Journal of Harbin Engineering University
ISSN: 1006-7043

Vol 44 No. 10
October 2023

Effects of Constituents of Concrete Locally Sourced in Kakamega County and their Effect on the Compressive Strength

Tabitha Nyaguthii Soo[1], Bernadette Sabuni[2] & Benard Omondi[3]
[1]Student, MSc. Structural Engineering, Masinde Muliro University of Science and Technology, P.O Box 190 – 50100 Kakamega, KENYA
[2]Dean School of Engineering and Built Environment, Masinde Muliro University of Science and Technology, P.O Box 190 – 50100 Kakamega, KENYA
[3]Chairperson, Department of Civil and Structural Engineering, Masinde Muliro University of Science and Technology, P.O Box 190 – 50100 Kakamega, KENYA

Abstract
This paper presents the findings of a research on the characteristics of the various locally sourced materials used in concrete production within Kakamega County and their effect on its compressive strength. The research sampled fine aggregates from quarries, rivers and roadside, coarse aggregates from a machine crusher and hand crusher and threePortland Pozzolana Cement and one Ordinary Portland Cement used as a control. They were subjected to characterization tests. The results showed that fine aggregates vary in their characteristics due to their different sources with silt contents values of 5%,12,82% and 33.33%, specific gravity for coarse aggregate was 2.02 and 2.28 while the cement brands had similar characteristics. Concrete mix design was done.1008 concrete cubes were cast and cured as compressive strength tests were conducted. The results showed that varying characteristics of aggregates affects the mix ratios. The results showed that PPC combined with machine crushed coarse aggregate and quarried fines or river sand can be used to produce concrete class C20/25: higher concrete classesare not feasible with PPC. It is therefore important to characterize constituents of concrete to determine theireffecton the compressive strength of concrete.

Keywords: Aggregates, Cement, Concrete Mix Design, Compressive Strength

Introduction

Concrete is the most used construction material in the world with about 13 billion metric tons being used every year (Victoria, 2017). The quality of the materials used in the production of concrete plays a vital role in the development of both physical and strength properties of the resultant concrete mix. All the constituents of concrete and any admixtures used should be free from harmful impurities that negatively impact on the properties of hardened concrete(Hannah, 2014).

In the recent past, between (2016 to 2022) over 50 multi-storied houses have collapsed in Kenya because of various reasons resulting in loss of life and property (Kioko, 2014). Kakamega County has not been exempted in the collapses as there has been 7 collapses within that duration. It was with this in mind that the Kenyan President launched an audit on buildings in January 2017 (Kiptum, 2018). The reasons for the collapse of buildings were poor quality of concrete, inadequate designs and poor quality of other construction materials. Kiptum (2018), also asserted that poor quality concrete can be attributed to low quality cement, quality of sand, water and aggregates.

Aggregates make up between 60% and 80% of the volume of concrete, being surrounded by the cement paste. They are considered to be the most important factor affecting concrete strength (Mahmood, 2021).

Lekan (2006), deduced that a high percentage of clay and silt content in sand used in concrete production leads to a lower compressive strength of the hardened concrete. Hannah (2014), also affirmed that 44% of concrete’s compressive strength is contributed by combination of silt and clay content and organic impurities in sand. Factors such as particle shapes, texture, workability and mode of sand formation also play a key role in determination of concrete strength. The geological formation of an area is also key in determining the type of sand available in an area, since sand is a product of weathering action of rocks (Bhatawdekar, 2021). A study by Gashahun A. D.

2022, recommended that the concrete design mix should always consider reduction of strength due to presence of these impurities to ensure that the desirable strength of the concrete is achieved.

Kiptum (2018),deduced that the quick setting of cement delivered to a site was due to the low values of CaO and high values of Al_2O_3 and Fe_2O_3. The study also asserted that very high values of insoluble residues contributed to the non-binding nature of the cement. Lack of a standard mixing method of the concrete ingredients led to poor quality concrete. This asserts the need to carry out a concrete mix design for area specific aggregates. The study recommended that each client should test the cement before use to avoid using bad cement that can result poor quality concrete leading to collapse of buildings and thereafter loss of life, property and reputation of the building team. Research conducted by Kazeem (2015), explained the fact that most consumers of cement do not know the difference between the different grades that exist and their respective structural uses since the roadside brick layers used the empirical 1:2:4 ratio to achieve C15/20 without consideration of the type of cement and the properties of the fine and coarse aggregates in the respective areas.

The use of constituent materials in their original state in production of concrete poses a challenge of not achieving the desired compressive strength. This qualifies the need to carry out this research.

The objective of the study was to determine the properties of the locally sourced constituents of concrete in Kakamega County, Kenya and their effect on its compressive strength. This would help in determining the extent at which the use of locally sourced materials in their original state would have on the quality of concrete. The findings would help the stakeholders in the construction industry to employ the use of PPC which is economical in concrete production with greater confidence levels and enhance the implementation of the Housing Agenda of the Kenyan Government with ease in Kakamega County.

