[[1]](#footnote-1)

Suitability of Anthill soil as a Supplementary Cementitious Material

J. Kamau, A. Ahmed, P. Hirst and J. Kangwa

***Abstract*—**

**Cement is the most utilised construction material and the second most consumed commodity in the world after water. It has been reported that the heavily energy-intensive processes that are involved in its production contribute about 7 to 10% to the total global anthropogenic carbon dioxide (CO2), which is the main cause of global warming; and are expensive economically. It is however possible, that energy and cost efficiency can be achieved by reducing on the amount of cement, and in its place utilizing Supplementary Cementitious Materials (SCMs), which require less process heating and emit fewer levels of CO2. This work aimed to provide an original contribution to the body of knowledge by investigating the suitability of Anthill Soil (AHS) as an SCM by testing for pozzolanic or hydraulic properties. Cement was replaced in concrete with AHS by weight at 0%, 5%, 7.5%, 10%, 15%, 20%, 25%, and 30% steps at the point of need. The 0% replacement was used as the reference point from which performances were measured. The chemical composition analysis by X-ray diffraction (XRD) showed that AHS contained the required chemical composition for pozzolans, while the compressive strengths achieved were above strength classes that are specified as being suitable for structural applications. The increase in compressive strength over time, density and workability behaviors of AHS were consistent with the characteristics of SCMs. All results across the tests showed good repeatability, highlighting the potential of using AHS as an SCM in concrete to enhance the sustainability and economic aspect of concrete, while at the same time improving its properties in both the wet and hardened states.**

*Index Terms*— **Anthill Soil; Supplementary Cementitious Materials; Partial Cement Replacements; Pozzolans,**

# Introduction

Global warming is a phenomenon that brings about a rise in global temperatures due to the presence of excessive carbon dioxide (CO2) in the atmosphere, and is cumulative and irreversible over timescales of centuries [1], [2].

Cement is heavily energy intensive and has a considerably high carbon footprint, contributing immensely to global anthropogenic CO2 through the burning of fossil fuels that power the processes of its production [3]. It is the main ingredient of concrete, constituting between 7 to 15% of the total mass of concrete [4]. Its yearly global

was 1.6 billion tonnes over 10 years ago, and accounted for about 7% of the total global CO2 loading in the atmosphere, a considerably high volume of emissions compared with only 2% of the total global CO2 emissions that is attributed to aviation [2], [5].

It has been suggested that the production of a tonne of cement emits approximately a corresponding tonne of CO2, making it the most energy-intensive material produced after steel and aluminium [6]. CO2 that is emitted during the production of cement comes from the raw materials, fossil fuels and electric power used as was summarised by [7] in (1),

CO2 total = CO2 raw materials + CO2 fuels + CO2 electric power (1)

A study conducted by [8] reported that the embodied carbon dioxide (ECO2) of cement from cradle to factory gate was 930kg CO2/tonne on average.

According to [9], the extent of the problem is compounded by the amount of cement that is consumed globally, with [10] describing it as the most utilised construction material in the world, its global consumption only seconding that of water. Reference [11] argued that the development of a nation is directly proportional to its consumption of concrete.

One tonne of concrete on average is produced every year for each human being in the world, a population that is currently standing above 7 billion [12], [13]. The ever-growing population that is matched by a corresponding increase in demand for socio-economic infrastructure that is aimed at creating affluent societies, especially in the developing world and former socialite countries, has brought about a steady increase in the demand for cement in the past few decades [11], [14]. As a result, construction investment has been directly linked to higher gross domestic product (GDP), and a suspension in this investment is referred to as a recession [11], [14].

In as much as development is required to match increasing populations, it should also be sustainable [15]. Steele, et al. [15]defined sustainability as a road for society advancement in which progress must be in harmony with the natural world rather than in conflict with it, whereas Reference [6], termed it as a regime in which endeavors are towards meeting the needs of the present generation, without compromising those of future generations. The underlying principles of sustainability lie in the appropriate balance of economic, social and environmental impacts [16].

