The Effect of the Properties of Constituent Materials on the Quality of Concrete in Kenya

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Abstract— Kenya's long term strategic plan under Vision 2030 includes, among others, a large component of infrastructure development to meet the demand for its population. Reinforced concrete is the most commonly used construction material in the country and therefore it forms an integral part of this development plan. In the recent past, Kenya has experienced a worrying rate of collapse of reinforced concrete buildings during construction. This phenomenon has been partly attributed to the quality of in-situ concrete and poor workmanship among other factors. Currently the concrete mix design methods used in Kenya are based on Ordinary Portland cement (42.5) which is normally directly replaced by the blended Portland cements (32.5). This work presents findings of an experimental investigation on the effects of cement type and properties of fine aggregates on the quality of concrete in Kenya. Four different brands of cement and fine aggregates from three different locations in the country were used during the study. The effect of eucalyptus plant extracts on the quality of concrete was also investigated. The British DOE mix design method was used to generate the concrete mix proportions. It was observed that the currently used mix design methods lead to production of concrete with compressive strengths that are less than the target strengths at 28days when the blended Portland cement 32.5N/mm^2 is used. Concrete made from Tiwi sand also had higher strengths compared to the other fine aggregates used in the experiments. It was further observed that Eucalyptus leaf extracts helped to increase both the initial and ultimate compressive strength development for the four selected cement brands. The study therefore proposes that a mix design procedure be developed for blended Portland cement concrete.

Keywords—Blended Portland cement, Concrete mix design. Ordinary Portland cement, Plant extracts.

I. INTRODUCTION

The construction industry plays a major role in social economic development of any society. In Kenya, the most commonly used construction material is concrete. Concrete is a composite material made by collective mechanical and chemical interactions of its ingredients (binder, aggregates and water) [1]. The wide usage is attributed to its unique characteristics such as strength and durability, affordability, low maintenance, fire-resistance, versatility, relatively low emissions of CO_2, excellent thermal mass, and energy efficiency in production, local production and use [2], [3]. The strength, durability and other qualities of concrete depend upon the properties of its constituent materials, proportions of the mix, the method of compaction, workmanship during placing and curing [2], [3], [4]. Concrete has good compression resistance and less tension capacity [5].

In the developed countries, the most widely used binder is ordinary Portland cement (42.5N/mm^2 and 52.5N/mm^2) while in developing counties the most commonly used binder is the blended Portland cements (32.5N/mm^2) [6]. Concrete mix design in Kenya is based on the British method popularly referred to as the "DOE method" which is based on ordinary Portland cement (42.5N/mm^2/52.5N/mm^2). Currently there is no mix design method designed for blended Portland cement (32.5N/mm^2) concrete production in Kenya. The available mix design methods are based on ordinary Portland cement and their usage for blended cement involves direct replacement of the ordinary Portland cement with the slower strength gaining blended cements. Research has shown that when the blended cements are used to directly replace the ordinary Portland cements in the mix design, the results are concrete with strengths lower than the target strengths [7], [8].

In 2015, about 17 reinforced concrete buildings in Kenya collapsed while under construction. This collapse has been attributed to the quality of in-situ concrete and poor workmanship among other possible causes of failure [9].

Research was undertaken to investigate the effect locally available constituent materials such as cement type and fine aggregates on the workability and strength of concrete and to assess the suitability of Eucalyptus plant extracts as an economical and eco-friendly admixture for concrete.

II. MATERIALS USED IN THE RESEARCH

Concrete constituent materials have varying properties and contribute differently to the final product 'concrete'. To achieve the desired concrete properties in terms of strength and durability, each constituent material is required to perform specific functions.

The laboratory experiments were divided into two parts: The first part was to investigate the effect of the type of cements and the fine aggregates from the different sources on the

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quality of concrete; while the second part was to investigate the suitability of the plant extract additives on the quality of concrete. The design characteristic strength of concrete was maintained at 25N/mm^2.

A) Fine aggregates

The fine aggregates used in the research were natural river sand obtained from the Kenyan South Coast region (Tiwi sand (TS)), Control Sand (CL) from the Jomo Kenyatta University of Agriculture and Technology (JKUAT) Laboratory, quarry fines obtained from Nairobi Quarry (QB) and Naivasha Quarry (QV). These aggregates were graded in accordance to BS 812:1992 while the physical properties of the fine aggregates were checked based on the BS standards: The Bulk Density (BS 812-2:1995), Specific gravity (BS 812-102:1995), Water Absorption (BS 813-2:1995) and Moisture Content (BS 812-109:1990).