Materials And Methods

Materials

The cement used in this study were three different brands of Portland Pozzolana Cement 32.5N**.** They were sourced in Kakamega, and they conform with *KS EAS 18-1*. (2001) which is an adoption of the European Norm EN 197 cement standards. The brands were labelled as Sample A, Sample B, Sample C and sample D which was OPC and would act as a control.

The Fine aggregates employed were from three different sources namely river sand (RS), road side sand (FS) and quarry dust (QD) all within Kakamega County.

Coarse aggregate used from a quarry in the neighbouring Vihiga County that was ungraded hand crushed (CA2) and graded machine crushed (CA1) obtained from Quarry in Turbo.

Experimental Procedures

Physical Properties of Cement

The physical parameters of cement were tested in MMUST Concrete & Structures Laboratory based on EAS 148-3 (Marangu, 2014).

Chemical Properties of Cement

The chemical parameters were tested following the procedures in East African Standards 148-2. These include Loss of Ignition (L.O. I) EAS 148-2, sulphate (SO_3) EAS 148-2, Insoluble Residue (I. R) EAS 148-2, Chloride (Cl^-) EAS 148-2 and Magnesia (MgO) were done in accordance to EAS 148-2 (Okumu, 2018). Soundness was done following Le Chatelier Method and Initial setting time was determined in accordance with EAS 148-3 were done in State Department of Infrastructure in the Ministry of Transport, Infrastructure, Housing and Urban Development of the Government of Kenya.

Properties of Fine Aggregates

The fine aggregates were subjected to grading test BS EN 1097-6-2013, specific gravity test EN 12390-7, silt content test (BS1881-120).

Properties of Coarse Aggregates

The coarse aggregates were subjected to grading test BS EN 1097-6-2013, specific gravity test EN 12390-7, water absorption test EN 1097-6, sodium sulphate soundness test.

Casting of Cubes

The concrete cube size measuring 150× 150× 150mm in dimension was used. The batching of theconcrete was carried out by weight. Mixture wasproportioned for a target cube strength of 25N/mm^2 and 30N/mm^2 using BRE and BSEN 206-1 and are shown in Table 1. The proportions were mixed to homogeneity and then filled in 3 layers in the greased cube moulds and compacted 25 times for each layer. A total of 1008 cubes were cast, demoulded after 24 hours and cured under water for 98 days with a 7-day compressive strength test regime.

Compressive Strength Test

For each ofthe 7-day curing period, cubes were tested and theaverage compressive strength recorded. The concretecubes were tested in compression testing machineand the results were reported.

Data Analysis

The method used for data analysis was ANOVA. The dependent variable is the quality of concrete defined in terms of compressive strength was continuous (interval or ratio) level of measurement. The independent variables were fine and coarse aggregate properties and the type of cement (OPC and PPC) The intervening and moderating variables were mix proportions and aggregate combinations in ANOVA must be categorical (nominal or ordinal) variables." The p value of the correlation of compressive strength of concrete and workability of fresh concrete was determined in relation to the aggregate combinations and type of cement. P- values greater than 0.05 showed that there was no significant difference in the correlation while values less than 0.05 showed a significant difference in the correlation.

Table 1: Mix Ratios for the Constituents of Concrete

AGGREGATE COMBINATIONS	PPC/OPC MIX DESIGN RATIOS	EMPIRICAL MIX DESIGN RATIOS
RSCA1 C20/25	1:1.2:2.7	1:2:3
RSCA1 C25/30	1:1.5:2.6	1:1.5:3
QDCA1 C20/25	1:1.8:2.2	1:2:3
QDCA1C25/30	1:1.7:2	1:1.5:3
FSCA1 C20/25	1:1.9:2.1	1:2:3
FSCA1C25/30	1:1.7:2	1:1.5:3
RSCA2 C20/25	1:1.2:2.6	1:2:3
RSCA2C25/30	1:1.1:2.5	1:1.5:3
QDCA2 C20/25	1:1.7:2.1	1:2:3
QDCA2C25/30	1:1.6:2	1:1.5:3
FSCA2 C20/25	1:1.8:2	1:2:3
FSCA2C25/30	1:1.7:1.9	1:1.5:3

Results And Discussion

Physical and Chemical Properties of Cement

Tables 2 and 3 show the physical and chemical properties of cement that were sampled under this study.

Table 2: Physical properties of the sampled cement brands.

