Effects of Different Fine Aggregate on Concrete Strength

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Abstract: Fine aggregate has been extensively used in the construction industry as a key component of concrete production. Although river sand is one of the major sources of fine aggregate, different sources exhibit different properties by virtue of the geological formation of the drainage basin. Further, the use of river sand as the source of fine aggregate has resulted in over-exploitation leading to depletion and environmental degradation. This has led to exploration of alternative sources to safeguard depletion and reduce the negative impacts on the environment. This research was conducted on a variety of river sands and alternative fine aggregates to assess their suitability for concrete manufacture. A quantitative experimental approach was adopted to test the Physical, chemical and mineralogical properties of fine aggregates sourced from Machakos, Mwingi, Naivasha and Kajiado and the resultant concrete strength after 7, 14 and 28 days recorded. The fineness modulus of all the material samples ranged from 1.92 to 3.66, specific gravity 1.73 to 2.27 and silt content 2.06% to 11.9%. All the samples fell within the overall grading envelope. The silicon dioxide concentration ranged from 65% to 80%, Aluminium oxide 9% to 19% and Calcium oxide 1.3% to 2.5%. Machakos sand had the highest Silicon dioxide and calcium oxide concentration of 80% and 2.5% respectively, while quarry dust had the highest aluminium oxide concentration of 19%. It was observed that concrete produced from natural river sand obtained from Mwingi, Kajiado and Machakos achieved strengths of 41.899N/mm^2, 37.173N/mm^2 and 33.645N/mm^2 respectively comparative to 30 N/mm^2 target characteristic strength after 28 days. On the other hand, concrete produced using fine aggregates obtained from Mlolongo rock sand, Naivasha sand and Mlolongo Quarry dust achieved strengths of 28.682 N/mm^2, 28.411 N/mm^2 and 27.661 N/mm^2 respectively falling short of the requisite compressive strength after 28 days.

Keywords: Concrete Mix Design, Concrete Strength, Fine Aggregates.

I. INTRODUCTION

Fine aggregate material has been widely used for manufacture of concrete for use in buildings and other infrastructural developments. The acceptability of concrete as the most versatile product in construction is hinged on the availability of the respective material constituents, durability and the relative ease of its moulding to required shapes [1]. Concrete constitutes of Cement, fine and coarse aggregates and water. The aggregates form 75% of concrete by volume whose properties significantly affect the durability and structural performance of concrete [2]. The fine and coarse aggregate proportions vary depending on the design mix required for construction. Quality assurance of building materials is very essential in order to build strong, durable and cost effective structures [3]. Therefore the need to use right type and quality of aggregates in concrete manufacture cannot be underestimated; and the selection of the constituent materials should be made to the highest standard if the integrity of the structures is to be maintained [4].

The increased demand for housing and other infrastructural developments due to increase in population and urbanisation has resulted in high demand for aggregate for concrete production. Globally, material mined every year amounts to between 47-59 billion tonnes, with fine aggregate (sand) and coarse aggregate (gravel) accounting for the largest percentage (about 68- 85%), as well as the fastest increase in its exploitation rate [5]. River sand has been the most preferred choice of fine aggregate due to its availability, affordability and minimal or no processing requirements. A conservative estimate for world consumption of aggregates gives more than twice the amount of sediment carried by all of the rivers of the world [6], resulting in man being the planet's largest transforming agent with respect to aggregates [7]. This level of exploitation has led to increase in cost for concrete production and environmental degradation. The dredging of creeks, riverbeds and lake basins has resulted in ecological imbalance affecting bio- diversity and landscape, as well as having socio- economic, cultural and political consequences [8].

There is considerable pressure in many countries to use secondary and recycled aggregates in construction because of the environmental problems associated with production of primary aggregates (river sand) [9]. These include rock sand, quarry dust and manufactured sand. These fine aggregates are often manufactured by crushing and processing hard rocks to produce fine-grained materials. The degree to which the crushed rock sand can replace natural sand varies with rock type, the degree of quarrying processing used and the end use. [9]. In some quarries, the sand is washed to remove fines thereby significantly improving the quality.

Most developed countries use manufactured sand produced from crushing and processing of hard rock like limestone, sandstone and igneous rocks, whose aggregate properties are well researched. However due to the variance in geological processes that led to the formation of the parent rocks, the research findings cannot be applied to other areas because of the variation in rock mineral compositions. In Nairobi Metropolitan, the major sources of fine aggregates are Kajiado, Naivasha, Machakos, Mwingi and Mlolongo area. However,

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we have limited data on these material which could explain the poor quality concrete and structural failures [10]. This forms the basis of this research with a view to establishing the suitability of different aggregates used in Nairobi Metropolitan.