B) Cement

Kenyan cement is produced in accordance to KS EAS 18-1: 2001 which is an adoption of the European Norm EN 197:2011 cement standards (Kenya Bereau of Standards, 2005). The specific cement tests were done based on BS EN 196-7:2007 and the KS EAS 18-1: 2001[10]. The cements used in the experiment were: Power plus (42.5N/mm^2), *Nguvu* cement (32.5N/mm^2), *Blue Triangle* cements (32.5N/mm^2) *Simba* cements (32.5N/mm^2) and the *Savannah* brand (32.5N/mm^2).

C) Course Aggregates

The coarse aggregate used in the research was crushed aggregates of maximum size of 20mm obtained from Juja. Sieve analysis was done on the coarse aggregates based on BS 812:1992. The percentage passing the BS sieves by mass was found to be within the recommended envelope. The same batch of coarse aggregates was used throughout the research.

D) Water

Tap water from Jomo Kenyatta University of Agriculture and Technology water treatment plant was used in the mixing of concrete and curing of all the concrete specimens.

E) Plant Extract

The Leaves of two species of *Eucalyptus spp.* plants found within JKUAT main campus were used in the research. These were *Eucalyptus polybractea* and *Eucalyptus citriadora / Corymbia citriadora*. The leaves were then washed thoroughly using tap water to remove any dust and organisms. The leaves were then boiled at a ratio of 1:3 by mass of water (1 part leaves to 3 parts water) after which the solution was allowed to cool for 24 hours in opaque containers to maintain stability. An experimental dosage of 1L of additive/15kg of cement was adopted and maintained to check the effect of the extract on the concrete made from the different cement brands.

III. METHODOLOGY

A) Concrete mix Design

Concrete mix design is the science of correct proportioning of concrete ingredient materials based on project requirements, to obtain the desired properties of concrete in plastic/wet as well in hardened state. It involves choosing suitable ingredients and determining their relative quantities in order to produce an economical concrete mix of certain minimum properties, practical workability, desired strength and durability [3]. The main parameters affecting the design of a concrete mixture are: cement type, water/cement ratio, coarse aggregate/total aggregate ratio and total aggregate/cement ratio [11], [12].

The research was divided into two parts. The first part was to investigate the effect of local fine aggregates and local cement brands on the properties of concrete while the second part was to investigate the effect of Eucalyptus plant extracts on the properties of concrete. The concrete mix design was based on the British DOE method. The concrete mix ratio used during the research was 1:1.5:3 for cement: sand: coarse aggregates to obtain concrete class 25N/mm^2. The slump was maintained at 50±5mm for the first part of the research and 40±5mm for the second part of the experiment [7].

B) Materials characterization

The fine aggregates were identified as: Tiwi sand (TS), Control Sand (CL), Nairobi Quarry fines (QB) and Naivasha Quarry fines (QV) as used in the first part of the research while the cement brands were coded as: Nguvu cement (CEM A), Savannah cement (CEM B), Blue Triangle cement (CEM C), and Simba cement (CEM D) in the second part of the research. Several concrete mix samples were developed using the four different local cement brands and the Eucalyptus spp. leaves plant extracts additives was also used. The fresh concrete properties were checked based on the slump while the compressive strength test was used to check the hardened properties.

IV. RESULTS AND DISCUSSIONS

A) Fine Aggregates Material Properties

Fine aggregates affect the workability and the surface finish of concrete. Table 1 shows the properties of the different fine aggregates used during the experiment.

Table 1: Properties of Fine Aggregates Used

Aggregate Source	Specific Gravity	Fineness Modulus	Water Absorption
Tiwi Sand (TS)	2.83	3.014	7.825%
Nairobi Quarry (QB)	2.80	3.540	2.050%
Naivasha Quarry (QV)	2.31	2.587	1.32.%

The sieve analysis and the percentage fines results were as shown in Figure 1 and Figure 2. From the sieve analysis graph, it is clear that the grading curve for the aggregates falls within the lower and upper limit of the grading requirement for aggregate from natural sources BS 882:1992