Physical Properties of Cement BS EN196:2010							
	Property	**Sample A 32.5N**	**Sample B 32.5N**	**Sample C 32.5N**	**Sample D 42.5N**	**Upper limit EAS**	**Remarks**
1.	Cement fineness %	94.18	97.9	99.04	99	≥ 90	Ok
2.	Consistency mm (vicat penetration from the bottom)	6.5	7	8	6.6	5-7mm	Sample C not Ok
3.	Initial Setting Time	1hr 53 minutes	4hrs 14 minutes	2hrs 20 minutes	1hr 28 mins	≥ 75 minutes	Ok
4.	Final Setting Time	2hrs	4hrs 24 minutes	3hrs 26minutes	3hrs	≤ 600 minutes	Ok
5.	Soundness aerated (mm)	1.0	1.0	0.9	1.0	10	Ok

All the samples passed the cement fineness test, initial and final setting time test and the aerated soundness test. A higher fineness will lead to a faster rate of strength development. The fineness property is okay for all the sampled brands of cement. Samples B and C have longer initial setting times making them inappropriate for faster placing. All the samples were viable in the final setting time test because they set at less than 10 hrs which is the upper limit. The aerated soundness test shows the resistance of the cement to disintegration by weathering and, in particular, freeze-thaw cycles. Meaning the cement should be at minimum volume change after it gets hardened. All the cements sampled in this study were okay in this test.

For consistency test and standard consistence, sample C had a value of 8mm which is greater than the limits of the EAS and 37 respectively. A higher value than the recommended implies that more water is required for mixing that will give a higher workability but also lead to segregation, bleeding and will finally affect concrete strength.

Table 3: Chemical Properties of the Sampled Cement Brands

Chemical Properties of Cement Tests Results							
S no.	**Property**	**Sample A 32.5N**	**Sample B 32.5N**	**Sample C 32.5N**	**Sample D 42.5N**	**Upper limit EAS**	**Remarks**
1.	Lossonignition@900^0 C, %m/m	1.99	1.56	1.78	0.11	5.0	Ok
2.	Insoluble Residue, %m/m	1.46	1.42	1.25	2.2	5.0	Ok
3.	Magnesium Oxide as MgO, %m/m	1.39	1.22	1.41	1.76	5.0	Ok
4.	Sulphate SO_3, %m/m	2.18	1.36	1.81	2.02	3.5	Ok
5.	Chlorides Cl, %m/m	0.009	0.007	0.006	0.012	0.1	Ok

The LOI was below the maximum allowable value of 5%. Althoughelevated levels of loss of ignition seen in samples A, B, and C may be ascribed to pre-hydration, indicating that the cement has been held for an extended duration (Kiptum, 2018).

All of the samples successfully passed the insoluble residue (IR) test, despite the fact that the content in Sample D exhibited comparatively higher levels than the other samples. The adulteration of cement can be assessed by examining the insoluble residue, which is caused by impurities present in gypsum (calcium sulphate). Previous research conducted by J. Chai (2000), has demonstrated that higher levels of insoluble residue can lead to a reduction in the strength of cement.

The maximum allowable content of magnesium oxide (MgO) in regular Portland cement should not surpass 5%. All of the cement samples analyzed in this study met the specified standard. The presence of magnesium oxide in cement is responsible for both the coloration and the hardness characteristics exhibited by the final concrete. Concrete will develop fractures if the amount of magnesium oxide (MgO) exceeds 5 percent (Philip, 2018).

The concentration of SO_3 in all cement brands fell within the permissible range. SO_3 is responsible for regulating the rate at which cement sets, hence preventing the occurrence of flash set. A decrease in the setting rate leads to an increase in the compressive strength of the solidified material.

The chloride concentration inside regular Portland cement ought to be maintained at a level below 0.1%. All of the cement samples examined in this study met the specified criterion. Increased levels of chloride present in cement will have a direct impact on the amount of chloride that becomes bonded inside the material.

Properties Of Aggregates

Silt Content of Sampled Fine Aggregates

Fig. 1 shows the silt content present in the sampled fine aggregates.

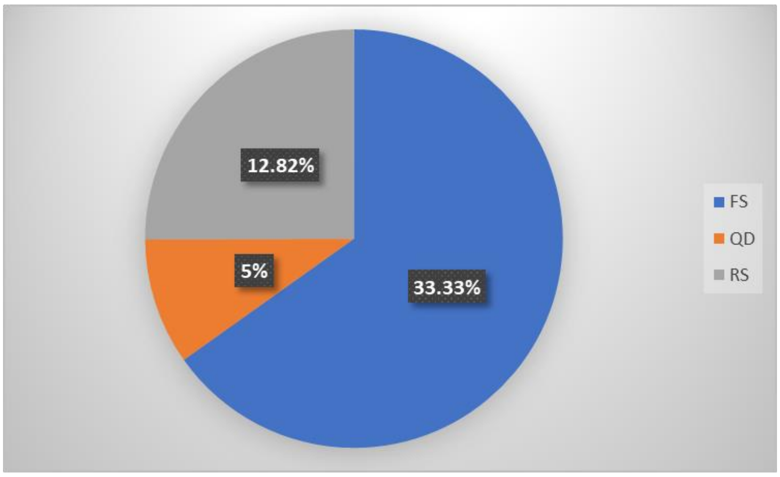

Figure 1: Percentage of Silt and Clay Content of Fine Aggregate.

