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Use of Plant-Based Accelerator to Enhance Rate of Gain of Strength of Kenyan Blended Cement

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Abstract

Concrete is the most widely used construction material in the world. The situation in the country is not an exception as most of the infrastructures in Kenya such as buildings, bridges, concrete drainage among others, are constructed using concrete. Sadly, the failure of buildings and other concrete structures is very common in Kenya. Blended Portland cement type 32.5 N/mm^2 is the most widely used concrete binder material and is found in all parts of the country. Despite blended cement CEM 32.5 being the most commonly used cement type in construction industry in Kenya and most developing countries as a result of its low price and availability locally, its strength gain has been proven to be lower compared to when other types of cement are used due to quantity of pozzolanic material added to the blend. This paper outlines findings of an experimental investigation on the use of cypress tree extract as an accelerator to enhance rate of gain of strength on Kenyan blended cements. Six different blended cement brands locally available were used during the study. Cement chemical analysis was done using X-ray diffraction method while for the cypress extract, Atomic Absorption Spectrometer machine was used. Physical and mechanical properties were checked based on the British standards. The generation of the concrete mix design was done using the British DOE method and concrete was tested for the compressive strength at 7, 14, 21, 28, 56 and 90 days. It was observed that 15% dosage of the extract expressed as a mass percentage of the cement content gives the most improved compressive strength of concrete, 10.4% at 7 days and 9.5% at 28 days hence the optimum. It was further noted that when Cypress tree extract is used as an accelerator in the mix, the blended cement concrete achieves the design strength at 27 days saving 10 days of the project duration compared to when no accelerator is used while the ultimate strength is achieved at 67 days. The study therefore recommends the use of the cypress

tree bark extract at a dosage of 15%, by mass, of the cement content as an accelerator when the structure is to be loaded at 28 days and waiting up to 39 days before loading the structure if no accelerator is used for blended cement concrete.

Keywords

Kenyan Blended Portland Cement Concrete, Concrete Compressive Strength, Blended Portland Cement, Ultimate Strength Age

1. Introduction

Concrete is the single most widely used construction material in Kenya [1] and cement paste plays a major role in binding the aggregates, which account for majority of the constituents of concrete. Hence, the properties of cement dictate the performance and reliability of Concrete structures. The main aim of structural design is to realize an acceptable probability that proposed structure will perform satisfactorily during the design period, sustain all the loads and deformations with adequate durability and resistance to the effect of misuse and fire [2]. Despite the design process of structural element being done, the failure of buildings and other concrete structures has been and is still very common in Kenya to date [3]. Concrete is a mixture of water, coarse and fine aggregate, and a binding material which in most cases is cement. Blended Portland cement type 32.5 N/mm^2 is found in all parts of the country hence majorly used as a binder for concrete production. The consumption of blended cements is currently increasing all over the world. However, there are differences regarding the types of additives and the quantities used in the blended cement types used in various countries and within the same country. Quality assurance of construction materials plays a significant role on structural integrity, serviceability, and durability of constructed infrastructures [4]. The properties of construction materials and compliance with design specification become the major factor responsible for premature failure of buildings in Kenya. Choices of cement brand used quantity of cement in the mix and the cement grade are some of the parameters that determine the compressive strength of concrete attained [5].

Worldwide, cement is the main form of binder used in concrete production and the most commonly used type is ordinary Portland cement (OPC) [6]. The basic chemical components of ordinary Portland cement are Calcium (Ca), Silicon (Si), Aluminum (Al) and Iron (Fe). These chemicals are extracted from Limestone (C_aCO_3), Sand (SiO_2), Shale, Clay (SiO_2, Al_2O_3, and Fe_2O_3) or Iron Ore/Mill Scale (Fe_2O_3). Cement composition and fineness influence the strength development of concrete.

Prior to the adoption and implementation of the blended Portland cement present in the Kenyan Market, the word ordinary Portland cement (OPC) be-

came such a natural part of construction vocabulary that even individuals who very remotely relate to modern construction processes make glib reference to the substance. This is because they were majorly available in the local market and approved for production. OPC which is now referred to as Portland cement is produced in bagged form and in bulk form for open market and hence available in major towns. However, the price for this cement is almost double compared to other blended cement types [7]. In the local hardware, 32.5 N/mm^2 blended cements are mostly available in the stock hence justifying the need to investigate their ultimate strength age [8].

