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Suitability of the Kenyan Blended Portland Cements for Structural Concrete Production

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Abstract The compressive strength, workability, durability and other properties of concrete depend upon the properties of its ingredient materials, proportions of the mixture, the adopted method of compaction and workmanship during placing and curing. Poor quality of blended Portland cement concrete in Kenya has necessitated research into the suitability of the blended Portland cements for structural concrete production. In this experimental study, the chemical, physical and mechanical properties of the locally available blended Portland cements have been investigated and their influence on the slump and compressive strength of concrete evaluated. The results show that due to the difference in the quality and quantities of blends (pozzolana and/or lime) added to the cements and the variations in the production systems, the locally available cement brands have varying physical, mechanical and chemical properties. These variations affect the slump and the compressive strengths of concrete produced by the blended cements from the different local manufacturers. It was also observed that the locally available blended Portland cements may not be suitable for the production of concrete class C25 and above since none of the locally available blended cement brands achieved the target design strength of 36.22MPa required for class C25 concrete at a workable slump of ≥30mm. The results further show that the blended Portland cement concrete compressive development continue beyond 28 days with the increase in strength of approximately 25% between 28 days to 90 days.

Keywords Blended Portland cement, concrete slump, concrete compressive strength, blended Portland cement concrete and concrete ingredient materials.

1. Introduction

Concrete's wide range of compressive strength, flexibility in usage, durability, ease of production and low maintenance makes it the most commonly used construction material [1]-[5]. Being a composite material, its production involves a combination of mechanical and chemical interactions of its ingredient materials which include; cement, fine aggregates, coarse aggregates and water. The properties of the individual ingredient materials, the proportions of each material in the mixture and workmanship affect the compressive strength, durability, workability and other properties of concrete [3], [6]- [8]. Concrete mix design on the other hand depends on the type and proportion of cement, water/cement ratio, fine aggregates/ coarse aggregates ratio and total aggregate/cement ratio [4], [8] - [10].

The compressive strength of concrete depends on the type and properties of cement used [3], [11] - [13]. The blended Portland cements (CEM 32.5) is the most commonly used type of cement in developing countries [1], [3]. These cements are cheaper, but have lower compressive strengths at 28 days compared to Ordinary Portland cements [4], [12], [14] - [18]. The reduction in strength has been reported to be dependent on the type and quantity of pozzolanic material added to the blend [19]. Mouli et al (2010) reported that the addition of natural pozzolan between 20-30% can improve the compressive, splitting and flexural strengths of the concrete in the long term [20], [21]. The variations in the chemical composition of the additives (Pozzolans and or lime) also affect the physical and mechanical properties of cement. Marar and Eren (2011) have also reported that the workability of concrete can be improved by increasing cement content [21]. It has further been reported that the differences in the constituent materials (cement, aggregates and water) also have an effect on the durability of concrete [22] - [24].

Aggregates constitute the bulk of the concrete volume (65% to 80%) [22]. Research has revealed that the type, proportion, composition, gradation and quality of aggregates influence the compressive strength and durability of concrete [8], [22] - [27]. It has also been reported that the gradation/particle size distribution and fraction of coarse aggregates in the concrete mix affect both the compressive strength and workability properties of concrete [23], [27]. Further, concrete compressive strength can be improved by up to 30% through the addition of fines as long as the workability can be controlled [28]. The most commonly used coarse aggregates in Kenya are the crushed stones produced in quarries distributed throughout the country while the most commonly used fine aggregates are the river sand obtained from river banks and river beds across the country.

In this study, the chemical, physical and mechanical properties of locally available blended Portland cements and their influence on the workability (slump) and compressive strength of blended Portland cement concrete have been investigated.

The objective of this study was to establish the properties of the locally available blended Portland cements and to evaluate their influence on the slump and the compressive strength of blended Portland cement concrete in Kenya.

2. Materials and Methods

The research experiments were divided into two parts: the first was to establish the chemical, physical and mechanical properties of the locally available blended Portland cements and the aggregates used in the study while the second part was to investigate the effect of the properties of the blended Portland cements on the workability (slump), compressive strength and density of in-situ concrete in Kenya. Key cement properties investigated included the chemical composition, fineness, compressive strength, setting time, consistency and density while the aggregates properties investigated included; particle size distribution, specific gravity, bulk density, silt content, aggregates crushing value and aggregate impact value.

2.1 Materials

2.1.1. Aggregates

Crushed stone coarse aggregates from the Mlolongo quarry and ordinary river sand fine aggregates from the banks of river Ewaso Nyiro in Meru were used as coarse aggregates (CA) and fine aggregates (FA) respectively. The aggregates sources were maintained throughout the experiments thus their properties were held constant. The aggregates particle size distribution was done in accordance to BS EN 1097-6-2013; while the tests on their physical properties were determined following the laid down procedures in their respective British standards: 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. The results were as summarized in Table 1 for fine aggregates and Table 2 for coarse aggregates.

Table 1. Fine aggregates physical properties [4]

Sieve Designation (mm)	Weight Of Agg. Retained (g)	% Weight Retained (%)	Cumulative % Retained	% Passing
10	0	0	0	100
5	7	0.70	0.70	99.3
2.36	16.5	1.66	2.36	97.6
1.18	103	10.36	12.72	87.3
0.6	372.5	37.46	50.18	49.8
0.3	261	26.24	76.42	23.6
0.15	221	22.22	98.64	1.4
pan	13.5	1.36	100.00	0.0
Total	994.5			
Grading	Zone II			
Fineness Modulus	2.41			
Specific Gravity	2.63			
water absorption	0.91%			
Moisture Content	0.73%			
Bulk Density	1564kg/m^3			

Table 2. Coarse aggregates physical properties [4]

Sieve Designation (Size) (mm)	Weight Of Agg. Retained (g)	Cumulative Wt. Retained (g)	% Weight Retained (%)	% Weight Passing (%)
50	0	0	0.00	100.00
38.1	0	0	0.00	100.00
20	590	590	59.00	41.00
10	380	970	97.00	3.00
5	21	991	99.10	0.90
pan	9	1000	100.00	0.00
AIV	12.06			
ACV	22.27			
Fineness Modulus	2.55			
Specific Gravity	2.5			
water absorption	1.25%			
Moisture Content	5.78%			
Bulk Density	1448kg/m^3			

The results in Table 1 and Table 2 revealed that the aggregates were suitable for concrete production since the tested properties were within the limits stated in the various British standards. The Fine aggregates grading curve was within Zone II envelope of the British standard and the fineness modulus was 2.41 which was within the recommended range of 2.0-4.0.