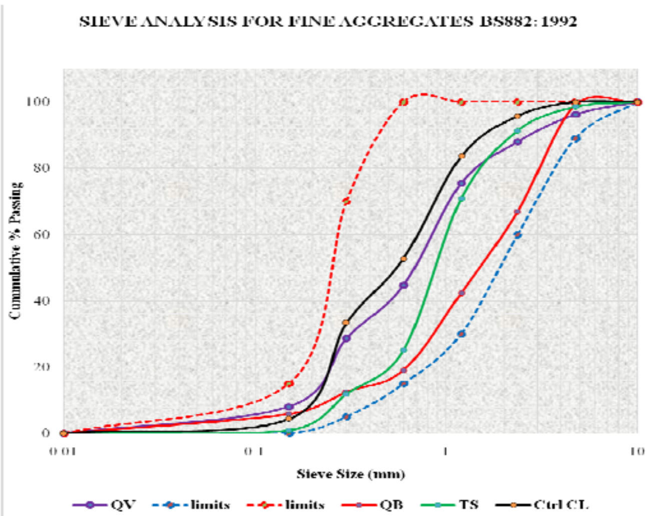

Figure 1: Sieve Analysis Results for the Fine Aggregates

The British standards and the Indian Standards recommend a maximum of 4% of silt and clay content in fine aggregates used in concrete production. Thus only QB sample and the control qualified for use according to the BS. The ASTM Standards on the other hand recommends 10%. Thus based on these international standards, the fine aggregates had silt contents within the recommended limit
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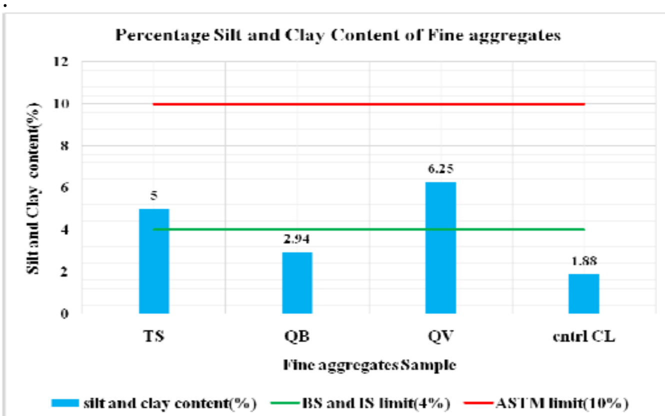

Figure 2: Silt Content Results

B) Effect of Fine Aggregates on the Water / Cement ratio

The experiment was based on a constant slump margin of 50±5mm. This was achieved through the variation of the water/ cement ratio while the concrete mix proportions was maintained at 1:1.5:3 for cement: fine aggregates: coarse aggregates.

It was observed that the fine aggregates with finer particles required more water to wet their larger specific surface area, whilst the irregular shape and rougher texture of the quarry dust angular aggregates demanded more water than rounded sand aggregates. The type of cement also affected the water cement ratio as the 42.5N/mm^2 cement type required more water due to its higher rate of hydration compared to the 32.5N/mm^2 cement types which have a slower rate of hydration.

The mix containing sand required a water/ cement ratio of 0.40 while the mix containing quarry dust required a water/cement ratio of 0.66 when cement type 32.5N/mm^2 was used. When cement type 42.5N/mm^2 was used, the mix containing sand required water/cement ratio of 0.5 while the mix containing quarry duct required a water/cement ratio of 0.65. It was observed that the sand (TS) fine aggregate were Spherical, well rounded with smooth surface and they had an increase in workability with less water requirements to attain the required slump. Quarry dust fine aggregate QB and QV were angular, elongated, rough surfaced aggregates with fine particles thus require more water to achieve the required slump in a given mix as illustrated by Figure 3.

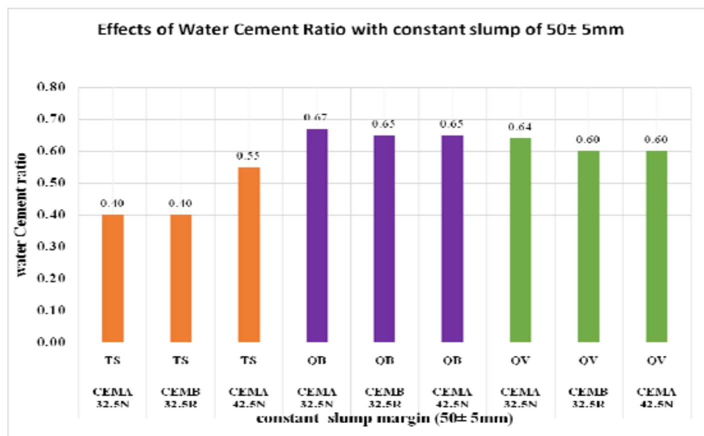

Figure 3: Effect of Fine aggregates type and cement type on the Water/ Cement Ratio Results