II. MATERIALS USED IN THE RESEARCH

The nature of concrete lies in the way the various materials are mixed, moulded and shaped to form a structure or element that can withstand its intended use over the lifetime of the structure without failure. Concrete volume is made up of 60-75% coarse and fine aggregates which significantly influence the fresh and hardened properties of concrete. The other components are Cement, water and additives (the latter is not considered in this study).

A. Cement

The cement used in the research was normal setting Ordinary Portland Cement of Class 42.5 strength, designated as OPC 42.5N. This is produced in accordance to KS EAS 18-1:2001, an adoption of the European Norm EN 197:2011 (Kenya Bureau of standards, 2005)

B. Coarse Aggregate

The coarse aggregate for the research was crushed aggregates of maximum size of 20mm sourced from Mlolongo quarry. Sieve analysis was done on the coarse aggregates in accordance to BS 812-1:1992. The percentage passing through the BS sieves was found to be within envelope limits. Coarse aggregates from the same source were used throughout the entire experiment.

C. Fine Aggregate

The fine aggregates used in the research were Natural river sand from Mwingi, Machakos and Kajiado, Quarry dust from Mlolongo, rock sand from Mlolongo and Naivasha sand from Naivasha quarry. The aggregates were graded in accordance to BS 812-1:1992. The Physical properties were determined in accordance to BS and ASTM standards; Bulk density (BS EN1097-3:1998), Specific gravity (ASTM C128), water absorption (BS 812-2:1995), Clay particles and friable materials (ASTM C142-97). The chemical properties were determined in accordance to BS EN 1744-1.

D. Water

Water used for concrete mixing and curing was obtained from Jomo Kenyatta university of Agriculture and technology treatment plant.

III. METHODOLOGY

The study employed experimental research divided into two parts; the first part was investigating the physical, chemical and mineralogical properties of fine aggregates collected from various sources; the second part involved determining the suitability of these fine aggregates for use in concrete. The design characteristic strength was maintained at $30N/mm^2$.

A. Physical, Chemical and Mineralogical Properties

The fine aggregates used in this research were identified as S2 (River sand obtained from Mwingi), S3 (River sand obtained from Kajiado), S4 (Rock sand obtained from Mlolongo), S5 (River sand obtained from Machakos), S6 (Naivasha Sand) and S7(Quarry dust obtained from Mlolongo). The physical properties were established in accordance with the British and American standards; while chemical properties were obtained using Atomic Absorption spectrometry (Varian Spectra AA10 machine) and validated using X-Ray Fluoresce method (Bruker S1 Titan machine) at the Ministry of Mining laboratory in Nairobi. The mineralogical properties were also determined using the X-Ray diffraction method (Bruker D2 Phaser machine) at the Ministry of Mining laboratory in Nairobi and counter checked with the geological formation of the catchment areas.

B. Concrete Mix Design

Concrete mix design using the different samples was done for class 30 concrete using D.O.E (Department of Environment)/British method at the JKUAT structures laboratory. This involved selecting and proportioning the constituents to give the required strength, workability and durability. [11]. Water/cement ratio, coarse aggregate/total aggregate ratio and total aggregate/cement ratio are the key parameters affecting design of a concrete mixture. For specified strength and durability requirements, a water/cement ratio has to be selected. [12] In this experiment a designed mix was used with strength testing forming an essential part of the requirements for compliance. [11] A characteristic strength of $30 N/mm^2$ was specified with defective proportion of 2.5% yielding a standard deviation of 8N/mm2. A water /cement ratio of 0.52 was used (obtained from Table 2, Fig4 of the D.O.E) A slump of 10-30mm and a maximum crushed aggregate of 20mm was used yielding a free water content of 190 m^3 (Table 3 of the D.O.E). The aggregate was assumed to have a relative density of 2.7. The composition of Fine aggregate material was determined from the percentage passing Sieve no. 600µmm (Fig 6 – D.O.E). The respective constituents were then determined and varied based on the percentage of the material passing sieve no 600µmm.