With a heavy demand for concrete in the developing world and other major and equally populous economies such as China and India predicted, cement producing companies have not anticipated in the foreseeable future any major changes in production that will reduce on emissions [17]. However, energy efficiency and improved properties of concrete can be achieved by reducing on the amount of clinker and utilising Supplementary Cementitious Materials (SCMs) such as Pulverized Fuel Ash (PFA), Ground Granulated Blast Furnace Slag (GGBS), Silica Fume (SF), Rice Husk Ash (RHA) and Corncob Ash (CCA), which require less process heating and emit fewer levels of CO2[6], [17].

It has also been argued that cement is the most expensive constituent of concrete, its prices bearing the characteristic of an astronomical increase annually, and thereby becoming a constraint to the delivery of affordable housing and other essential development [18]. As prices continue to increase, the need for low-cost but functional construction materials that are capable of being sourced locally for use by low-income earners cannot be emphasised enough [19]. The successive use of SCMs in concrete could be a potentially large market for their utilisation in the construction of low cost buildings [17].

Anthills, shown in Fig.1 are natural clay soils that are very cohesive in nature, and therefore must have a high plasticity index [20]. They are made up of soil grains that are coated with sticky rapidly hardening secretions from the recta and mouths of ants [21].

Fig 1. Anthill soil in Tsavo National Park West (picture by authors)

# CHARACTERISTICS OF SCMs

The right chemical composition is essential for a material to be an effective SCM. The American Society for Testing and Materials [22], [23] recommendations are that the chemical composition should constitute of a sum of at least 70% silicon dioxide (SiO2), Aluminium oxide (Al2O3) and Iron oxide (Fe2O3), a maximum of 10% calcium oxide (CaO) and a loss on ignition (LOI) of between 5% and 10% for pozzolanic materials. According to [17], gain in compressive strength after 28 days and at a higher rate than 100% cement specimens over time is a major characteristic of SCMs. The author explained this characteristic as being a result of the reaction of silicone dioxide (SiO2) present in SCMs with calcium hydroxide [Ca(OH)2] that is released during the early hydration of cement, to produce strength giving compounds such as calcium silicate hydrate (C-S-H).

SCMs reduce the width of the transition zone, porosity and the amount of free Ca(OH)2 between cement and aggregates, thereby contributing to enhanced strength and durability with time [17]. Lower densities than cement are also another characteristic of SCMs and are facilitated by their lower particle specific gravity [17]..

Improving the workability of concrete is another characteristic of SCMs [17]. The high slumps that result from the use of SCMs are attributed to the their lower densities which lead to an increased volume of mixes per unit mass, their prevention of the block formation of cement particles, and by the filler effect their reduction of friction between particles, facilitating a better flow of concrete [24].

In investigating for the suitability of AHS as an SCM, this study assessed the performance of Anthill Soil (AHS) against these major characteristics, alongside compressive strength, which is relied upon by concrete to perform under load, and tensile strength, as it is essential that structural integrity of the resultant concrete is not compromised [25]

# RESEARCH SIGNIFICANCE

This work investigated the suitability of using AHS as an SCM in concrete for the purposes of enhancing the sustainability of cement in concrete, while at the same time improving the properties of both fresh and hardened concrete through improved workability and enhanced durability, which are the characteristics of SCMs [17].

Anthills have been observed to endure extremely hot daytime tropical temperatures and very low night temperatures, as well as heavy tropical rainfall. People in rural areas of Africa have also been known to use anthill soil on paths that carry heavy human traffic and on plinths of huts as additional mountings or footings to houses. Anthills, being coated with sticky rapidly hardening secretions from the recta and mouths of ants [21], are cohesive, and an informed guess could be that they contain the same chemicals as those found in cement, such as calcium oxide (CaO), silicon dioxide (SiO2), aluminium oxide (Al2O3) and magnesium oxide (MgO) among others.

Should a significant presence of pozzolanic properties be found in AHS, their use in concrete would serve in enhancing the sustainability of concrete by reducing on the CO2that is emitted by cement production processes, replace scarce natural resources by reducing the mining and quarrying of limestone, clay and coal, and improving the properties of fresh and hardened concrete [17]. This could in turn lead to enhanced service life of structures and a decrease in ownership costs [17].