2.1.2. Cement

The increased sophistication of design, cost of construction materials, new construction techniques and the greater attention to variations in regional and environmental conditions has created demand for modifications of certain properties of construction materials. The wide usage of Concrete in construction has thus resulted in the development of several brands and blends of Portland cement and a greater use of concrete admixtures. The production of the different types of blended Portland cements involves certain adjustments in the manufacturing process such as the selection of raw materials, Chemical composition, Special additives, and the degree of grinding. These variations lead to production of cements with varying properties and thus affect the quality of concrete produced by the different cement brands.

The Blended Portland Cement (BPC) is a type of cement produced by either inter-grinding Ordinary Portland Cement (OPC) clinker along with lime, gypsum and pozzolanic materials in certain proportions during cement production, or by grinding the OPC clinker, lime, gypsum and pozzolanic materials separately and thoroughly mixing/ blending them together in certain proportions during concrete production [1]. Constituent materials that are permitted in blended Portland cements are lime, natural pozzolans (siliceous or siliceous aluminous materials such as volcanic ash glasses, calcined clays and shale) and artificial pozzolans (blast furnace slag, silica fume, and fly ashes)[16].

In Kenya, cement is produced in accordance to KS EAS 18-1: 2001 standard which is an adoption of the European Norm EN 197 cement standards [6]. Lime and natural pozzolanic materials such as volcanic ashes, tuffs and diatomaceous earths deposits are the most commonly used additives in the manufacture of blended Portland cements in the country. The production involves the addition of the lime or pozzolanic materials to the clinker during grinding resulting in blended Portland cement production [1]. Different manufactures employ different mechanisms in the manufacture of cement such as grinding their cement to higher fineness to achieve the minimum requirements, while others use higher percentage of clinker to achieve the same results. The cement types readily available in the Kenyan market include Portland Pozzolanic Cement (PPC) CEM II/B-P containing 21-35% natural pozzolana, Pozzolanic Cement (PC) CEM IV/A containing 11-35% pozzolanic material, and Portland Limestone Cement (PLC) CEM II/A-LL with 6-20% limestone addition. A limited quantity of Ordinary Portland cement (OPC) CEM I is produced for special uses [1], [4], [29].

The cements setting time, compressive strength and consistency were tested based on BS EN196:2010 while the cement chemical analysis was done based on the Atomic Absorption spectrometer (AAS) in accordance to the EAS 148-2:2000I CS 91.100.10. East African Standard: Cements- Test Methods Part 2: Chemical Analysis. 2000. First Edition and following the procedures in Atomic Absorption Spectroscopy: Analytical Methods by Perkin Elmer [30]. Cement fineness tests were done using the Blaine apparatus and the 32 Micron residue methods.

The recommended cement properties based on KS EAS 18-1: 2001 standard are summarised in Table 3. The tests were done at the Kenya Bureau of Standards Laboratories. The results of the chemical analysis of the blended Portland cements from all the six local manufacturers coded as CEM AL, CEM AP,CEM B, CEM C, CEM DG, CEM DS, CEM E and CEM F have been summarized in Tables 4 while the results of the physical properties of the blended Portland cements have been summarised in Table 5.

CEM AP and CEM AL are from the same manufacturer but the difference is that CEM AL is blended using Lime while CEM AP is blended using Pozzolanic materials. CEM DG and CEM DS are also from the same manufacturer though the two brands have varying properties. The rest of the cement manufacturers produce only one brand of blended Portland cements.

Table 3. Recommended cement properties given as characteristic values based on EAS 18-1:2001

Strength Class	Compressive Strength (Mpa)				Initial Setting Time (Min)	Soundness (Expansion mm)	Insoluble Residue	Loss of ignition	Sulphate content (SO_3)	Chloride content
	Early Strength		Standard Strength							
	2 Days	7 Days	28 Days							
32.5N	-	≥16.0	≥32.5	≥52.5	≥75	≤10	≤5.0%	≤5.0%	≤3.5%	≤0.10%
32.5R	≥10.0	-								
42.5N	≥10.0	-	≥42.5	≥62.5	≥60					
42.5R	≥20.0	-							≤4.0%	
52.5N	≥20.0	-	≥52.5	-	≥45					
52.5R	≥30.0	-								