C) Effects of Fine Aggregates on the Compressive Strength development

The 7 and 28 days compressive strength were used to determine the strength development. It was observed that sand fine aggregate (TS) yielded a higher strength with all the cement brands used compared to the quarry dust fine aggregates QB and QV at a constant slump. The higher amount of finer particles in the quarry dust required more water to wet their large specific surface area at a constant slump, thus decreased its strength. This results show that the strength development of concrete does not only depend on the grading of the fine aggregates but also the shape of the particles and the chemical composition [13].

As expected, it was also observed that the cement type affect the compressive strength development of concrete as cement type 42.5N/mm^2 concrete yielded higher strengths compared to cement type 32.5N/mm^2 which did not achieve the target design strengths of above 30N/mm^2 required for a class 25N/mm^2 [7]. This therefore shows that the same mix design procedure should not be used for the two different types of cements as their rate of hydration and strength development are different. All the different fine aggregates showed an impressive high strength when ordinary Portland cement 42.5N/mm^2 cement was used as shown in Figure 4.

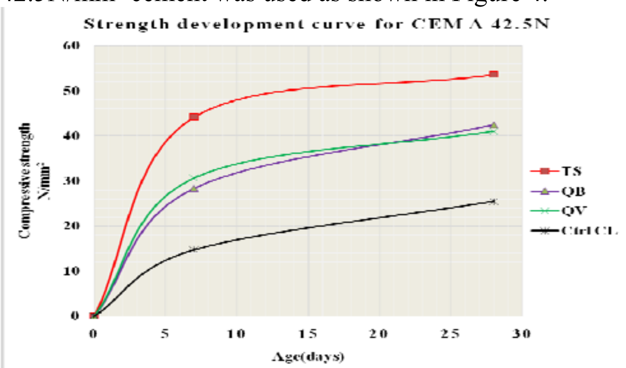

Figure 4: Strength Development for CEM A 42.5N/mm^2.

The difference in ultimate compressive strengths at 28 days obtained using the 42.5N/mm^2 and 32.5N/mm^2 was about 37%. The mixes with the 32.5N/mm^2 cement types did not however obtain the design ultimate target strengths for all the different types of fine aggregates as shown in Figure 5. This is due to the fact that the Portland pozzolanic cements have a slow rate of strength development and thus at 28days they may have not reached their ultimate strengths. Their strength development however continues over a longer period of time compared to the ordinary Portland cements. TS sand fine aggregates however produced concrete with higher compressive strengths of approximately 25% compared to the other fine aggregates used in the experiment.

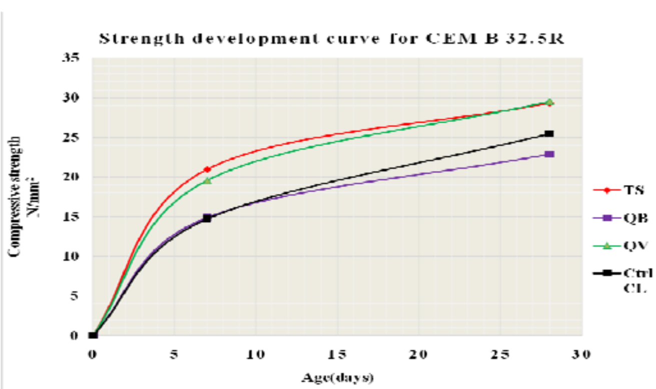

Figure 5: Strength Development for CEM 32.5N/mm^2.

D) *Effect of water cement ratio on compressive strength*

It was observed that at a constant slump of 50± 5mm, the different fine aggregates required varied amount of water to achieve the required workability. These varied water/cement ratios yielded different compressive strengths depending on the fine aggregates and the cement types. An average compressive strength was computed for each of the fine aggregates against their average water/cement ratio as shown in Figure 6. As expected, the results show that the higher the water/ cement ratio, the lower the compressive strength and the lower the water/ cement ratio, the higher the compressive strengths.