The use of AHS in concrete could also lead to the reduction on the overall cost of construction and stimulate growth in the construction industry through the lowering of material costs, and provide affordable housing, social amenities and other infrastructure, thereby creating jobs and providing safety and security [26]. Limited work was found on the use of anthill soil as an SCM.

IV. METHODS

AHS was sourced from Kenya and transported to the United Kingdom (UK) under license. Snowcrete cement type CEM 1 52.5 N conforming to [27] was used.

Apparent density (AD) (defined by [28] as the mass in grams of a powder which occupies a volume of one millilitre (ml) under standardized conditions), of AHS and cement were obtained conforming to [28]. The apparatus were a stainless steel lockable funnel, a 500ml receiver and a stand. The receiver was weighed before and after it was filled with powder through the funnel. A total of two measurements were taken and the arithmetic mean of the two was used to calculate the apparent density using (2) [28], [29].

(2)

Where M3 is the mass in grams (g) of the receiver with the powder,

M0 is the mass in grams of the empty receiver

V is the volume of the receiver in millilitres (ml).

Cube and cylinder moulds that were used to make specimens measured 100mm x 100mm x 100mm, and 150mm diameter x 300mm height respectively conforming to [30] and the specimens were cast conforming to [31]. The target mix of the study was strength grade C40 (which was converted to a mean strength of 48N/mm2 using (2) after [32]) at mix proportions of 1: 2: 3 (cement: sand: aggregates).

Cement was substituted with AHS by weight in percentages of 0%, 5%, 7.5%, 10%, 15%, 20%, 25%, and 30%. The 0% replacement also referred to as the ‘control specimen’ was used as the reference from which the performances of all replacements were measured [33].

fcm =fcu+8 (N/mm2) (3)

Where fcm is mean compressive strength

fcu is characteristic compressive strength

The concrete mixing process conformed to [34]. The concrete mixer was run for a total of eight minutes, with a three-minute rest in between the mixing, after cement, aggregates and water had been introduced. A Water Cement Ratio (WCR) of 0.5 was used to ensure a good balance of workability and strength in line with Abram’s law which states that the strength of a concrete mix is determined by the WCR, with lower WCRs spelling higher strengths and vice-versa [35]. It is also possible to target the slump of a mix based on the weight of cement and total aggregate proportions from the specifications in [36] and free water specifications in [37]. However, this method was not used as the study aimed to test the effect of AHS on the workability of concrete.

The insides of the moulds were sprayed with a thin film of non-reactive release material. Cube moulds were then filled with concrete and firmly secured on to a mechanical vibrating table to commence the compaction process. Full compaction was deemed to have been achieved when there were no further appearances of large bubbles on the surface of the concrete, and the surface became smooth with glazed appearance as is specified by [31]. To ensure repeatability, a total of three cubes were cast for each test and the average compressive strength was reported [38].

The cubes were left in the moulds for 24 hours, before being stripped, marked and submerged in a water tank at temperatures of 200 ±2 until their testing age. Compressive strength tests conformed to [39] at 7, 28, 56, and 91 days. For the splitting tensile strength specimens, the cylinders were filled with three equal layers of concrete and compacted using 25 uniform, vertical strokes of the tamping rod along the whole surface of each layer. The sides of the moulds were tapped with a mallet for each layer after compaction to remove air bubbles. The specimens were stripped from the moulds after 24 hours and cured in a water tank at temperatures of 200 ±2 for 91 days, with tests conforming to [40].

# esults and discussion

## Chemical composition

The values in Table I were obtained using X-ray diffraction (XRD) on a sample of AHS that was used for this research.

Table I. Percentage oxide composition in ahs

|  |  |
| --- | --- |
| Chemical | Percentage Composition |
| Silicon dioxide (SiO2) | 51.9 |
| Aluminium oxide (Al2O3) | 23.4 |
| Iron oxide (Fe2O3) | 7 |
| Calcium oxide (CaO) | 1.6 |
| Magnesium oxide (MgO) | 2.4 |
| Sodium oxide (Na2O) | 0.4 |
| Potassium oxide (K2O) | 1.9  9.3 |
| Loss on ignition (LOI) |
| Sulphur trioxide (SO3) | 0.1 |

The apparent densities of AHS and cement were calculated to be 1325 kg/m3 and 1093 kg/m3 respectively using (1).