All three categories of fine aggregates employed in this investigation exceeded the prescribed minimum requirement of 4% as stipulated in the British Standards. The silt contents of Samples QD, RS, and FS were determined to be 5%, 12.82%, and 33.33% respectively. The aforementioned discovery indicates that a considerable fraction of the fine aggregates used in building sites exceeds the prescribed minimum criteria.Hannah (2014) ,haddiscovered that 86.2% of the sand samples tested exceeded the allowable limit of silt and clay content.

Specific Gravity of Fine Aggregates

Fig 2 shows the specific gravity of fine aggregates tested in this study.

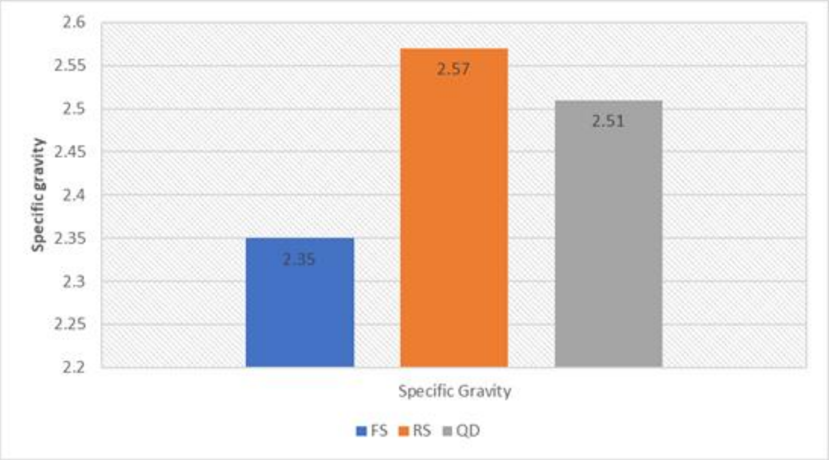

Figure 2: The Specific Gravity of the Aggregate

Fine aggregates RS and QD passed the specific gravity test with values of 2.57 and 2.51 respectively while FS had a value of 2.35 which is below the recommended range of 2.5 to 3.0.

Particle size Distribution for Fine Aggregates

Fig 3 shows the gradingcurves of fine aggregates tested in this study.

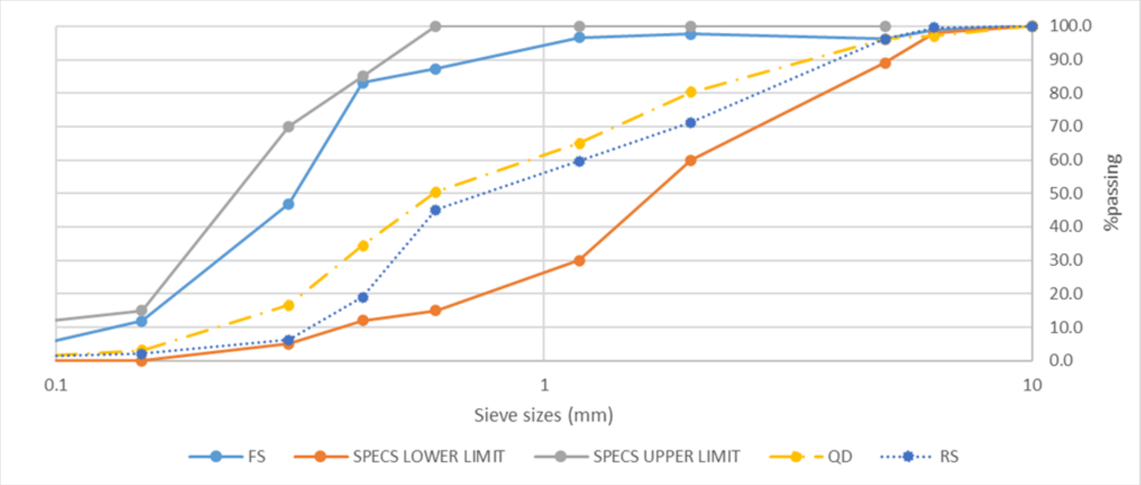

Figure 3: The Particle Size Distribution of the Fine Aggregate Samples

The grading of the fine aggregates, namely FS, QD, and RS, utilized in this investigation was determined to conform to the grading envelopes outlined in BS 882.

Particle size Distribution Test Curves for Coarse Aggregates

Fig.4 shows the grading curves of the coarse aggregates tested in this study.