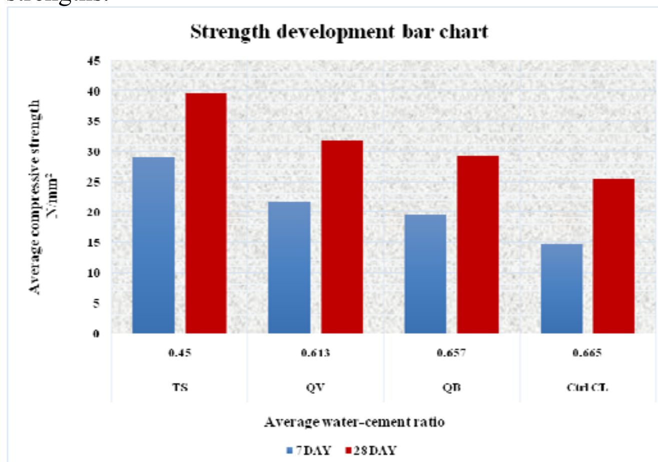

Figure 6: The Relationship between the Water/Cement Ratio and the Compressive Strength

E) The Effects of Eucalyptus Plant Extracts on the Properties of Concrete

The second set of experiments was based on a constant workability in terms of slump of 45±5mm. The water/cement ratio was also maintained at ≤ 0.45 to maximise on strength and durability of concrete. The concrete mix proportions were maintained at 1:1.5:3 for all the cement brands. The effects of the cement brands and the plant extract additives on the properties of concrete were investigated while using the same aggregates obtained from Juja.

The Coarse aggregates had the properties shown in Table 2: The maximum size of the aggregates was 20mm and they were graded in accordance to the BS 812:1992 sieves. The results were: 37.5mm (100%), 20mm (99.6%), 10mm (40%) and 5mm (9%) passing.

Locally available river sand from Juja was used as fine aggregates. The fine aggregates were graded based on BS 812:1992 sieves. The results were: 5mm (99.5%), 2.36mm (98.5%), 1.18mm (86.75%), 0.6mm (58.25%), 0.3mm (23.75%) and 0.15mm (4%) passing and was falling under zone II. The fine aggregates properties were as shown in Table 2.

Table 2: Aggregates Properties

Property	Specific gravity (BS 812:1992)	Bulk density (BS 812-2:1995)	Water Absorption (BS 813-2:1995)	Moisture content (BS 812-109:1990)	Fineness Modulus	M si
Coarse aggregates	2.76	1420 kg/m^3	2.7%	2.2%.		2
Fine aggregates	2.62	1470 kg/m^3	8.63%	8.1%.	3.3	

The cement brands used were Nguvu, Savanna, Blue triangle and Simba cements all of which are 32.5N/mm^2 strengths. For each cement brand, 3 mixes were made. The first mix had no additive; the second mix contained *Eucalyptus polybractea* leaf extracts additive (Esp. 1); and the third mix contained *Eucalyptus citriadora* leaf extracts additive (Esp. 2).

a. Effect of Cement Type on the Compressive Strength

The 7 and 28 day compressive strengths for the four cement brands without additives is summarized in Figure 7 below. The results clearly show that none of the mixes achieved the design target strength of above 30N/mm^2 expected for class 25N/mm^2 concrete. This is due to the fact that blended Portland cements have a slower strength development compared to the ordinary Portland cements 42.5N/mm^2 which are recommended in the British DOE mix design method used in this study. The difference in compressive strengths between concrete made from the different brands of 32.5N/mm^2 cements can however be attributed to the difference in fineness and composition of the cements.

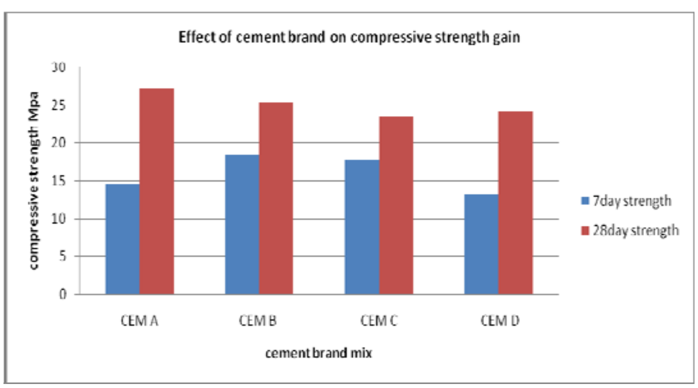

Figure 7: Effect of Cement Brand on Compressive Strength

b. Effect Of *Eucalyptus Polybractea* (Esp.1) On Compressive Strength Gain

There was a notable increase in compressive strength at 7 and 28days in all the mixes when Esp. 1 was added as shown in Figure 8. This shows that the plant extract acted as a plasticizer thus increasing the rate of hydration of the different cement brands leading to an increase in compressive strength at both 7 days and 28days.

