual mechanism of the clay effects was not within the scope of this particular study.

It can also be observed in Figures 3 to 5 that at low contents of 20 to 30% clay, the RD and S2 mixtures exhibited similar strength behaviours at both the early and the late ages. However, at the high clay content of 40%, differences in strength behaviours between the two clays emerge, with S2 mixtures showing significantly higher strengths than the corresponding RD mixtures. At low strengths of below 10 MPa, these differences diminish, as shown in Figure 6. While the fundamental parameters responsible for the intrinsic influence of S2 clay on strength are not known at this stage of the investigation, it may be speculated to be associated with the factors that influenced workability positively, as earlier reported.

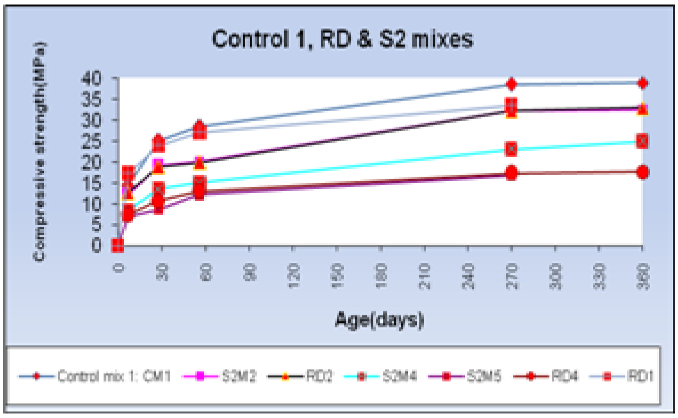


Figure 3: Compressive strength of W:CC = 0,70 and cementitious content 350 Kg/m$^3$

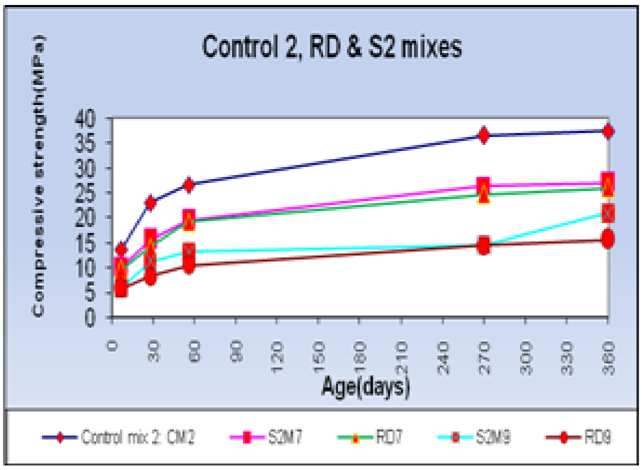


Figure 4: Compressive strength of w:cc = 0,75 and cementitious content 350 Kg/m$^3$

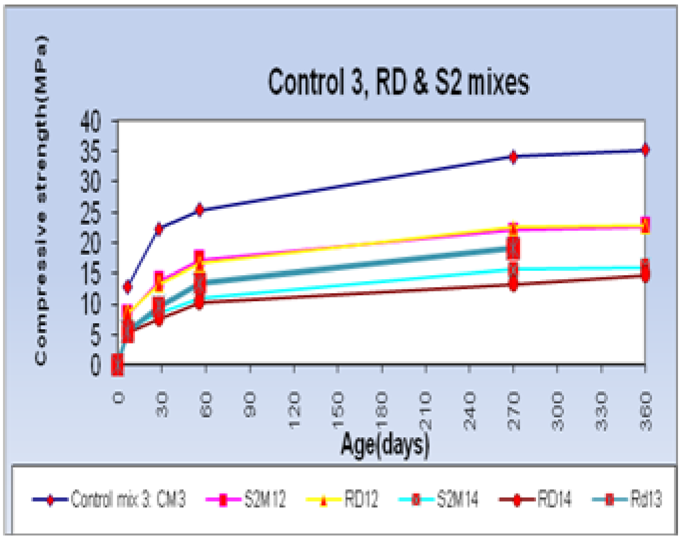


Figure 5: Compressive strength of W:CC = 0,80 and cementitious content 280 Kg/$m^3$