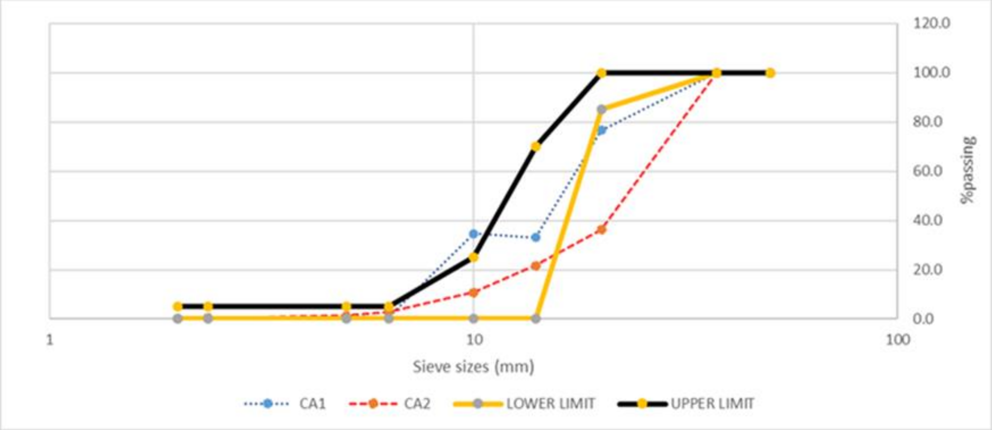

Figure 4: The Particle Size Distribution Curves of the Fine Aggregate Samples

The two coarse aggregate samples were out of range in some parts of the bracket. Sample CA1 has more fines while Sample CA2 has more large diameter aggregates.

Sodium Sulphate Soundness in Coarse Aggregates

Fig. 5 shows the sodium sulphate soundness for the coarse aggregates in this study.

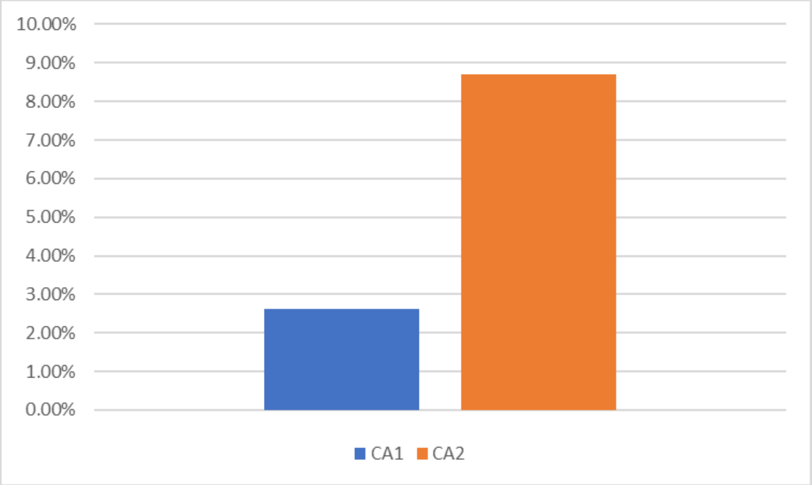

Figure 3: Sodium Sulphate Soundness in Coarse Aggregates

Aggregate CA1 is more resistant to weathering action by chemicals present with a value of 2.7% in cement than aggregate CA2 with a value of 8.7% hence will produce a more durable concrete. The upper limit for the sodium sulphate soundness is 10%.

Specific Gravity Test for Coarse Aggregates

Fig. 6 shows the sodium sulphate soundness for the coarse aggregates in this study.

The specific gravity values of both aggregate CA1 and CA2 fall below the prescribed range necessary for construction purposes with values of 2.28 and 2.02 respectively.