The chemical composition of AHS was assessed against the requirements of natural pozzolans to [22], [27], which are that natural pozzolans should contain a combined sum of SiO2, Al2O3 and Fe2O3 of at least 70% of the total mass and a LOI of between 5% and 10%. LOI is a measure to control unburned materials from the furnace, which influences water demand in concrete for standard consistencies and does not contribute in chemical reactions [17].

The analysis showed a sum of SiO2 + Al2O3 + Fe2O3 of 82.3%, a CaO of 1.6% and a LOI of 9.3%, evidence that the AHS tested contained the required chemical composition for pozzolans and could therefore be suitable for use as a pozzolanic material.

## Workability

Table II and Fig. 2 show the workability of AHS replaced mixes. AHS was observed to reduce workability for the 5% replacement but improve it with further replacement. The high slumps achieved can be attributed to the lower density of AHS, which leads to an increased volume of mixes, the prevention of block formation of cement particles, and the reduction of friction between particles through the filler effect, thereby facilitating a better flow of concrete [41].

As a result of this evidence, it can be concluded that AHS could be used as a SCM since it emulates the properties of SCMs in improving the workability of concrete. These results on workability also highlight the possibility of using AHS in concrete to reduce the WCR and optimise on strength in line with Abram’s law which states that the strength of a concrete mix is determined by the WCR, with lower WCRs spelling higher strengths and vice-versa [35].

Table II. Slumps of AHS -replaced mixes (mm)

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Specimen | Slumps at percentage replacements (mm) | | | | | | | |
| 0% | 5% | 7.5% | 10% | 15% | 20% | 25% | 30% |
| ASH | 30 | 28 | 31 | 33 | 38 | 40 | 60 | 80 |

Fig. 2. Slumps of AHS replaced mixes (mm)

## Densities

Table III and Fig. 3 show the densities of AHS replaced specimens over a curing period of 91 days. Even though the apparent density of AHS was found to be higher than that of OPC, the densities of AHS replaced specimens were lower than those of the control specimens throughout all replacements and decreased with further replacement. Bapat [17] posited that the lower particle specific gravity of SCMs increase the volume of mixes per unit mass.

The densities of AHS replaced specimens were observed to decrease with curing age, a behaviour which was explained by [17] as being a result of the eventual consumption of Ca(OH)2 by the reaction that involves SCMs during secondary hydration to form the less dense C-S-H. From this evidence, it can also be concluded that the density behaviour of AHS emulates that of SCMs, and it could therefore be suitable to be used as one.

Table III. Densities of AHS -replaced specimens (kg/m3)

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Curing Age (days) | Densities at percentage replacement (kg/m3) | | | | | | | |
| 0% | 5% | 7.5% | 10% | 15% | 20% | 25% | 30% |
| 7 | 2350 | 2330 | 2329 | 2326 | 2325 | 2278 | 2274 | 2266 |
| 28 | 2350 | 2320 | 2327 | 2325 | 2323 | 2271 | 2265 | 2259 |
| 56 | 2356 | 2320 | 2326 | 2323 | 2316 | 2258 | 2247 | 2238 |
| 91 | 2366 | 2318 | 2314 | 2312 | 2307 | 2250 | 2243 | 2202 |

Compressive strength

Table V and Fig. 4 show the compressive strengths obtained from specimens that were partially replaced with AHS. Replacements of up to 10% achieved the study’s target characteristic strengths (fcu) of concrete grade C40 or mean strengths (fcm) of 48N/mm2, which is listed by [42] as being suitable for structural applications. However, the 15% to 30% replacements also achieved impressive strengths that were above the minimum grade C25 that is also listed among the classes that are suitable for structural applications by [42].