Table 4. Chemical properties of locally available blended Portland cements

Cement Type	**Brand**	**Al_2O_3**	**CaO**	**Fe_2O_3**	**K_2O**	**MgO**	**Mn_2O**	**Na_2O**	**P_2O_5**	**SO_3**	**SiO_2**	**CL**	**L.O.I.**	**IR**
Requirement EAS 148		3-8%	60-67%	0.5-6%	0.5-1%	0.1-4%				1-3.5%	17-25%	0-5%	0-4 %	0-5%
CEM II/B-L 32,5 R	CEM AL	3.65	58.84	2.39	0.34	0.50	0.04	0.58	0.07	2.01	18.57	0.01	13.24	12.76
CEM IV/B-P 32,5 N	CEM AP	6.25	43.70	5.34	2.10	1.40	0.05	1.63	0.06	1.91	31.90	0.01	4.98	28.34
CEM IV/B-P 32,5 N	CEM B	5.43	46.97	4.46	1.33	2.58	0.06	1.18	0.13	1.66	31.88	0.01	4.00	27.98
Cem IV /B-P 32.5R	CEM C	6.76	43.85	6.16	2.12	1.32	0.07	2.51	0.06	1.78	33.00	0.01	1.64	28.43
Cem II /B-P 32.5N	CEM D G	6.14	50.04	5.34	1.72	1.18	0.06	1.82	0.09	1.78	30.32	0.03	1.76	32.93
Cem II /B-P 32.5N	CEM D S	6.29	49.00	5.46	1.76	1.25	0.05	1.92	0.08	1.78	30.08	0.05	2.00	31.28
Cem II/B-P 32.5R	CEM E	5.81	51.71	5.46	1.27	0.79	0.06	1.49	0.32	1.67	28.39	0.03	2.00	28.28
Cem IV/B-P 32.5N	CEM F	7.00	40.13	6.56	2.48	1.25	0.07	2.39	0.06	1.68	35.97	0.02	2.39	32.57

Table 5. Blended Portland cement mechanical and physical properties

BLENDED PORTLAND CEMENT FINENESS				**COMPRESSIVE STRENGTH MPa**			**CONSISTENCY AND SETTING TIME**			**DENSITY**
CEMENT TYPE	**BRAND**	**Residue (32 Micron) %**	**Blaine cm^2/g**	**2 days**	**7 days**	**28 days**	**Consistency**	**Initial S.T (min)**	**Final S.T (min)**	**Kg/m^3**
CEM II/B-L 32,5 R	CEM AL	17.41	3856	20.2	31.4	46.9	27.6	182	251	3063

CEM IV/B-P 32,5 N	CEM AP	16.58	3935	13.6	23.8	37.6	33.3	200	295	3052
CEM IV/B-P 32,5 N	CEM B	17.55	4471	12.1	23.9	32.6	34.9	230	319	3109
Cem IV /B- P 32.5R	CEM C	21.98	4063	20.1	35.3	45.5	31.5	197	270	3091
Cem II /B-P 32.5N	CEM D G	22.98	3191	13.2	26.6	43.8	29.7	251	393	3117
Cem II /B-P 32.5N	CEM D S	21.86	3451	13.5	28	39.3	30.9	208	292	3120
Cem II/B-P 32.5R	CEM E	28.03	3034	10.3	24.9	40.1	30.56	201	290	3091
Cem IV/B-P 32.5N	CEM F	27.38	3918	14	25	32.3	30.2	215	318	3114

2.1.3. Water

ACI 318 recommends that any water that is potable and that has no pronounced odour or taste is satisfactory for use in mixing and curing of concrete. BS EN 1008 on the other hand requires that the water to be used for concrete production should have a pH of ≥ 4.0. IS 456-2000 however specifies a pH of ≥6.0 and goes ahead to state that the water should be clean and free from high amounts of oils, acids, alkalis, salt, sugar, organic materials or other substances that may be deleterious to concrete and steel [31]. Tap water from Jomo Kenyatta University of Agriculture and Technology water treatment plant was used during the research. The water is potable hence considered suitable for concrete production.

2.2 Concrete Mix Design and Concrete Testing

The blended Portland cement concrete mix design proportions were generated from first principles using three variables (water/ cement ratio, cement/ aggregates ratio and the fine aggregates/ coarse aggregates ratio) and employing the central composite design method using MINITAB 17 software.

Central Composite Design (CCD) which is a classified design for Response Surface Method (RSM) useful in sequential experiments by addition of axial and center points enables estimation of the regression parameters for the polynomial regression model for the response. They consist of factorial or fractional factorial design (2k or 2k-1 factorial points, where k is the number of factors) which allow for the estimation of linear and interaction effects while the center points are used to check for curvature as the axial (or star) points are used to estimate the quadratic terms [4], [32] - [37].

In this study, CCD and MINITAB 17 software was used to generate the concrete mixture proportions for experiments to evaluate the properties of blended Portland cement concrete. Three variables namely; (i) Water/ Cement ratio as x_1, [0.4, 0.5, 0.6], (ii) Cement / Total aggregates ratio as x_2 [0.18, 0.22, 0.26] and (iii) Fine Aggregate / Coarse aggregates ratio as x_3 [0.56, 0.6, 0.64] were used with each variable having the settings given in brackets. The variables were randomly mixed to obtain a total of 60 runs, constituting 20 base factorial points, 24 cube points, 12 center points, 18 axial/ star points, 6 center points on the axial points and 3 blocks. The generated mixtures were then cast and tested experimentally maintaining the ingredient materials (CEM C cement, coarse aggregates from Mlolongo quarry, river sand from Ewaso Nyiro river banks and water from JKUAT water taps) and the response evaluated in terms of Slump as Y_1, 7 days compressive strength as Y_2, 14 Days compressive strength as Y_3, 28 days compressive strength as Y_4 and Density as Y_5. The results were as shown in Table 6 [4].

150 x 150 x 150 mm cubes were cast and used for testing the compressive strength at 7, 14 and 28 days using a universal testing machine with a loading capacity of 1500KN in accordance to BS 1881-116: 1983 while slump test was used to evaluate the workability of the fresh concrete mix.

The results were then used to plot the mix design curves which were further used to generate 20 mix proportions for the evaluation of the effect of the properties of the cement brands on the compressive strength and slump of the produced concrete. Six different cement brands from the six locally available cement manufacturers were used in the experiments. The results were then compared with both the chemical composition and physical properties of the different blended Portland cement brands.

3. Results and Discussions

Table 6 gives the results of the 60 runs generated using the three variables based on the CCD method and MINITAB software.