Table 1 Concrete Mix Design of the Samples

Sand type	Water/ Cement ratio	Water content (kgs)	Cement content (kgs)	Fine aggregate (kgs)	Coarse aggregates (kgs)
S2	0.52	190	365	656	1219
S3	0.52	190	365	525	1350
S4	0.52	190	365	788	1087
S5	0.52	190	365	656	1219
S6	0.52	190	365	562.5	1312
S7	0.52	190	365	787	1087

S2-Mwingi Sand, S3-Kajiado Sand, S4-Mlolongo Rock Sand, S5-Machakos Sand, S6-Naivasha Sand, S7-Mlolongo Quarry dust

IV. RESULTS AND DISCUSSION

A. Mineralogical Composition of the Aggregates

The mineral composition of the aggregate samples are shown in table 2.

Table 2 Mineral Composition of fine Aggregates

Mineral	Formular	S2	S3	S4	S5	S6	S7
Labradorite	Al0.814 Ca0.32 Na0.18 O4 Si1.184	16.70%	16.40%		14.70%		
Berzalianite	Cu1.95 Se	25.40%	18.10%				
Berzalianite	Cu2 Se	23.40%					
Perryite	Fe0.24 Ni7.76 P0.63 Si2.37	5.20%					
Monipite	Mo Ni P	2.60%					
Quartz low	O2 Si	26.70%	21%		21.50%		
Quartz	O2 Si				20.40%		
Albite	Al Na O8 Si3		15.70%		10.20%		
Orligoclase	Al1.277 Ca0.277 Na0.723 O8 Si2.723		14.80%		11.90%		
Anorhtite Sodian	Al1.52 Ca0.52 Na0.48 O8 Si2.48		13.90%				
Polybasite	Ag31 As0.203 Cu S22 Sb3.797			2.60%			
Sanidine	Al Ba0.014 Fe0.003 K0.789 Na0.16 O8 Si3			14.60%			
Sanidine	Al K0.65 Na0.35 O8 Si3			13.30%			
Sanidine	Al1.04 Ca0.04 K0.65 Na0.31 O8 Si2.96					39.70%	28.10%
Sanidine	Al K O8 Si3						42.10%
Augite	Al Ca0.61 Fe0.13 K0.17 Mg0.43 Mn0.01 Na0.05 O6 Si1.61			6%			
Orthoclase	Al K O8 Si3			25.60%			
Microcline	Al K O8 Si3			17.30%			
Microcline	Al KO.95 NaO.05 O8 Si3				9.80%		
Diopside	Al0.078 Ca Fe0.024 Mg0.976 O6 Si1.922			5.80%			
Diopside	Ca Fe0.26 Mg0.74 O6 Si2					10.50%	
Augite	Al0.7 Ca Fe0.2 Mg0.6 O6 Si1.5			4.80%			
Bushmakinite	Al0.74 Cr0.26 Cu0.26 H O9 P1.22 Pb2 V0.52			1.10%			
Nepheline	Al3.84 K0.57 Na3.24 O16 Si4.16			7.50%			
Thorikosite	As0.2 Cl H0.5 O2 Pb1.5 Sb0.3			0.50%			
Smirnite	Bi2 O5 Te			1%			
Andesine	Al0.735 CaO.24 NaO.26 O4 Sil.265				11.40%		
Boulangerite	Pb10.159 S22 Sb7.841					5.20%	
Anorthoclase	Al K0.333 Na0.667 O8 Si3					46.50%	
Andorite VI	Ag Pb S6 Sb3						2.40%
Feldspar	Al1.9 O8 Si2.1 Sr						13.80%
Baricite	Mg3 O16 P2						13.60%

The aggregates mineral composition varied depending on the geology of the source. The mineral composition of the aggregates influences their chemical composition which in turn has an effect on the concrete strength development**.**

The mineral composition of S2 is comparable to the mineral composition of rocks at Mwingi catchment area whose geological formation indicates a highly metamorphosed series of sedimentary origin. The rocks mainly constitute quartz and iron oxides minerals [13].

The composition of S3 is similar to the mineral composition of the rocks at Kajiado catchment area whose geology indicates presence of volcanic rocks consisting of basalts, alkali trachytes and pyroclastics. These rocks are mainly composed of labradorite, orligoclase and quartz [14]. The composition of S4 and S7 is equivalent to the rocks at Mlolongo catchment area. The geological formation of the area indicates the presence of igneous and metamorphic rocks formed from volcanic eruptions. The rocks constitute mainly sanidine, orthoclase and microcline [15].