Table1 IV. Compressive strengths of AHS Specimen (N/mm2)

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Curing Age (days) | Compressive strengths at percentage replacements (N/mm2) | | | | | | | |
| 0% | 5% | 7.5% | 10% | 15% | 20% | 25% | 30% | |
| 7 | 56.2 | 40.4 | 40.3 | 38.1 | 33.2 | 32.6 | 27.1 | 22.3 | |
| 28 | 61.6 | 50.8 | 53.4 | 46 | 43.4 | 38.7 | 34.6 | 28.8 | |
| 56 | 67.6 | 53.4 | 50.6 | 47.9 | 48.1 | 44.8 | 39.2 | 31.8 | |
| 91 | 71.3 | 59.3 | 63.1 | 55.6 | 54.1 | 49.1 | 44.4 | 37.8 | |
| Fcu at 91  days | 63.3 | 51.3 | 55.1 | 47.6 | 46.1 | 41.1 | 36.4 | 29.8 | |

Fig. 4. Mean Compressive strengths of AHS specimens (N/mm2)

*E. Tensile strength*

Table V and Fig. 5 show the tensile strengths of AHS replaced specimens at 91 days. Results showed a good relationship between AHS and the control specimens at all replacements, spelling the possibility of AHS being used in concrete without affecting its structural integrity.

Table V: Tensile strengths of AHS REPLACED SPECIMENS at 91 days (N/mm2)

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Specimens | Tensile strength at percentage replacements (N/mm2) | | | | | | | |
| 0% | 5% | 7.5% | 10% | 15% | 20% | 25% | 30% |
| Ternary | 3.6 | 3.9 | 3.9 | 3.7 | 3.5 | 3.4 | 3.1 | 3.0 |

Fig.5. Tensile strengths of AHS replaced specimens at 91 days (N/mm2)

## Percentage increase in compressive strengths

Table IV and Fig. 6 show the percentage increase in compressive strengths of AHS replaced specimens between 28 and 91 days. From the results, all AHS replacements showed increases in compressive strength that were above those of the control specimens during this curing period. The results also showed higher increases in compressive strength with further replacement.

As was pointed out earlier, gain in compressive strength at a rate that is higher than 100% cement specimens over time is one of the major characteristics of SCMS, and is brought about by the reaction of SiO2 present in SCMs with Ca(OH)2 that is released during the early hydration of cement, to produce strength giving compounds such as C-S-H [17],

The pozzolanic reaction of SCMs reduces the width of the transition zone, porosity and the amount of free Ca(OH)2 between cement and aggregates, thereby contributing to enhanced strength and durability with time [17]. This pozzolanic reaction is the basis of the contribution that is made to strength through secondary hydration [17].

Table VI. Percentage increase in compressive strengths of AHS replaced specimens between 28 and 91 days

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Specimen | Percentage increase in compressive strength | | | | | | | |
| 0% | 5% | 7.5% | 10% | 15% | 20% | 25% | 30% |
| AHS | 15.7 | 16.7 | 18.2 | 20.9 | 24.7 | 26.7 | 28.3 | 31.3 |

Fig. 6. Percentage increase in compressive strengths of AHS-replaced specimens between 28 and 91 days

From this evidence, it can be concluded that AHS could be used as an SCM as it emulates the gain in strength behavior of SCMs.

# Conclusion

This study investigated the suitability of anthill soil (AHS) to be used as a Supplementary Cementitious Material (SCM) in concrete and concluded that AHS satisfied all the characteristics of SCMs that were investigated. This evidence highlights the great potential of using AHS as an SCM in concrete to enhance the sustainability and economic aspect of concrete, while at the same time improving its properties in both wet and hardened states. This conclusion was arrived at based on the following evidence: -

1. The chemical analysis showed that AHS contained the sum of SiO2, Al2O3 and Fe2O3 of at least 70% by mass, which is the requirement for natural pozzolans.
2. AHS improved the workability of concrete tested, with slumps increasing with increased replacement. Improving the workability of concrete is one of the characteristics of SCMs.
3. The lower densities of AHS specimens compared with those of the control specimens, and the decrease in density over curing age due to the consumption of Ca(OH)2 by the reaction that involves SCMs during secondary hydration to form the less dense C-S-H is another major characteristic of SCMs.
4. The compressive strengths achieved by all replacements at 91 days were of concrete grades that are suitable for structural applications.
5. Tensile strengths observed showed a good relationship between AHS specimens and the control specimens, spelling the possibility of AHS being used in concrete without affecting its structural integrity.
6. In line with the characteristics of SCMs, AHS replaced specimens gained strength at a higher rate than the control specimens.