The results in Table 6 were used to generate concrete mixture design curves for the blended Portland cement concrete production. Combined curves for the relationship between the three variables; Water/cement ratio (x_1) variable, cement/aggregates ratio (x_2) variable and fine aggregates/coarse aggregates ratio (x_3) and the slump was as shown in Fig.1, while the relationship between the variables; Water/cement ratio (x_1) variable, cement/aggregates ratio (x_2) variable and fine aggregates/coarse aggregates ratio (x_3) and the ultimate compressive strength were as shown in Fig. 2 -4 respectively.

Table 6. Concrete mixture variables proportions based on CCD and results of the experiments

		Variables			Slump	7 days strength	14 days strength	28 days strength	Density
Run	**Blocks**	**x_1**	**x_2**	**x_3**	**Y_1 (mm)**	**Y_2 (MPa)**	**Y_3 (MPa)**	**Y_4 (MPa)**	**Y_5 (kg/m^3)**
1	3	0.5	0.285	0.6	119	17.68	20.667	24.831	2426.2
2	3	0.5	0.22	0.6	5	25.395	28.260	32.863	2465.5
3	3	0.337	0.22	0.6	0	31.889	33.704	37.565	2425.3
4	3	0.5	0.22	0.6	60	17.759	21.12	26.678	2436.0
5	3	0.5	0.22	0.535	20	19.490	23.3520	25.603	2431.6
6	3	0.5	0.22	0.665	16	24.754	28.039	31.914	2471.0
7	3	0.663	0.22	0.6	178	9.5227	12.1453	13.874	2403.1
8	3	0.5	0.22	0.6	22	20.330	24.648	28.369	2451.0
9	3	0.337	0.22	0.6	0	14.798	16.895	22.248	2296.5
10	3	0.663	0.22	0.6	145	10.023	13.619	16.873	2395.0
11	3	0.5	0.155	0.6	0	22.197	26.934	30.713	2448.8
12	3	0.5	0.22	0.535	46	18.125	22.945	26.984	2437.4
13	3	0.5	0.285	0.6	79	21.529	26.798	29.345	2418.4
14	3	0.5	0.22	0.535	25	21.307	25.471	29.091	2479.5
15	3	0.5	0.22	0.6	40	22.518	27.008	28.610	2442.0
16	3	0.5	0.22	0.6	34	20.972	26.264	28.336	2448.6
17	3	0.5	0.22	0.665	17	24.260	27.084	31.252	2469.1
18	3	0.5	0.155	0.6	0	27.651	32.038	32.964	2474.9
19	3	0.5	0.22	0.665	19	22.205	26.239	29.225	2450.9
20	3	0.5	0.155	0.6	0	22.599	25.926	28.501	2507.2
21	3	0.5	0.285	0.6	48	22.526	26.463	28.959	2165.2
22	3	0.5	0.22	0.6	36	18.124	23.615	26.482	2482.5
23	3	0.337	0.22	0.6	0	21.079	34.395	40.266	2404.5
24	3	0.663	0.22	0.6	127	11.760	14.125	16.223	2419.1
25	1	0.5	0.22	0.6	19	20.080	25.332	28.054	2459.3
26	1	0.4	0.26	0.64	0	30.067	36.266	40.059	2470.8
27	1	0.6	0.26	0.56	179	13.337	16.428	20.305	2329.9
28	1	0.6	0.18	0.64	54	18.057	19.890	24.618	2458.4
29	1	0.4	0.18	0.56	0	37.052	38.860	45.037	2497.1
30	1	0.4	0.26	0.64	0	35.432	41.790	44.205	2491.2
31	1	0.5	0.22	0.6	29	17.778	22.171	26.613	2426.4
32	1	0.5	0.22	0.6	24	21.493	25.668	31.060	2444.4
33	1	0.5	0.22	0.6	26	22.208	28.660	31.941	2436.8
34	1	0.6	0.18	0.64	59	17.049	18.942	22.969	2457.6

35	1	0.5	0.22	0.6	15	21.635	26.520	30.240	2469.6
36	1	0.6	0.18	0.64	47	20.878	24.396	25.999	2462.6
37	1	0.6	0.26	0.56	162	14.242	17.664	22.152	2404.0
38	1	0.4	0.18	0.56	0	31.322	34.266	37.104	2483.7
39	1	0.4	0.26	0.64	0	34.024	37.110	41.892	2504.1
40	1	0.4	0.18	0.56	0	31.118	37.749	40.684	2483.5
41	1	0.6	0.26	0.56	171	16.406	19.153	20.749	2451.4
42	1	0.5	0.22	0.6	16	21.926	27.775	30.029	2457.5
43	2	0.5	0.22	0.6	9	25.385	30.036	31.428	2467.3
44	2	0.5	0.22	0.6	16	23.338	26.769	30.478	2464.7
45	2	0.6	0.26	0.64	189	13.377	15.615	19.730	2430.9
46	2	0.5	0.22	0.6	15	25.024	28.965	31.965	2488.5
47	2	0.5	0.22	0.6	11	24.537	28.661	31.965	2473.9
48	2	0.6	0.18	0.56	39	14.539	18.0910	21.449	2411.3
49	2	0.4	0.26	0.56	0	29.810	34.551	40.169	2502.1
50	2	0.6	0.26	0.64	173	14.067	17.243	21.143	2376.5
51	2	0.6	0.18	0.56	92	12.278	15.176	18.668	2388.6
52	2	0.6	0.26	0.64	192	11.346	15.381	16.509	2371.6
53	2	0.4	0.18	0.64	0	32.237	34.174	39.780	2457.4
54	2	0.4	0.26	0.56	2	32.559	36.601	45.595	2487.6
55	2	0.5	0.22	0.6	15	25.746	27.887	32.075	2466.5
56	2	0.4	0.26	0.56	9	29.981	33.528	40.345	2465.9
57	2	0.4	0.18	0.64	0	32.741	36.208	38.903	2471.1
58	2	0.5	0.22	0.6	12	18.133	23.436	29.145	2458.8
59	2	0.4	0.18	0.64	0	30.723	35.649	39.738	2463.1
60	2	0.6	0.18	0.56	53	15.916	16.659	20.683	2450.6