The comparison of the compressive strength development patterns of concrete using different cement types at 28 days, which is considered as the ultimate strength gain period shows that the ordinary Portland cement have significantly high compressive strength compared to the blended Portland cements [9]. Ordinary Portland cement concrete reach their ultimate compressive strength at 28 days above which the cement types exhibit marginal strength gain while the blended Portland cements continue to gain significant amount of compressive strength between 28 days to 90 days.

Concrete strength level and rate of strength gain are dependent on many factors. Hydration rate and percentage strength level that can be reached sooner when concrete cures at higher temperature or when certain cement/admixture combinations are used are two factors related to the use of cement. Besides the cement used, there are many factors contributing to both strength level and its rate of gain at different ages which includes mix compositions, aggregate type and properties, temperature degree, curing time and methods among others [10].

Despite blended cement CEM 32.5 being the most commonly used cement type in construction in Kenya, there are fear of compromise in strength at the time of loading, and durability of constructed buildings due to their slower strength gain as compared to the ordinary Portland cement concrete. Since locally blended cement is the main binding material in concrete making in Kenya, its properties influence the quality of concrete so produced by it and therefore its chemistry will dictate the chemistry of concrete [11]. Previous studies had shown that none of the brands of the blended Portland cement achieved the target design strength for >C25 concrete. Okumu *et al.* (2016) reports that none of the Kenya blended cement achieve the target design strength at 28 days of age and it continues to gain significant amount of compressive strength even beyond 90 days [12]. Yan Feng *et al.* (2019) also reported a reduction on the compressive strength and strength development rate on blended cement mortar due to the effect of ultrafine granulated copper slag [6]. Hiremath P.N. *et al.*, 2020 further reported in his study on the early strength development of blended cement concrete that it requires a minimum of 56 to 90 days to attain the desired strength [10]. Changing cement grades changes the structural properties of concrete hence changing the cement grade during concreting the structural

member is not acceptable. The choice of cement brands to be used should be based on the expected strength requirement since each brand has a varying property [13].

The suitability of the Plant extract has been investigated and proved to have a wide range of organic components and materials used as an admixture to alter the properties of cement. Chege John *et al.* (2014) recommended the use of pine tree bark extract at a dosage of 20% by mass of the cement content to be used as an admixture. Sathya A *et al.*, (2014) also reported that compressive strength and setting time of cement are influenced by the bio-admixture hydro-extract and bio fine powder of water hyacinth which is one of the common plants in Kenya. According to research done by Oyawa W *et al.*, (2014), cypress tree extract is proved to increase compressive strength by increasing the dosage at a constant slump and also increasing the workability by reducing the liquid requirement of the wet concrete mix.

This study therefore comparatively assess the performance of the Kenyan blended cement concrete produced from different brands of cement manufactured in Kenya by evaluating the ultimate compressive strength age, the margin by which the strength of the blended Portland cement varies from the target and design strength at 28 days and the viability of accelerating the strength development by adding optimum percentage of cypress tree as an accelerator while still meeting the requirement of a sustainable development concrete. The durability of concrete is an actual issue linked to sustainable development considerations [14], hence the use of boiled cypress tree extract is a welcome development due to its sustainability nature and low cost compared to the chemical accelerators.

2. Materials and Methods

2.1. Material

2.1.1. Fine and Coarse Aggregate

Locally available Crushed stone aggregates from Sinopec quarry in Naivasha was used as coarse aggregate (CA) and fine aggregate (FA) in the manufacture of concrete constituted from size 0 - 20 mm. The suitability of the aggregate for the concrete production was checked through particle distribution in accordance with BS EN 1097-6-2013; and tests on their physical properties determined following the laid down procedures in their respective British standards: Specific gravity (BS 812-109:1995), Bulk density (BS 812-2:1995). Water Absorption (BS 813-2:1995) and Moisture content (BS 812-109:1990).

2.1.2. Cement

The cement used was Kenyan blended Portland cement of grade 32.5 manufactured by six different local companies. The product conforms to KS EAS 18-1:2001 which is the adoption of the European Norm EN 197:2011 cement Standards. The six companies whose cement brands were sourced from local hardware's within

Naivasha have been coded in this study as company A to F.