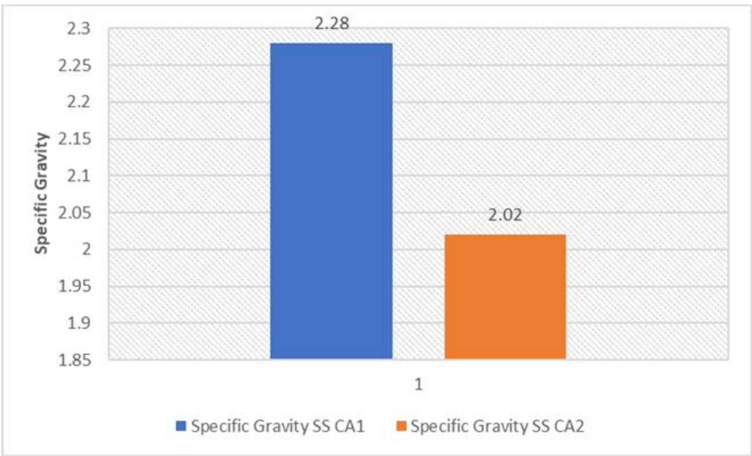

Figure 6: Specific Gravity of Coarse Aggregates

Water Absorption for Coarse Aggregates

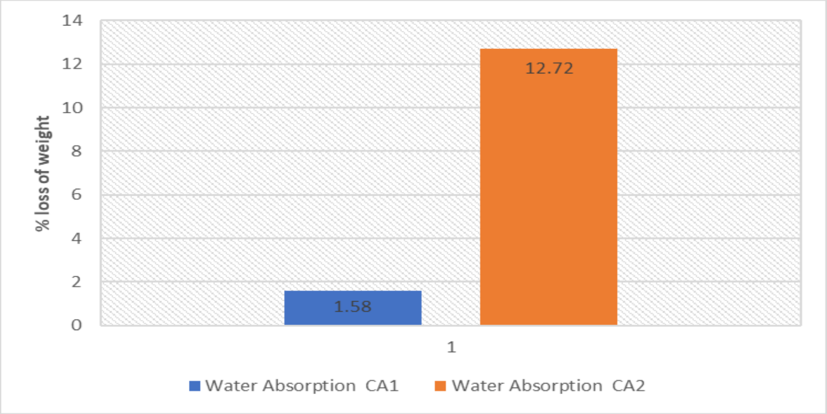

Figure 7: Water Absorption of Coarse Aggregates

Aggregate CA1 passed the water absorption rate while CA2 had an abnormally high absorption rate. The aggregate CA2 weathered upon soaking and pores were evident on its surface thus leading to the high absorption rate. The upper limit for water absorption is 3%.

Compressive Strength

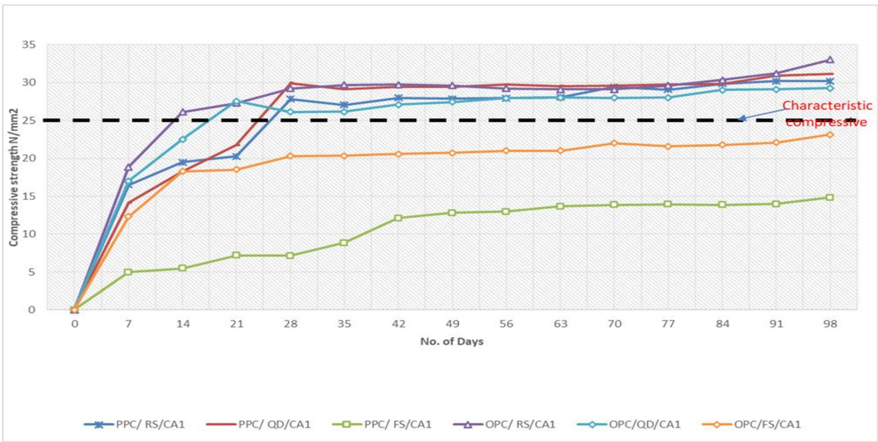

Figure 8: Compressive Strength vs Aggregate Combination for C 20/25 for PPC and OPC based Concrete for Aggregate CA1 Combinations with Aggregates RS, FS and QD

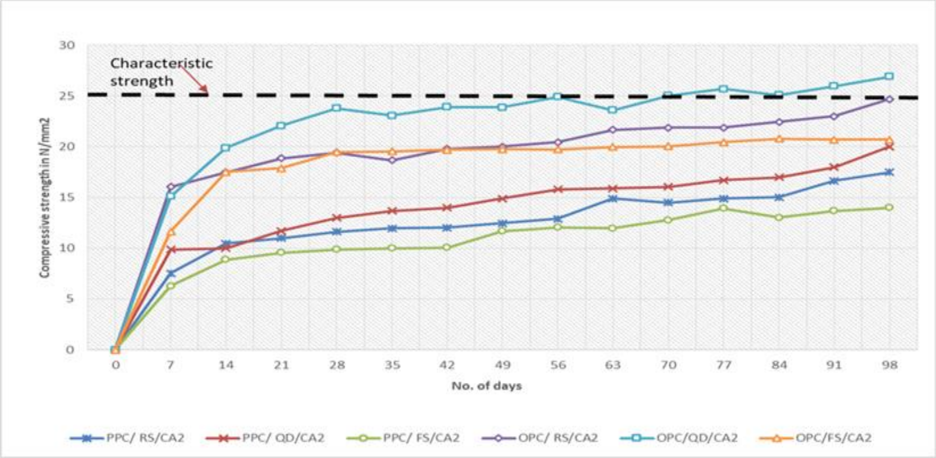

Figure 9: Compressive Strength vs Aggregate Combination for C 20/25 for PPC and OPC based Concrete for Aggregate CA2 Combinations with Aggregates RS, FS and QD