The mineral composition of S5 is analogous to the rock composition at Machakos- Mwala river catchment area. The geological formation of the area indicates presence of metamorphic series of pelitic, psammitic and calcareous rocks formed during the volcanic era. These rocks are mainly composed of diopside, biotite, dolomite, microcline and quartz. [15] The mineral composition of S6 is equivalent to the rock composition of Naivasha (Suswa) catchment area. The geological formation of the area indicates presence of lavas, pyroclastic and lacustrine deposits formed during the volcanic era. The rocks are mainly composed of sanidine and boulangerite [16].

The geological formation of all the samples conform to the laboratory XRD results shown in Table 2, this indicates that true representative samples were obtained for testing in this experiment.

A. Physical Composition of the Aggregates

The physical characteristics of fine aggregates influences the properties of both freshly mixed and hardened concrete. The Fineness Modulus is a measure of the fineness of aggregates and is useful in determining the proportions of fine and coarse aggregates to be used in concrete mixtures. A higher fineness modulus implies a coarser aggregate hence requires more water to produce workable concrete [2]. Silt and clay content influences the strength development in concrete and should be maintained within the recommended limits. High silt and clay content has an effect on the resultant concrete as it will not achieve the expected strength [17].

Sieve analysis was used to determine the grading of the fine aggregates. The grading limits and the nominal maximum aggregate sizes are specified for fine aggregates as they affect the proportions of fine and coarse aggregates, water to cement ratio, workability and durability of the resulting concrete. Aggregates that do not have a large deficiency or excess of a particular size and give a smooth grading curve yields suitable concrete [18].

The bulk density of aggregate refers to the weight of aggregate divided by its volume. The volume includes that occupied by the aggregates as well as the voids between aggregate particles. The void content between the particles affect the paste requirements in the mix design. The specific gravity of aggregates refers to the ratio of its mass to the mass of an equal volume of water and is used in computations for mixture proportioning. [18]

The physical properties are shown in table 3.

Table 3 Physical Properties of Fine Aggregates

Sno.	Test Parameter	S-2	S-3	S-4	S-5	S-6	S-7
1	Specific gravity	2.12	2.06	2.24	2.31	**1.73**	2.27
2	Apparent Specific gravity	2.57	2.5	2.6	2.63	2.36	2.59
3	Bulk density	1497	1469	1407	**1613**	1327	**1684**
4	Water Absorption	8.3	8.62	6.31	5.16	15.3	5.37
5	Fineness Modulus	2.66	1.92	3.37	2.54	1.94	3.66
6	Silt and clay content	4.85	4.16	2.06	6.66	9.37	11.9
7	Sieve Analysis	C&M	F	C	C&M	F&M	C
8	Surface texture	Rough	Smooth	Coarse	Rough	Smooth	Coarse
9	Particle shape	R	R	A	R	R	Fl & E

C- Coarse, F-fine, M-medium, R-rough, A-angular, Fl-flaky, E-elongated

The specific gravity of all the aggregates samples fell below the minimum accepted limit of 2.6 required in a concrete mix according to the ASTM C127 standards. The water absorption of the all aggregate samples exceed the 2.3% maximum accepted limit according to ASTM C127 standards. The highest was recorded in S6 while S5 had the least. The higher the water absorption the higher the amount of water required to produce workable concrete. The silt and clay content in all the aggregate samples exceeded the maximum limit of clay content

According to the ASTM C142 standard that stipulate a limit of 1% maximum. The highest concentration was recorded in S7 while the lowest was in S4. The high silt and clay content in S7 reduces concrete strength.

The fineness modulus of all the aggregate samples ranged between 1.93- 3.66. The standard limits of fineness modulus are 2.3-3.1 according to ASTM C33.The highest Fineness Modulus was recorded in S7 indicating that the aggregate is coarse and will require more water to produce workable concrete. The lowest fineness modulus was recorded in S3 therefore will require less water.