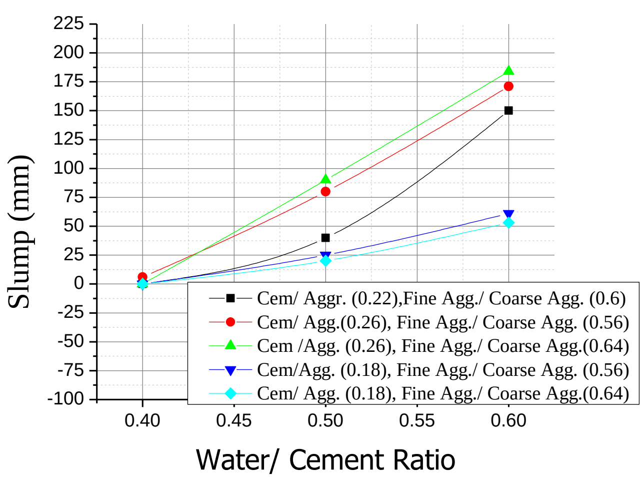

Fig. 1. Effect of water/ cement ratio on combined workability (Slump)

Concrete with high amounts of cement in the mix are richer, have proper lubrications and flow of the aggregates. Fig. 1 shows that the workability of the blended Portland cements in terms of slump depends on the water/ cement ratio of the mixture. The higher the water/ cement ratio is the higher the slump becomes. It is also noted that the increase in the amount of cement through the raising of the cement/ total aggregates ratio leads to an increase in the workability as the concrete made using higher cement/ aggregates ratio (0.26) had higher slumps compared to the concrete made using a lower cement/ total aggregates ratio of (0.18). The results further show that lower fine aggregates/ coarse aggregates ratios (0.56) lead to higher slumps compared to higher fine aggregates/ coarse aggregates ratio (0.64). This can be attributed to the increased water demand posed by the increase in the amount of fines in the mix which have a higher exposed surface face area leading to a reduction in the workability.

Fig. 2 showed that the ultimate (28 days) compressive strength of the blended Portland cement concrete reduced with an increase in the water/ cement ratio. This proves that as expected, the compressive strength of the blended Portland cement concrete is inversely proportional to the water/cement ratio.

Fig. 3 illustrates the influence of the fine aggregates/ coarse aggregates ratio on the 28 days compressive strength of blended Portland cement concrete and show that with high cement/ aggregates ratio (0.26) there is a slight decrease in the 28 days compressive strength with an increase in the fine aggregates/ coarse aggregates ratio. This is due to the overall surface area increase which in turn impose a higher water demand on the concrete thus increasing the water/ cement ratio thereby decreasing the compressive strength of the concrete.

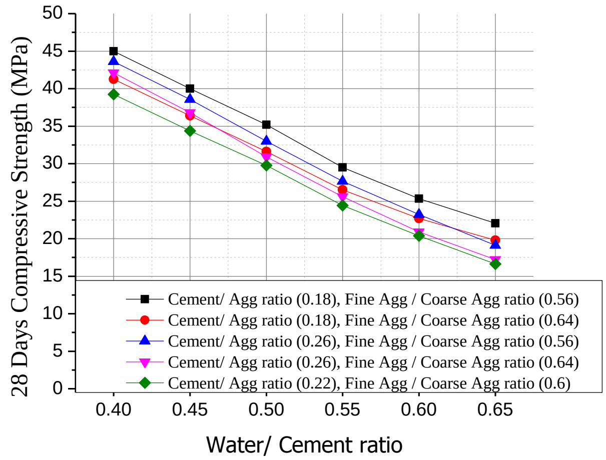

Fig. 2. Influence of water/ cement ratio on 28 Days Compressive Strength

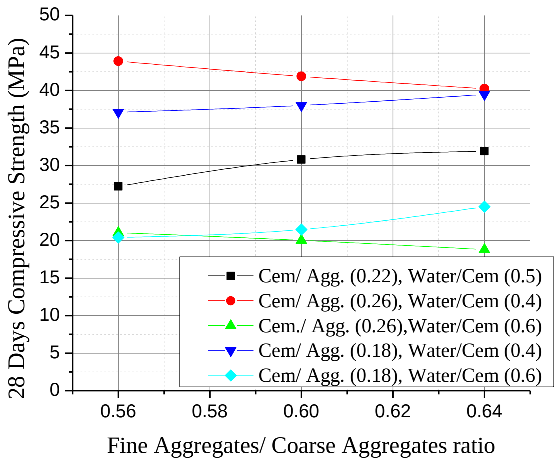

Fig. 3. Influence of fine aggregates/ coarse aggregates ratio on the 28 Days Compressive Strength

In Fig 4, the results show that in all cases, the lower the water/cement ratio is the higher the 28 days compressive strength becomes. It further indicates that at lower water/cements ratio of 0.4, the compressive strength increases with an increase in the cement/ total aggregates ratio while at higher water/ cement ratios of ≥0.5, the compressive strength decreases with an increase in the cement/total aggregates ratio.