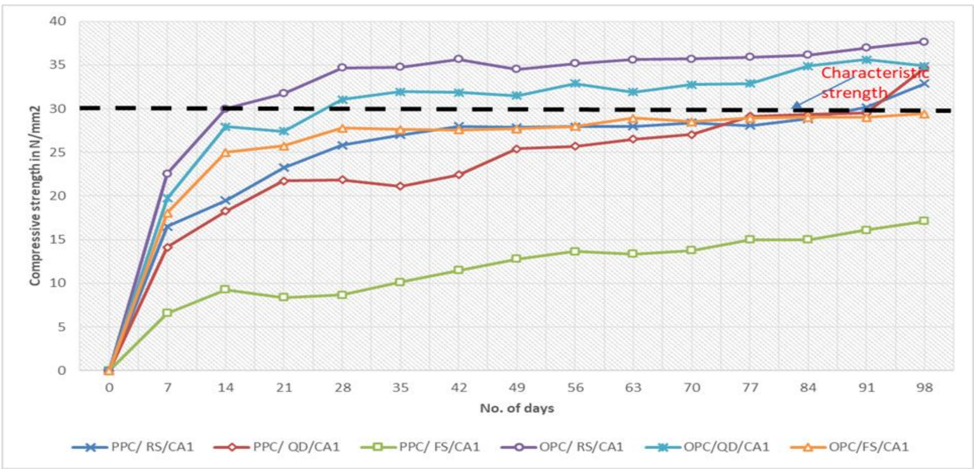

Figure 10: Compressive Strength vs Aggregate Combination for C25/30 for PPC and OPC based Concrete for Aggregate CA1 Combinations with Aggregates RS, FS and QD

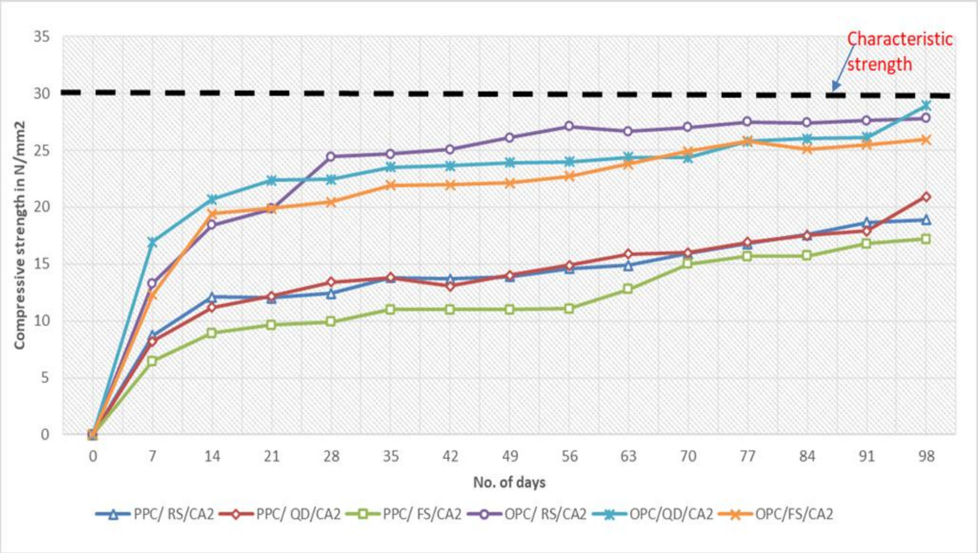

Figure 11: Compressive Strength vs Aggregate Combination for C 25/30 for PPC and OPC Based Concrete for Aggregate CA2 Combinations with Aggregates RS, FS and QD

At 28 days, the OPC and PPC concrete achieve 99% of the compressive strength of concrete of 25N/mm^2 as shown in From Fig 9. In both coarse aggregate and fine aggregate combinations PPC concrete compressive strength is less than that of OPC based concrete. The compressive strength of Ordinary Portland Cement concrete is higher by 9% than for Portland Pozzolana Cement concrete at 28 days. The strength values exhibited a steady increase in direct correlation with the duration of curing, suggesting a significant influence of curing age on the development of concrete strength. The level of strength exhibits a gradual increase from 77 days to 98 days, with a subsequent decrease in the rate of improvement in compressive strength.

For C20/25 and C25/30 for all aggregate combinations there is a significant difference between the compressive strength development for OPC and PPC based concretes because p- value (<0.05) as shown in Fig. 13.

For both C20/25 and C25/30 for all the aggregate combinations with different percentages of silt contents the p-value (<0.05) there is a significant difference in compressive strength development as shown in Fig. 14. Fine aggregate QD produces a strong mix followed by RS and FS. This could be attributed to the fact that silt content has an impact on the compressive strength of a concrete mix since RS has a silt content of 12% followed by QD at 5% and FS at 33.33%. This is evident because of the low compressive strength of the FS mixes.