2.1.3. Water

Tap water from the Olkaria water treatment plant was used during the study in the mixing of concrete and curing of all the concrete specimens. The water met the requirement as per the BS EN 1008 standard requirement.

2.1.4. Cypress Tree Extract

The plant extract used as an accelerator was prepared by boiling cypress bark in water. The bark of cypress was cut into very small pieces and then 1 Kg of the bark was boiled with four litter of water for two hours under pressure. From the boiling, 700 ml/kg was obtained.

The element analysis for boiled plant extract was done by Atomic Absorption Spectroscopy at Multimedia University of Kenya chemistry Laboratory and the results are shown in **Table 1**.

2.2. Methodology

Below is the methodology used to carry out the experiment.

2.2.1. Concrete Mix Design

For this research, the design for characteristic strength class C25 concrete was done in accordance with Department of Environment's Design Method (DOE Method). Concrete mix design being the science of correct proportioning of constituent materials of concrete to obtain the desired properties based on the requirement of the structures, The quantity of cement, fine and coarse aggregates, and water was generated according to the British standards [15].

2.2.2. Material Characterization

The chemical composition of the blended cement analysis was done using the X-ray diffraction (XRD) method employing power diffractometry technique to obtain data in accordance with the ASTM C 1365-18. Kenya Bureau of Standards (2000) EAS 148-2: 2000 ICS 91.100.10. East African Standards. Cements-Test Methods. Part 2. Chemical Analysis. Kenya Bureau of Standards, and following the procedures in ASTM C 1365. The initial and final setting time, consistency, and compressive strength at 7 and 28 days was based on BS EN 196:2010 [16]. The tests result obtained are shown in **Figure 2**. The chemical analysis of the Cypress tree bark extract was done using the Atomic Absorption spectrometer (AAS) of metal concentration following the procedures in Atomic Absorption spectroscopy. Perkin Elmer analytical method was used using calibration curves to verify the result [17].

The physical and mechanical preparties tests on aggregates were done at the Olkaria Laboratory. Sieve analysis was done on the aggregate based on the BS EN 1097-6-2013; Bulk Density tested using (BS 812-2:1995), Specific gravity using (BS 812-102:1995), Water Absorption (BS 813-2:1995) and moisture content using (BS 812-109:1990).

Table 1. Chemical concentration in ppm.

Element	Cypress extract
Potassium (K)	587.4067
Magnesium (Mg)	320.4367
Iron (Fe)	3.267667
Zinc (Zn)	0.366667
Cardium (Cd)	0.001881
Copper (Cu)	0.1126
Lead (Pb)	0.324667
Manganese (Mn)	15.63

Source: Field Data (2022).

2.2.3. Compressive Strength Test

Casting of concrete cubes was done in compliance with BS EN 12390-1:2000 using 150 × 150 × 150 mm steel molds. A total of 360 cubes were cast *i.e.*, 90 cubes without plant extract as a control, 180 cubes containing plant extract at dosages of 5%, 10%, 15% and 20% in water and lastly another 90 cubes casted with a dosage of determined optimum dosage of the extract.

From the compressive strength test of the controls, three brands of blended cement were selected, cement concrete showing low, median, and highest compressive strength at 28 days of age for a partial substitution with the cypress bark extract. CEM E with the highest compressive strength, CEM A with median strength and CEM D with the lowest compressive strength result were selected for the establishment of the optimum percentage of the extract as an accelerator.

The slump test was used to assess the workability of the concrete and values reported to nearest 5 mm. Testing of the concrete cubes for the compressive strength was done at 7, 14, 28, 56 and 90 curing days according to BS EN 12390-3 and KS EAS 18-1:2008 standards.

3. Result and Discussions

3.1. Optimum Percentage of the Plant-Based Extract as an Accelerator on the Development of the Compressive Strength of Blended Cement Concrete

Compressive strength test of concrete was done when cypress extract was added at a varying dosage 0%, 5%, 10%, 15% and 20%. The measurement was taken at 7, 14, 28, 56 and 90 days of age. Graphical representation of compressive strength development when extract is added is represented below.