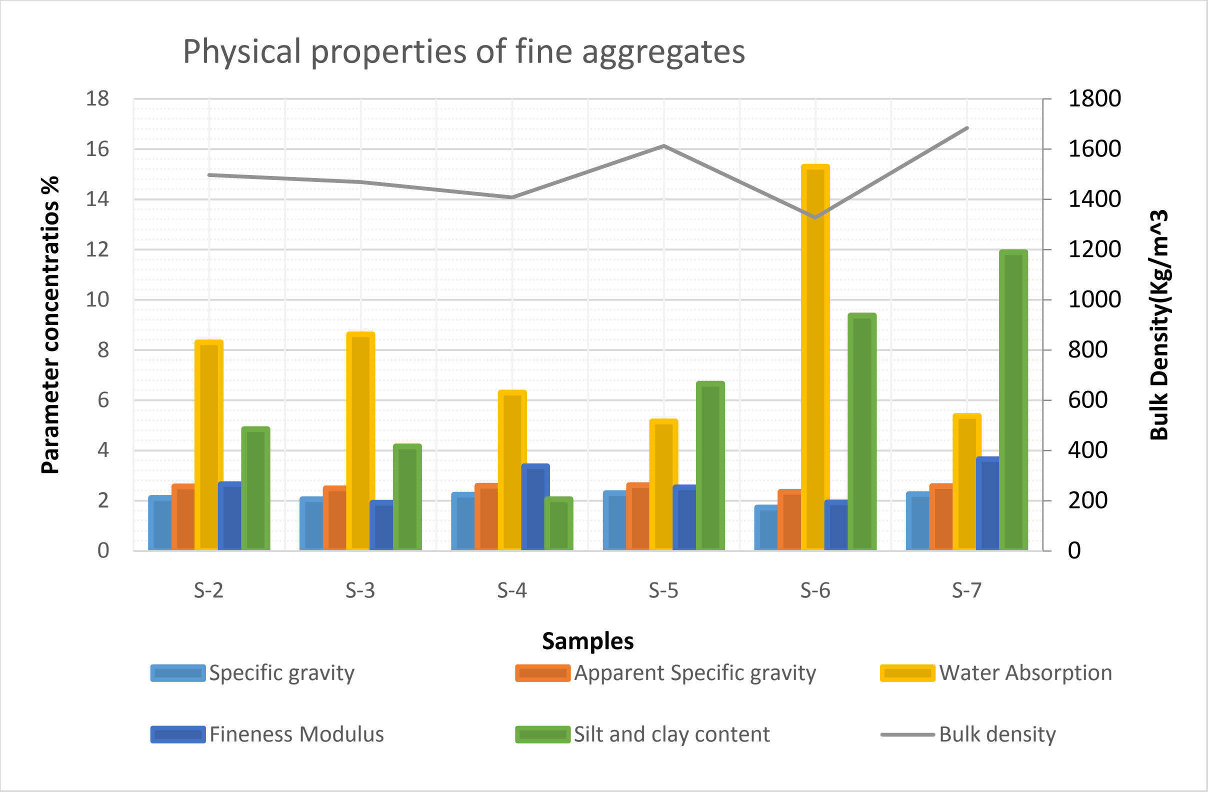

Figure 1Physical Properties of Fine Aggregate

The sieve analysis of the fine aggregates were as shown in figure 2. It was observed that the samples fell within the limits as per the requirement of BS 812-1:1992 for natural aggregates.