For C20/25 and C25/30 for all aggregate combinations the p-value (<0.05) hence there is a significant difference in the compressive strength development for different specific gravities of coarse aggregates as shown in Fig. 15. Aggregate CA1 produces a bigger concrete density and therefore a higher compressive strength for the concrete. This is due to the fact that it has a higher specific gravity and is resistant to weathering action by the MgO present in the cement composition.Aggregate CA2 gives lower compressive strength for both OPC and PPC. The concrete cubes do not achieve the desired target compressive strength. The concrete cube density is also low due to the fact that it has a low specific gravity. The aggregate is also prone to weathering action by sodium sulphate and its surface is coated with dust particles.

Conclusions

The main aim of this study was to investigate the effect of constituent materials on the quality of concrete in Kakamega Countyit can be concluded that:

The different cement brands had varying chemical and physical properties but were majorly within the permissible limits set in the standards. All the fine aggregates used in the study did not meet the standard requirements of silt and clay content which consequently reduced the compressive strength of concrete whereas grading and specific gravity test results were within the recommended range. The coarse aggregates under this study did not meet the grading and specific gravity standard requirements and the effect was a lower compressive strength of the concrete.

It is therefore prudent to do material testing on the aggregates and carry out a concrete mix design for each concrete class using the BRE criteria with BS 8500-1 and BSEN 206-1 to be used in casting since the mix proportions for Portland Pozzolana Cement concrete achieved the characteristic strength for C20/25.

As predicted, the conventional Portland cements demonstrated higher strength when compared to the Portland pozzolana cements. Therefore, it can be deduced that there exists a direct correlation between the compressive strength of cements and the compressive strength of concrete. The concrete's compressive strength was reduced due to the combination of a substantial quantity of silt and clay in the tiny particles, along with the comparatively low specific gravity of the coarse aggregates. The experimental results indicated that the specific gravity of machine crushed aggregate exhibited a greater value in comparison to that of hand crushed aggregate. thus, the concrete that was produced demonstrated an augmented mass, thus leading to an elevated level of compressive strength can therefore be used with the machine crushed aggregate and quarry dust/river sand for concrete C20/25 since it achieves the characteristic strength at 28 days but not viable for C25/30. The hand crushed ungraded aggregate and roadside sand should not be used for production of concrete due to their low specific gravity and high silt and clay content respectively.

References

[1] A.S.M. Abdul Awal, M. W. (2009). Strength, Modulus of Elasticity and Shrinkage Behaviour of POFA Concrete. Malaysian Journal of Civil Engineering 21(2), 125-134.

[2] BS882. (1992). Specification for Aggregates from Natural Sources for Concrete. London: British Standard.

[3] Hannah N. Ngugi, R. N. (2014). Effects of Sand Quality on Compressive Strength of Concrete: A Case of Nairobi County and Its Environs, Kenya. Open Journal of Civil Engineering.

[4] Haque, F. A. (2017). Comparison Of Properties of Fine Aggregate Obtained from Recycled Concrete with that of Conventional Fine Aggregates. IJIRSE, 693-701.

[5] J. Chai, K. K. (2000). Effect of Insoluble residues on properties of Portland cement. Cement and concrete research,30, page 1209-1214.

[6] Kiptum, C. K. (2018). Analysis of Some Physical and Chemical Properties of Bad Cement Delivered to a Construction Site in Eldoret, Kenya. International Advanced Research Journal in Science, Engineering and Technology Vol. 5, Issue 4,, 107-109.

[7] Lekan Makanju Olanitori, J. O. (2006). Mitigating the Effect of Clay Content of Sand on Concrete Strength. 31st Conference on Our World in Concrete & Structures (pp. 344-352). Singapore: Open Journal of Civil Engineering.

[8] Mahmood Naderi, A. K. (2021). Experimental study of the effect of aggregate type on concrete strength and permeability. Journal of Building Engineering, 1-5.

[9] Mohammed Abas Abdela Salem, R. K. (2015). Influence of Specific Gravity on Weight of Proportions of Concrete. International Journal of Engineering Research & Technology (IJERT), 318-320.

[10] Olanitori, L. a. ((2005)). The Effect of Clayey Impurities in Sand on the Crushing Strength of Concrete (A Case Study of Sand in Akure Metropolis, Ondo State, Nigeria). Open Journal of Civil Engineering, 373-376.

[11] Philip Mogire, S. A. (2018). The effect of Selected Cement Brands in Kenya on the Critical Penetration Depth of Rust in Reinforced Concrete Water Conveyancing Structures. International Journal of Scientific and Research Publications, Volume 8, Issue 11, 276-285.

[12] Savitha, A. (2012). Importance of Quality Assurance of Materials for Construction Work. Building Materials Research, 1-5.

[13] Tauseef B., M. K. (2018). Effect of Silt Content on the strength Property of Concrete- A Case Study. IJERT, 1-10.

[14] OkumuV.A ,Shitote M. (2017). Influence of Constituent Materials Properties on the Compressive Strength of in Situ Concrete in Kenya. Open Journal of Civil Engineering, 63-81.