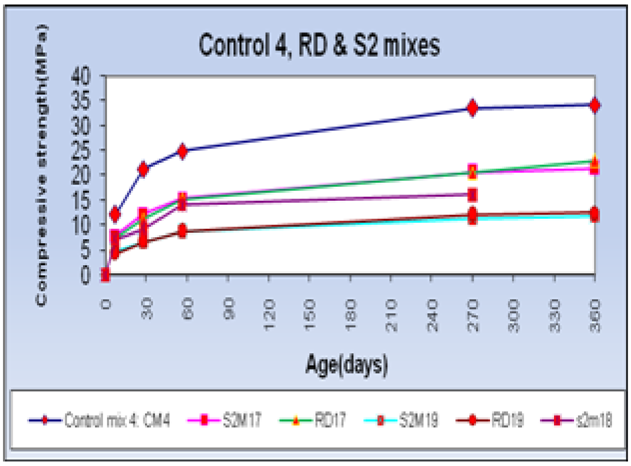


Figure 6: Compressive strength of w: cc =0,85 and cementitious content 280 Kg/$m^3$

## 4.4 GLOBAL ANALYSIS OF WORKABILITY AND STRENGTH CHARACTERISTICS

Global strength was obtained by the addition of the values of strength of all the mixes of the same w:cc and age divided by the number of mixes i.e regardless of the clay content. These globalised values for RD, S2 and CM control mixes have been normalised relative to 28 days result for 7, 28 (i.e. 100% =1), 56, 270 and 360 days. All mixes of CM, RD1 – 2 -4 – 7 - 9 – 12 – 13 – 14 – 17 - 19, and S2M2 – 4 – 7 – 9 -12 -14 -17 – 18 – 19, with or without 10-40 % clay contents were examined in the form of global averages. For example, mixes CM1 to CM4 had 7 days strengths of 14,5, 13,7, 12,9, 12 MPa and their global average would be 13,3 MPa. The 28 days strength of these control mixes are 25,1, 23,0, 22,3 and 21,2 MPa respectively, and their global average is 22,9 MPa. By taking the global values of 7 day strength divided by 28 day result, the fractional number 0,581 (approximated 0,6) is obtained for CM normalised strength factor ($Fc_{cf}$) as shown Table 7. In the same way, the normalized factors of respective 56, 270 and 360 days average strengths would be divided by the 28 day value (22,9 MPa) to get the different strenfth factors, at 28 days ($Fc_{cf}$ = 1), 56 days ($Fc_{cf}$ = 1,2), 270 days ($Fc_{cf}$ = 1,6), and 360 days ($Fc_{cf}$ = 1,6), as shown in the Table 7 and Figure 7 for mixtures of …..?? .

Table 7: Normalised strength factors for control mixes and clay-concretes of ….w/c???

| Ages (days) | 7 | 28 | 56 | 270 | 360 |
|---|---|---|---|---|---|
| $Fc_{cf}$, CM | 0,6 | 1 | 1,2 | 1,6 | 1,6 |
| $Fc_{cf}$, RD | 0,7 | 1 | 1,3 | 1,7 | 1,8 |
| $Fc_{cf}$, S2 | 0,7 | 1 | 1,2 | 1,7 | 1,8 |

$Fc_{cf}$-coefficent of compressive strength

It can be seen that the approximate normalised strength factor for both clay-cement concretes of RD and S2 mixes are similar to $Fc_{cf}$ values of ordinary concrete at 7 days, but at the later ages exceeding 270 days, the strength factors for clay concretes are higher than those of ordinary concrete. At 360 days, the strength factor value of concrete mixes made of RD and S2 clays are 1.8 and 1.8 respectively compared to 1.6 for ordinary concrete, as shown in Table 7 and Figure 7. Similar results can be seen in Table 8 and Figure 8.