From **Figure 1**, it is evident that the compressive strength decreases at 5% followed by an increase at 10% to 15% with a slight decrease at 20%. This implies that at 5%, the extract act as a retarder, at 10% and 15%, it acts as a plasticizer by reducing the water demand and increasing the strength of concrete.

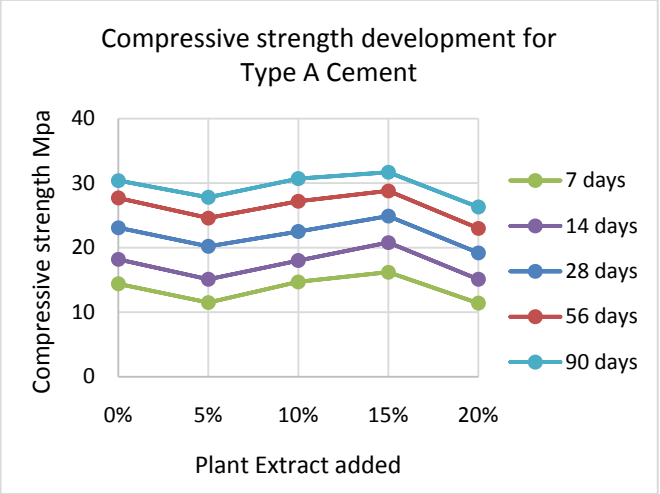

Figure 1. Effect of cypress tree extract on the compressive strength for cement type A.

Figure 1, the 28 days results show, the variations between the conventional concrete (no extract added) and concrete with 15% of dosage of the plant extract increase the compressive strength by 4.69 Mpa and at 5%, the compressive strength reduces by −2.86 Mpa.

Below is the graph obtained when CEM D cement is used.

Figure 2 shows an increase of the compressive strength at 28 days by 3.56 Mpa when 155 of the boiled extract added while when 5% od the dosage is added the compressive strength reduces by 1.57 Mpa.

Below is the graph obtained when CEM E is used.

From **Figure 3** shows that at 28 days, concrete with 15% of dosage of the plant extract increase the compressive strength by 3.25 Mpa and at 5%, the compressive strength reduces by −6.27 Mpa.

Based on the study, the highest rate of compressive strength improvement is realized at 28 days when 15% of the cypress tree extract dosage is added hence being the optimum.

The boiled extract act as a plasticizer by reducing the water demand and increasing the strength of concrete hence is comparable to super plasticizer at the optimum level of 15%. Previous researchers on super plasticizers like Sulphonated naphthalene polymer and sulphonated naphthalene formaldehyde among others increased the compressive strength by 5.5 Mpa and 4.4 Mpa respectively [18], Comparable, the cypress tree extract has also increased the compressive strength by 4.69 Mpa (The highest) at 28 days. Therefore, the cypress tree extract has chains that react with Ca^{2+} to give calcium silicate hydrate gel which increases the strength of concrete. Carboxylic group which are contained in the super plasticizer and other chains present in plant extract increased the strength of concrete by increasing calcium hydrate gel and decreasing calcium hydroxide content [19].

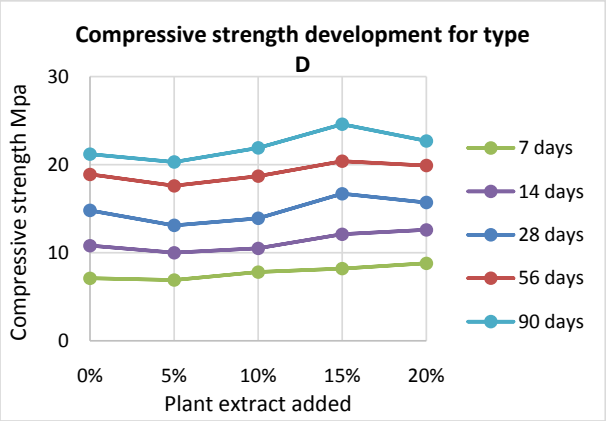

Figure 2. Effect of pant extract on the compressive strength at 28 days and 56 days using type D cement.