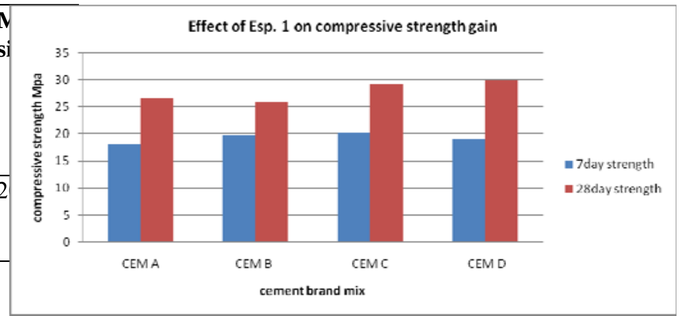

Figure 8: Effect of Plant Extract on Compressive Strength

The different cement brands reacted differently with the additive leading to varied rates of strength gain. At 7 days, CEM A had 30.62%, CEM B had 6.42%, CEM C had 14.34% and CEM D had 44.65% increase. At 28days however, there was a very small increase in strength in all the cement brands which was in average less than 3%. This shows that additive Esp.1 improved the early and ultimate compressive strength gain at the experimental dosage of 1L of additive/ 15 kg of cement. The best results were with CEM C and CEM D which initially failed to attain the characteristic compressive strength of 25Mpa at 28 days.

c. Effect Of *Eucalyptus Citriadora* (Esp. 2) On Compressive Strength Gain

Eucalyptus citriadora leaf extracts Esp. 2 also had varied strength gains when added to concrete made from the different cement brands both at 7 days and 28days as shown in Figure 9. The percentage increment in compressive strengths for the different brands at 7 days and 28days were as shown in Table 3.

Table 3: Percentage Increment in Compressive Strength

Cement	CEM A	CEM B	CEM C	CEM D
7 Days	37.77%	3.42%	26.11%	56.00%
28Days	24.00%	0.00%	21.00%	25.00%

The results show that the plant extract had a higher effect on the early strength development compared to the ultimate strength development. This species of Eucalyptus had a higher percentage gain compared to the Esp. 1 plant extract at the same dosage.

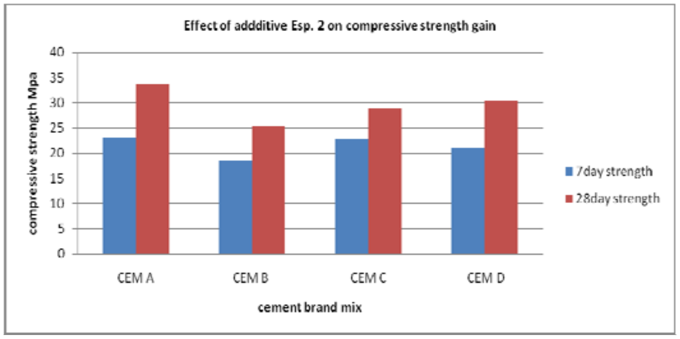

Figure 9: Effect of Esp 2. Plant Extract on Compressive Strength

V. CONCLUSION

The strength, durability and other characteristics of concrete depend upon the properties of its ingredients materials, proportions of the mix, the method of compaction, workmanship during placing and curing. Based on the observations made during this experimental study, the currently used mix design procedures yield concrete mix proportions that do not meet the design target strength requirements when the blended Portland cements are used. This is however improved when Eucalyptus plant extracts are used to increase the rate of hydration leading to improved early strength gains. This aspect however requires further investigations to establish the actual property of the plant extract that improve the strength of concrete.

The different cement brands also have an influence in the compressive strength due to the varied composition of pozzolanic materials added to them and the level of fineness. The results also indicate that the river sand fine aggregates produce higher compressive strengths in concrete compared to the quarry dust when the slump is fixed.

With proper materials and workmanship, the results did not achieve the designed target strengths. This shows that the mix design methods need to be investigated to establish their suitability for blended Portland cements concrete. The results also show that when ordinary Portland cements are used, the material yields compressive strengths exceeding the designed target strengths. This clearly show that the ordinary Portland cements should not be directly replaced by the blended cements in the mix design and therefore, there should be a mix design procedure specifically for blended cement concrete production.

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