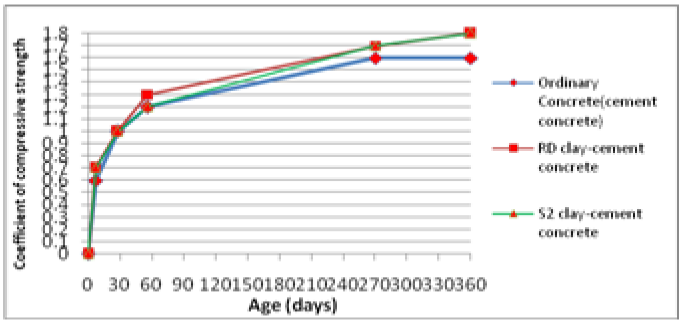


Figure 7: A plot of normalized strength factor for clay concrete mixes of ……

Table 8: Normalised strength factors for control mixes and clay-concretes of ….w/c???

| Ages (days) | 7 | 28 | 56 | 270 | 360 |
|---|---|---|---|---|---|
| $Fc_{cf}$, CM | 0,6 | 1 | 1,2 | 1,6 | 1,6 |
| $Fc_{cf}$, RD | 0,7 | 1 | 1,4 | 1,8 | 2,1 |
| $Fc_{cf}$, S2 | 0,8 | 1 | 1,3 | 1,7 | 1,9 |

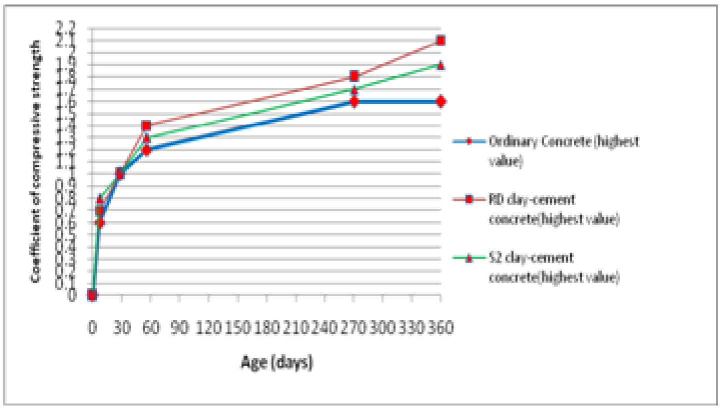


Figure 8: A plot of normalized strength factor for clay concrete mixes of ……

In general, clay-cement concretes gained higher strength performance factors at later ages and may suggest possible pozzolanic behavior, however minimal.

## 5 DISCUSSIONS

Addition of RD clays in concrete coats aggregates significantly reducing mix workability. RD clay has a higher specific surfac area, along with a chemical structure more suited to absorbing water compared to S2 (which is silica or Kaolin clay). So RD-incorporated mixes require a higher w:cc ratio for a given workability than the kaolin-contaminated or uncontaminated-clay mixes. Increasing the clay content of RD mixes has a similar effect of reducing workability as it increases the surface of aggregate to be water-coated relative to the amount of cement. Since good bond is essential to ensure a satisfactory strength and durability of concrete, the problem of clay coatings is an important one.

The usefulness of the models is rather that they show the trends to be expected from the interaction of various parameters and, where applicable, the form of possible empirical equations describing this interaction. The analysis presented has also shown the relative performance of the different local raw clay-cement concretes tested. The results of Figure 10 on workability trends, shows that increasing the w:cc ratio has different effects on workability of the clay-concrete mixes. The RD clay showed increasing workability and S2 clay gave decreasing global workability, while the control exhibited a relatively constant workability with increase in w:cc ratio.