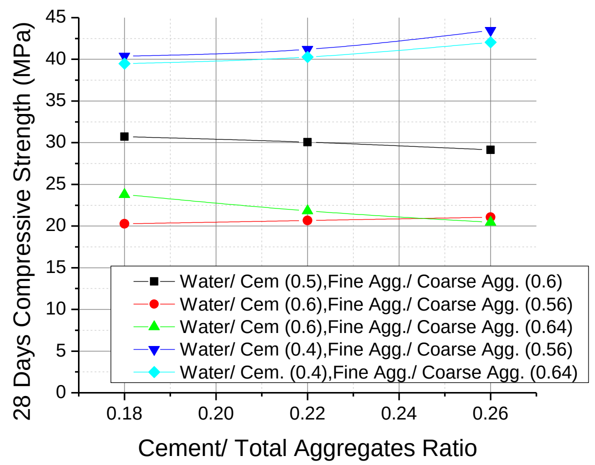

Fig. 4. Influence of cement/ total aggregates ratio on the 28 Days Compressive Strength

The curves were used to come up with the concrete mix proportions for four various target compressive strengths (15MPa, 20MPa, 25MPa and 30MPa). Five different possible mix proportions were generated for each of the five target compressive strengths using MINITAB software as shown in Table 7. The mixtures were cast and tested for slump and compressive strengths at 7 days, 14 days and 28 days. The same cement brand used in developing the curves was first used to check the accuracy of the curves where four trials were done and an average used to compare with the target strengths as shown in Table 8. Five other brands of blended Portland cements were thereafter used to establish the effect of the cement properties and brands on the slump and compressive strengths of blended Portland cements using the same proportions as shown in Table 9.

Table 7. Mix Design Proportions for blended Portland cement concrete production

Runs	Design	Variables			Constituent Materials Proportions per cubic meter concrete in kgs					Target
		W/C (x_1)	C/ T. A (x_2)	F.A/C.A (x_3)	Cement	Water	Total Agg.	Coarse Agg.	Fine Agg.	MPa
1	30 MPa	0.48	0.29	0.67	491.28	236.87	1721.85	1033.95	687.90	**30.00**
2		0.50	0.22	0.60	405.26	202.63	1842.11	1151.32	690.79	**29.91**
3		0.50	0.22	0.53	405.26	202.63	1842.11	1200.32	641.79	**28.47**
4		0.50	0.29	0.60	489.53	244.76	1715.71	1072.32	643.39	**29.70**
5		0.50	0.22	0.67	405.26	202.63	1842.11	1106.16	735.95	**31.36**
6	25 MPa	0.50	0.24	0.53	432.35	216.18	1801.47	1173.84	627.63	**25.00**
7		0.60	0.18	0.64	342.39	205.43	1902.17	1159.86	742.31	**24.42**
8		0.50	0.22	0.53	405.26	202.63	1842.11	1200.32	641.79	**28.47**
9		0.50	0.29	0.60	489.53	244.76	1715.71	1072.32	643.39	**29.70**
10		0.50	0.22	0.60	405.26	202.63	1842.11	1151.32	690.79	**29.91**
11	20 MPa	0.58	0.15	0.53	304.49	177.03	1968.49	1282.67	685.82	**20.00**
12		0.60	0.26	0.56	449.86	269.92	1730.23	1109.12	621.11	**19.97**
13		0.60	0.18	0.56	342.39	205.43	1902.17	1219.34	682.83	**20.35**
14		0.60	0.26	0.64	449.86	269.92	1730.23	1055.02	675.21	**19.42**
15		0.60	0.18	0.64	342.39	205.43	1902.17	1159.86	742.31	**24.42**
16	15 MPa	0.65	0.15	0.53	301.76	197.34	1950.89	1271.20	679.69	**15.00**
17		0.60	0.26	0.64	449.86	269.92	1730.23	1055.02	675.21	**19.42**
18		0.60	0.26	0.56	449.86	269.92	1730.23	1109.12	621.11	**19.97**
19		0.60	0.18	0.56	342.39	205.43	1902.17	1219.34	682.83	**20.35**
20		0.60	0.18	0.64	342.39	205.43	1902.17	1159.86	742.31	**24.42**

Table 8. Slump and compressive strength results for the 20 runs using CEM C

	SLUMP Y_1 (mm)				**7 days Compressive Strength (MPa) Y_2**				**28 days compressive strength (Mpa) Y_4**					
Run	**Trial 1**	**Trial 2**	**Trial 3**	**Trial 4**	**Trial 1**	**Trial 2**	**Trial 3**	**Trial 4**	**Trial 1**	**Trial 2**	**Trial 3**	**Trial 4**	**Average**	**Target**
1	86	70	90	50	22.49	23.15	21.22	21.08	30.14	31.45	31.48	30.61	**31.18**	**30**
2	23	18	15	10	22.95	22.97	20.7	21.32	29.32	31.42	30.42	30.52	**30.79**	**29.91**
3	37	31	23	29	23.43	20.2	19.48	23.11	30.9	30.01	28.24	29.72	**29.32**	**28.47**
4	88	101	110	83	22.59	18.32	19.32	20.78	30.15	28.32	28.15	28.33	**28.26**	**29.7**
5	35	57	22	25	24.38	21.47	19.65	20.57	32.99	31.18	29.2	29.72	**30.03**	**31.36**
6	31	30	27	30	20.49	21.46	18.04	21.05	29.16	31.08	25.19	27.86	**28.04**	**25**
7	34	37	30	25	16.7	17.27	16.38	16.4	25.02	23.56	21.79	25.18	**23.51**	**24.42**
8	30	16	22	18	22.24	22.53	21.25	23.01	32.21	31.6	27.58	31.07	**30.08**	**28.47**
9	92	141	119	80	21.25	19.73	19.86	22.85	29.07	28.03	28.06	30.43	**28.84**	**29.7**
10	21	32	18	9	21.72	19.21	20.67	23.41	29.18	29.21	28.23	31.32	**29.58**	**29.91**
11	11	23	10	14	19.42	17.09	16.96	16.62	25.1	24.56	22.53	25.09	**24.06**	**20**
12	122	181	181	192	16.01	17.09	14.45	12.33	20.02	24.04	18.93	20.41	**21.12**	**19.97**
13	33	33	42	28	15.98	18.9	15.7	16.04	20.49	27.42	21.95	22.76	**24.04**	**20.35**