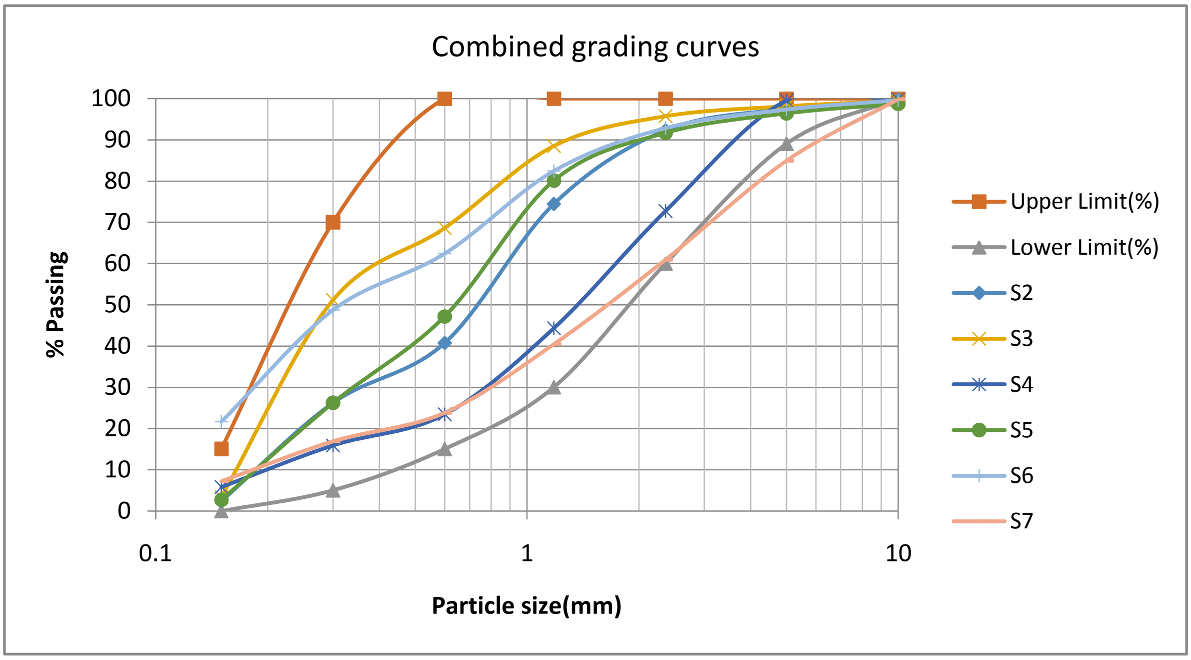

Figure 2 Grading Curves of Fine Aggregates

B. Chemical Properties of Aggregates

The chemical properties of aggregates have a great influence on strength development of concrete. The main chemical constituents are Silicon IV oxide, Aluminum III oxide and calcium oxide which influence the setting time, early strength and final concrete strength. Silica concentrations of between 70-90% prolongs the setting time but increases the final concrete mix strength [19], alumina concentrations of between 8-12% reduce the setting time but increases the concrete strength [19] and Calcium oxide concentrations of between 2-5% prolong the setting time of concrete but gives an early strength. [19].

The chemical properties of the fine aggregates are shown in table 4.

Table 4 Chemical Properties of Fine Aggregates

Sno.	Parameter (%)	S-2	S-3	S-4	S-5	S-6	S-7
1	Sio_2	76.00	78.00	67.00	80.00	69.00	65.00
2	Al_2O_3	11.00	9.00	17.00	10.00	14.00	19.00
3	Fe_2O_3	1.40	1.20	4.00	1.00	5.50	4.00
4	CaO	1.60	1.50	1.40	2.50	1.30	1.40
5	MgO	0.80	1.00	0.05	0.02	0.04	0.08
6	Na_2O	2.00	1.40	1.50	1.80	3.00	4.00
7	K_2O	1.00	1.00	3.00	1.00	1.80	1.60
8	TiO_2	0.30	0.17	1.40	0.12	0.30	0.60
9	LoI	0.72	1.04	3.50	1.70	2.00	3.80

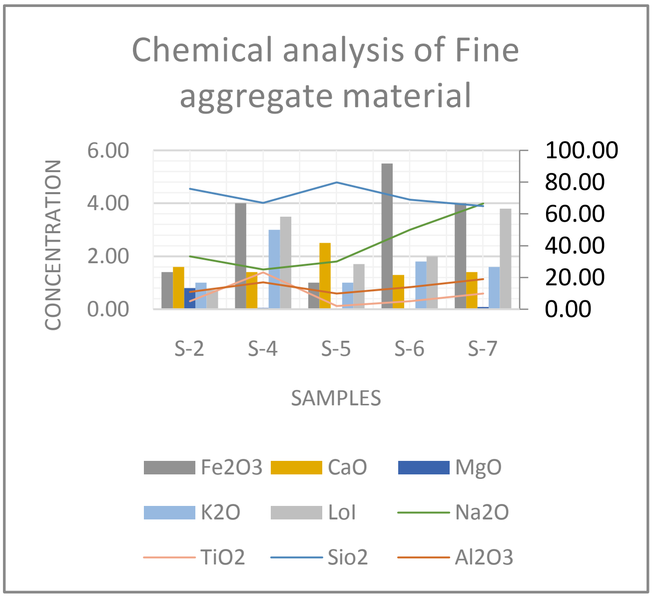

Figure 3 Chemical Properties of Fine Aggregates

The Silicon IV oxide concentration in the aggregate samples varied between 65-80%. The adequate Silicon IV oxide concentration for fine aggregates in concrete production is 70-90%. The highest concentration (80%) was recorded in S5 and it is expected to develop a high final concrete strength. The lowest concentration was recorded in S7 (65%) which would result in reduced final concrete strength.