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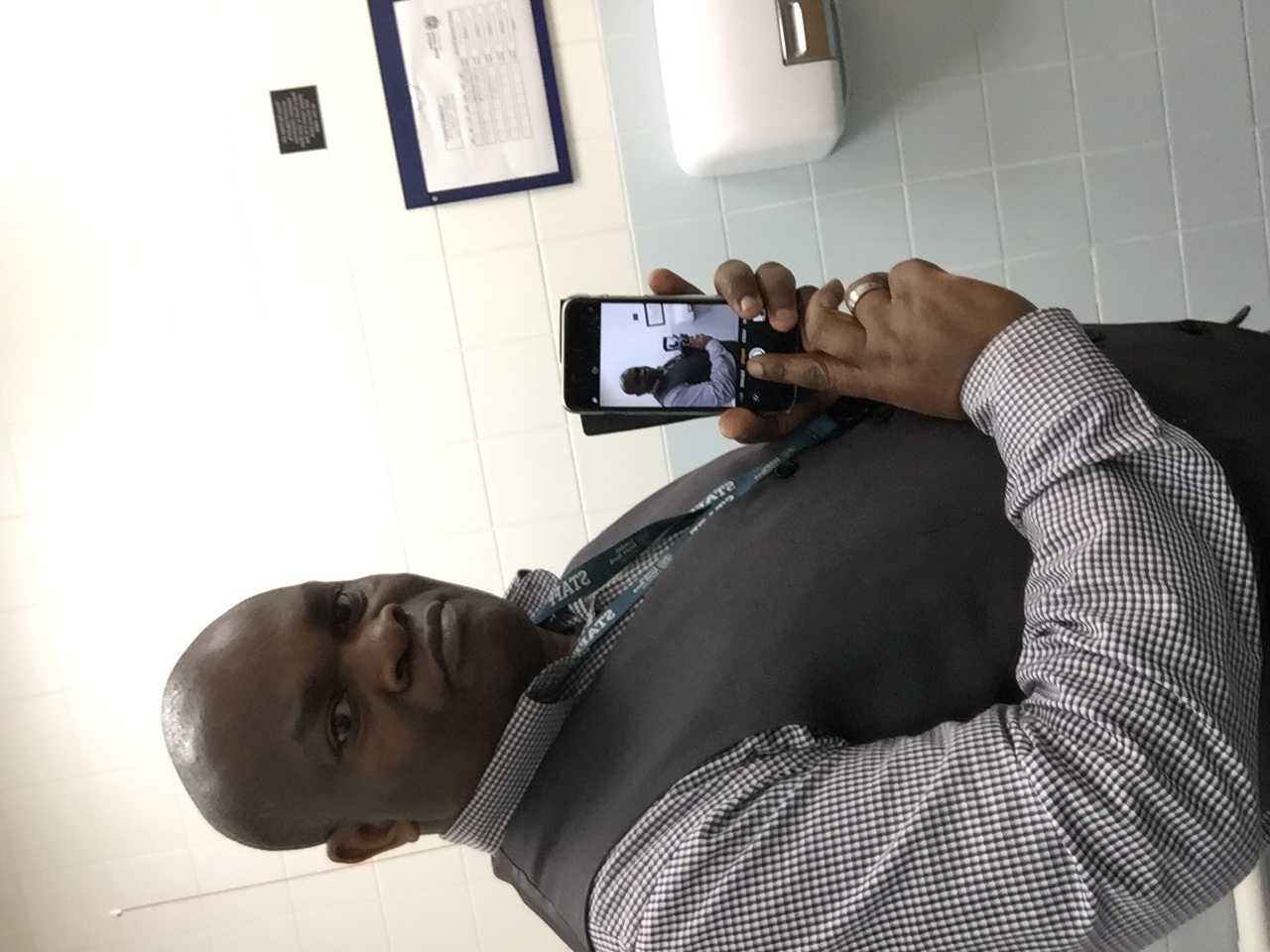
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