14	137	197	187	170	15.12	14.74	12.89	15.49	20.93	20.84	21.27	22.43	**21.51**	**19.42**
15	40	32	27	32	12.54	15.49	14.32	14.07	20.31	22.11	20.79	22.79	**21.9**	**24.42**
16	22	27	41	38	12.98	13.13	12.97	12.29	16.82	18.31	18.15	17.99	**18.15**	**15**
17	133	170	179	177	12.35	13.91	16.36	15.41	17.71	19.88	21.59	23.19	**21.55**	**19.42**
18	119	179	169	182	12.18	13.75	17.86	13.54	18.03	19.98	24.07	20.34	**21.47**	**19.97**
19	31	37	38	37	13.9	12.61	17.25	16.82	18.85	18.87	21.46	24.02	**21.45**	**20.35**
20	27	31	20	17	16.53	13.13	17.34	16.56	22	22.54	25.03	24.73	**24.1**	**24.42**

Table 7 gives the blended Portland cement concrete mix proportions used in the experiments. The results met the 28 days target compressive strength at 95% confidence interval. The same mix design proportions could thus be used to check the influence of the cement properties on the slump and the compressive strength of blended Portland cement concrete by using blended Portland cements from all the six local manufacturers to cast and test the concrete and compare the results with the cement properties.

Table 9 gives the results obtained when all the blended Portland cements from the six local manufacturers were used to cast and test concrete using the mix design proportions in the 20 runs given in Table 7.

Table 9. Slump and compressive strength for six brands of blended cements

	SLUMP (mm)						**7 DAYS COMPRESSIVE STRENGTH (MPa)**						**28 DAYS COMPRESSIVE STRENGTH (MPa)**						
Runs	CEM AP	CE M B	CE M C	CEM DG	CE M E	CE M F	CEM AP	CE M B	CE M C	CEM DG	CE M E	CE M F	CEM AP	CE M B	CE M C	CEM DG	CE M E	CE M F	target
1	43	40	86	136	139	76	20	18	22	20	20	16	29	26	30	32	30	24	**30**
2	9	10	23	25	30	29	20	16	23	24	19	15	28	24	29	34	26	22	**30**
3	16	9	37	20	20	25	19	17	23	21	19	14	29	24	31	32	28	22	**28**
4	44	60	88	145	170	95	20	15	23	19	17	14	28	22	30	30	28	21	**30**
5	28	5	35	14	27	23	18	18	24	19	16	15	27	24	33	31	26	21	**31**
6	16	4	31	11	23	22	17	14	20	20	12	13	25	21	29	28	21	20	**25**
7	33	20	34	24	32	22	12	12	17	15	12	12	19	18	25	23	19	18	**24**
8	16	10	30	24	28	11	17	17	22	23	16	18	26	24	32	34	24	26	**28**
9	41	48	92	141	174	105	17	17	21	19	16	14	23	22	29	32	25	21	**30**
10	5	5	21	12	25	9	18	19	22	21	19	16	26	27	29	32	28	22	**30**
11	4	2	11	6	6	5	15	16	19	16	12	11	21	21	25	26	18	18	**20**
12	156	179	122	203	227	202	11	12	16	14	12	8	17	18	20	21	17	13	**20**
13	40	29	33	46	47	20	13	13	16	15	14	11	20	19	20	28	22	16	**20**
14	145	180	137	118	204	218	12	13	15	18	14	11	19	18	21	24	20	16	**19**
15	38	38	40	69	52	13	12	14	13	15	15	10	17	18	20	28	20	15	**24**
16	39	55	22	75	70	21	9	9	13	15	12	10	16	14	17	22	18	14	**15**
17	150	201	133	215	211	202	8	11	12	13	13	10	15	15	18	21	20	15	**19**
18	135	204	119	207	209	229	7	10	12	10	13	9	12	18	18	15	18	16	**20**
19	26	13	31	16	47	21	13	13	14	15	14	10	20	19	19	25	22	16	**20**
20	16	28	27	17	32	15	15	12	17	12	12	12	21	18	22	18	24	15	**24**

3.1 Effect of chemical composition of Blended Portland cement on concrete compressive strength and slump

The chemical composition of the locally available blended Portland cements can be summarized in Fig. 5. From Table 4, it is seen that the chemical properties of blended Portland cements have Insoluble Residues values ranging between 12.76% to 32.93%. This is much higher than the value of ≤ 5% recommended by the KS EAS 18-1:2001 for Insoluble Residues as shown in Table 3. The amount of CaO which ranges between 40.13% and 58.84% is also less than the minimum required value which is 60%. Other than CEM AL, the blended Portland cements also have a higher percentage of SiO_2 (28.39% to 35.97%) which exceed the maximum limit of 25%. The high amounts of insoluble residues and low amounts of CaO leads to the reduced strength of the blended Portland cements and thus the quality of concrete produced by the blended cements. CEM F has the lowest amount of CaO (40.13%) and a high amount of Insoluble residue (32.57%) which has resulted in the cement having the least value of 28 days compressive strength (32.3MPa) and thus giving the lowest values of concrete compressive strength as shown in Table 9.

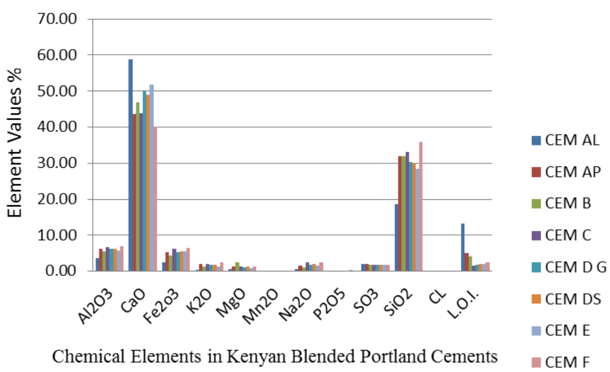

Fig. 5. Blended Portland cement chemical composition

It is therefore clear that the chemical composition of the cement and more specifically the amount of CaO and insoluble residue has a direct impact on the cements compressive strength and subsequently on the concrete compressive strength. From the results, lower amounts of CaO led to lower the compressive strength.