The Aluminium III oxide concentration varied between 9-19%. For concrete production, the adequate Aluminium III oxide concentrations in fine aggregates is 8-12%. The highest was recorded in S7 (19%).The lowest was recorded in S3 (9%).

The calcium oxide concentration for all aggregate samples varied between 1.3-2.5%. The adequate calcium oxide concentrations in fine aggregates for concrete production is 2-5%. The highest was recorded in S5 (2.5%) and it would therefore develop a higher early strength (7days) .The lowest was recorded in S6 (1.3%) and it would therefore have reduced early concrete strength.

The variation in chemical properties in the various aggregate samples can be attributed to the mineral compositions of the parent rock.

C. Compressive Strength of Concrete From the Samples.

The compressive strength developed by the concrete produced from different fine aggregates samples is shown in table 5.

Table 5 Compressive Strength Development with Curing Age

Days	S2	S3	S4	S5	S6	S7	characteristic target strength
7	24.756	25.395	20.893	21.78	20.89	20.032	20
14	32.146	31.196	25.121	27.617	24.748	26.064	27
28	41.899	37.173	28.682	33.645	28.411	27.661	30

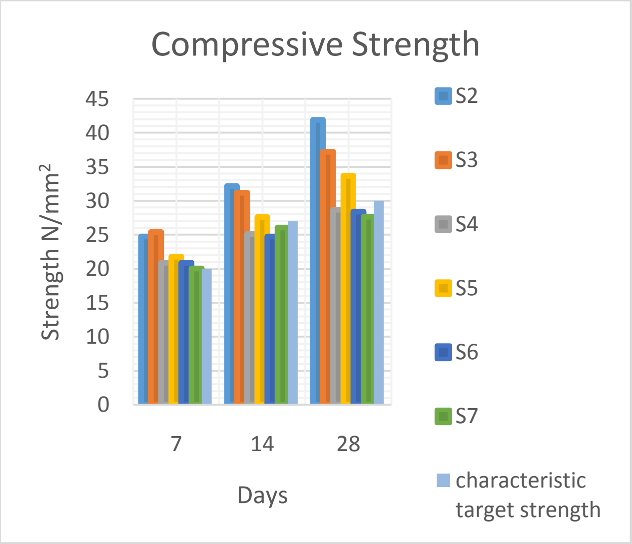

Figure 4 Compressive Strength Development with Curing Age

The compressive strength test was done at 7, 14 and 28 days to assess strength development of concrete. All samples indicated a progressive strength gain with curing age with Sample S3 developing the highest initial strength and S7 recording the lowest. At 7 days curing, all the samples attained early strength of 65% (20N/mm2) of the characteristic strength which can be attributed to the presence of calcium oxide in all the samples thereby contributing to early strength. The hot climate of the area also promoted early strength [2]. At 28 days curing, samples S2, S3 and S5 obtained 100% of the characteristic strength (30N/mm2) while samples S4, S6 and S7 did not achieve the characteristic strength. Samples S2, S3 and S5 had quartz as the predominant mineral which could contributed to high concentration of Silicon IV oxide. Though this prolongs the setting time of concrete it eventually increases the final concrete mix strength. Samples S4, S6 and S7 had lower concentrations of Silicon IV oxide, which contributes to the lower strength in 28 days. The choice of aggregates used influenced compressive strength development in the concrete samples. The compressive strength results indicate that concrete strength is influenced by the chemical composition of the aggregates, grading and the particle shape and texture.

V. CONCLUSIONS

The compressive strength and other properties of concrete are influenced by the physical, chemical and mineralogical properties of the fine aggregates used, the mix design, curing and the concrete placement method. Observations made during this research indicate that different fine aggregates vary in chemical, physical and mineralogical properties depending on the area of source and the weathering and crushing processes. The observations made on the resultant concrete indicate that concrete manufactured using natural river sand obtained higher compressive strengths than the concrete manufactured using alternative aggregates when the slump and water/cement ratio are constant at 28 days curing. All natural river sand sample aggregates obtained from Mwingi, Machakos and Kajiado area attained the target strength at 28 days and therefore suitable for use in the construction industry. Fine aggregates obtained from Naivasha, quarry dust and rock sand obtained from Mlolongo did not meet the design target strength requirement at 28days with an average deviation 5-6%. This can be explained by the inherent physical and chemical properties of these aggregates especially due to low Silica concentration, high silt and fineness modulus.

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