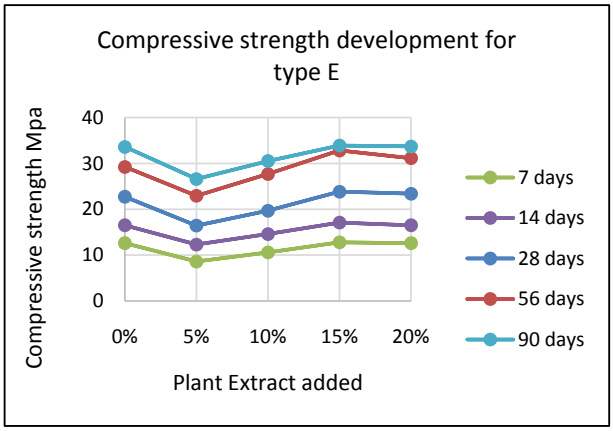

Figure 3. Effect of pant extract on the compressive strength at 28 days and 56 days using type F cement.

3.2. Compressive Strength Acceleration Rate to Achieve Compliance at 28 Days of Age

The study has shown that the concrete does not meet the design strength when blended cement is used but improves when cypress extract is added as an accelerator to increase the rate of hydration leading to improved early strength gains.

Below graph **Figure 4** shows the percentage increase in compression strength when 15% of the cypress extract is added to the blended cement concrete. The trend in percentage is for the three cement CEM A, D and E indicating that there was an effect of cypress tree extract on its compressive strength hence acting as an accelerator. the extent of increase in the compressive strength is presented in **Figure 4**.

Figure 4 shows that the cypress extract had a higher effect on the early strength development compared to the ultimate strength development. Previous research has shown that accelerators in concrete promotes Early strength of concrete with OPC and secure its constructability using additional retarders to control the quick setting of concrete [20], They promote early strength devel-

opment of concrete by increasing the hydration rate of the cement composition accelerating the precipitation of hydration products, and speeding up the initial crystallization.

Since the plant extract accelerate the strength of blended concrete at an early stage, the age at which the blended cement will attain its ultimate strength will therefore be lower as compared to when no extract is used.

Below is the graph Figure 5, showing the compressive strength development when 15% of the cypress extract is used.

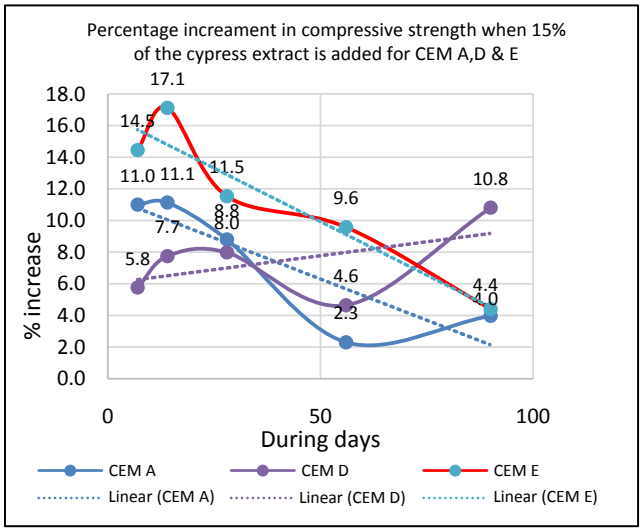

Figure 4. Percentage increasement on the compressive strength for CEM A, D and E when 15% of the cypress extract added from the control.