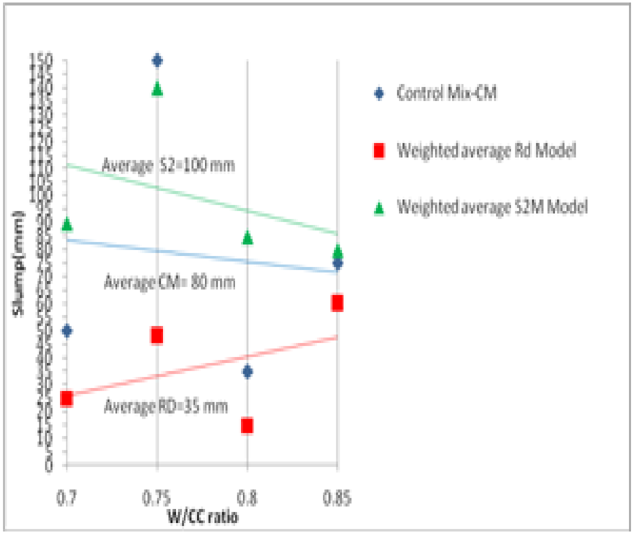


Figure 10: Workability effect of the control and clay-concrete mixes of various w: cc ratios

In Figure 11 is shown the global strength relationships for both clay-concretes and ordinary concretes, basing on the data generated from this investigation. The expressions generally obey the second order polynomial function trend.

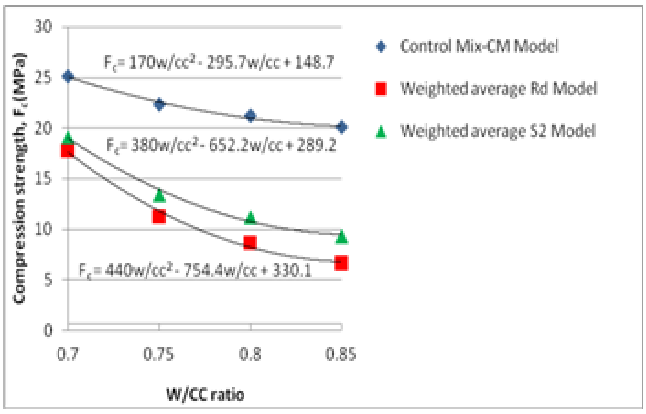


Figure 11: Strength effect of the control and clay-concrete mixes of various w: cc ratios

According to Montgomery and Orton (2001) and Orton (1992), a compressive strength range of 3 to 7 MPa is common for use with building materials in less developing world and is specified in building standards for masonry including walls, columns and lintels. Therefore, satisfactory concretes can be made from incorporation of clay soil into concrete mixtures, permitting these building materials to be used and removing the necessity to transport earthen materials over long distances. Recommended characteristic 28-day concrete strengths in the range of 7 to 10 MPa can be used for various purposes such as mass concrete of roughest type in large, lightly loaded footings and foundations; retaining walls making up over-excavation in trenches etc. (Jordaan andVan Wyngaard, 1997).

## 6 CONCLUSIONS

The presence of clay in the aggregate has a significant effect on the workability of concrete, depending on the clay type. It was found that RD clay decreases workability while S2 clay increases workability of the mixtures.

Global analysis of the strength effects of the clay contents appears to suggest that clay-concrete mixes may infact give higher strength performance factors compared to plain cement concrete. This effect of clays is more pronounced at the later ages of curing. The result may also suggest a possible pozzolanic behavior by the clays and further investigation is needed on this.

Structural concrete made with such materials would need to be investigated with regard to durability, particularly dimensional stability, and is the subject of current ongoing research by the authors of this paper and will be reported in future.

It may not be necessary to transport `quality` earthen materials from long distances as local materials can usually perform as adequate building materials. Concrete blocks of sufficient integrity for low-cost housing may be made from lean mixes of cement with such sands by artisanal builders.

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