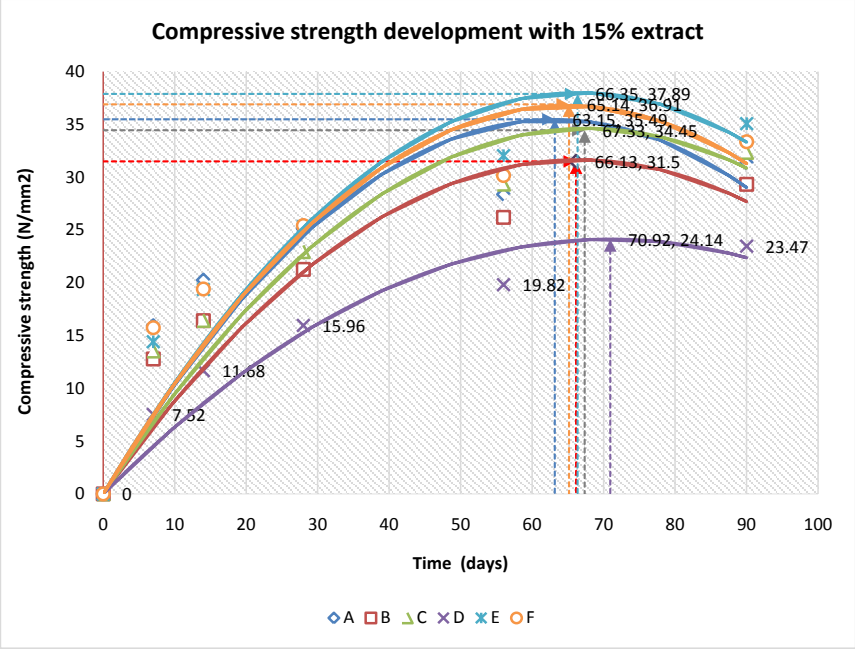

Figure 5. Compressive strength development of the cement types when 15% of the cypress tree extract is added.

As indicated in Figure 5, when the plant extract is added, concrete will achieve its design strength at 28 days for CEM A, 36 days for CEM B, 32 days for CEM C, 26 days for CEM E and 27 days for CEM F while the strength continues to develop up to 67 days where it achieves the ultimate compressive strength. Table 2 shows the maximum values of compressive strength for the Kenyan blended cement with an accelerator generated from the graph in Figure 5.

From Figure 5, it is also evident that the ultimate strength age for the blended cement is at 67 days where the compressive strength gain is minimum for all the Kenyan blended cement.

From Table 3, it is evident that blended cement concrete achieves its design strength at 27 days of age when 15% dosage of extract is used as compared to 37 days of age when no accelerator is used in the mix, a reduction of 10 days curing time. The use of 28 days in the design and determination of the construction guideline limits can only apply when the accelerator is used on the Kenyan blended cement concrete. Cypress tree extract used as an accelerator is a very significant improvement on the setting time hence permitting earlier removal of formwork, reducing the required period of curing the blended cement concrete should take to achieve the design and ultimate compressive strength before being loaded and finally advancing the time the structure can be placed in service safely.

To guarantee safety and reducing the level of risk on building collapse in Kenya when blended cement concrete is used, all structures should therefore be subjected to construction loads at 37 days of age and not 28 days.

Table 2. Maximum values of compressive strength and age.

A		B		C		D		E		F	
X	Y	X	Y	X	Y	X	Y	X	Y	X	Y
0	35.49	0	31.5	0	34.45	0	24.14	0	37.89	0	36.91
63.15	35.49	66.13	31.5	67.33	34.45	70.92	24.14	66.35	37.89	65.14	36.91
63.15	35.49	66.13	31.5	67.33	34.45	70.92	24.14	66.35	37.89	65.14	36.91
63.15	0	66.13	0	67.33	0	70.92	0	66.35	0	65.14	0

Table 3. Age at which blended cement concrete achieves ultimate and design compressive strength.

Cement type	A	B	C	D	E	F
Design strength Age when no extract added (Days)	38	70	48	-	37	35
Design strength when 15% plant extract added (Days)	28	36	32	-	26	27
Ultimate strength age when no extract added	65	67	72	69	71	66
Ultimate strength age when 15% dosage of cypress extract added	64	67	68	71	67	66

4. Conclusions

Based on the experiment carried out and the result on the effect of the plant-based extract as an accelerator on the blended Portland cement concrete, the following conclusions are made:

1) The ultimate compressive strength age development when no accelerator is added is averagely 67 days of age for blended cement concrete.

2) Plant extract increased the strength of blended cement concrete hence acted as an accelerator.

3) The optimum percentage of the plant-based extract as an accelerator on the development of the compressive strength of blended cement concrete is 15% dosage of the extract expressed as a mass percentage of the cement content.

4) The use of the optimum percentage of cypress tree extract improved the strength development, blended cement concrete achieving the design strength at early stage 27 days instead of 37 days.

Recommendations

From the result of the study, I recommend the following:

1) The research recommends the use of the cypress tress extract at 15% as an accelerator in Kenyan blended cement concrete.

2) The research recommends of waiting up to 39 days before loading the structures if no accelerator is used for Kenyan blended cement concrete.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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