3.2 Effect of Blended Portland cement Physical and Mechanical Properties on Concrete Compressive Strength and Slump

The Kenyan blended Portland cement compressive strengths are as summarised in Fig. 6 while the results of the cement fineness is summarised in Fig. 7.

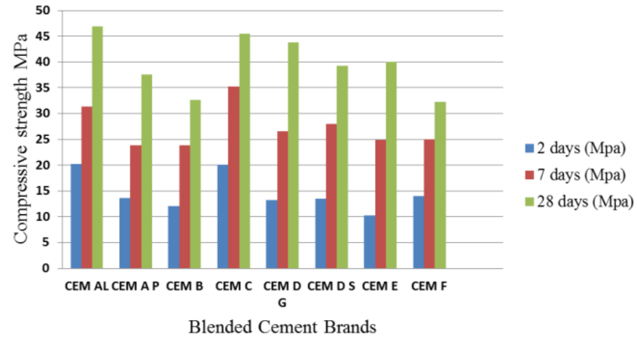

Fig. 6. Blended Portland cement compressive strength

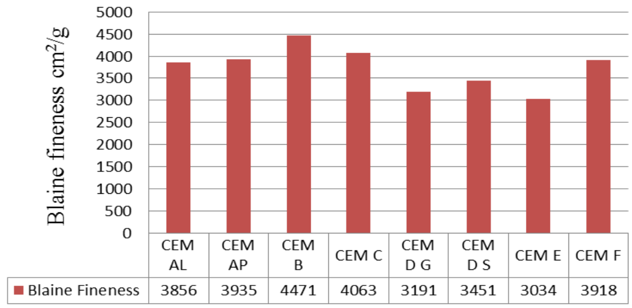

Fig. 7. Blended Portland cement blain fineness

Research has shown that concrete compressive strength depends on the properties of cement used [3], [16]. The blended Portland cement concrete have lower compressive strengths at 28 days compared to Ordinary Portland cements concrete [6] [11][16]. The reduction in strength is proportional to the type of and percentage of pozzolanic material added to the blend [16]. The variations in chemical constituents also affect the physical and mechanical properties of the cements.

Fig. 6 shows that at 28 days, CEM AL had the highest Compressive strength (46.9MPa) followed by CEM C (45.5MPa), CEM DG (43.8MPa), CEM E (40.1MPa), CEM DS (39.3MPa), CEM AP (37.6MPa), CEM B (32.6MPa) and the least was CEM F (32.3MPa). Comparing the results in Fig. 6 with those of Table 9, it is clear that the blended Portland cement concrete compressive strength depends on the cement compressive strength and fineness. Since CEM DG, CEM C and CEM E produced concrete with higher compressive strengths compared to CEM B and CEM F which produced concrete with compressive strengths which did not achieve the target compressive strength at 95% confidence interval. The two cement brands CEM B and CEM F also did not meet the minimum requirements for 28 days compressive strength (>32.5MPa) as shown in Fig. 6. All the cement brands however met the minimum requirement for Blaine fineness which are 1800-3420 cm^2/g and 1800-

3240cm^2/g for CEM 32.5 and CEM 42.5 respectively.

The results in Fig. 8 shows that all the blended Portland cements met the minimum requirements for the initial and final setting time as stated in Table 3 since all the cement brands had initial setting time >75min as shown in Fig. 8.

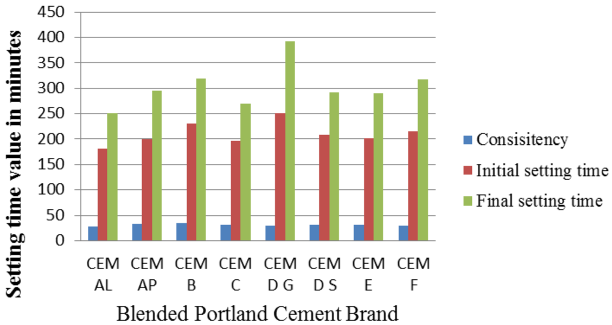

Fig. 8. Blended Portland cement consistency and setting time

3.3 Suitability of the Blended Portland cements for Structural concrete Production

Due to the variability in production of concrete caused by the differences in material properties and workmanship, it is necessary to design a concrete mix such that the expected mean strength is greater than the specified design characteristic strength by a specified margin. The British Research Establishment through the design of concrete mixes specifies that the margin should be calculated as shown in Equation 1.

$$f_m = f_c + ks \quad (1)$$

Where f_m is the target mean strength, f_c is the specified characteristic strength, s is the standard deviation and k is a constant for percentage defective. The value for k is 1.28, 1.64, 1.96 and 2.33 for 10%, 5%, 2.5% and 1% respectively [16].

The standard deviation s for the 28 days compressive strength results was 6.841 as illustrated in Fig. 9. The British standards, BS 5328 specifies a k of 1.64 for 5% defective. The 28 days compressive strength margin was thus calculated as shown in Equation 2 giving a compressive strength margin of 11.22MPa for all the strength classes of the blended Portland cement concrete.

$$ks = 1.64x6.841 = 11.22MPa \quad (2)$$

Considering the results in Tables 9, only three out of the six blended Portland cement brands (CEM C, CEM D1 and CEM E) achieved the target compressive strength of 30MPa. The other three brands (CEM AP, CEM B, CEM F) did not achieve the target strength of 30MPa. Based on the calculated compressive strength margin of 11.22MPa given in equation 2, the target 28 days compressive strength for C15 concrete is 26.22MPa, for C20 is 31.22MPa, for C25 is 36.22MPa and for C30 is 41.22MPa. It was therefore observed that for a workable concrete with a slump of ≥ 30mm none of the blended cement brands achieved the target design strength for strength class C25 and above. It was therefore observed that the blended Portland cements may not be suitable for producing structural concrete strength class C 25 and above.

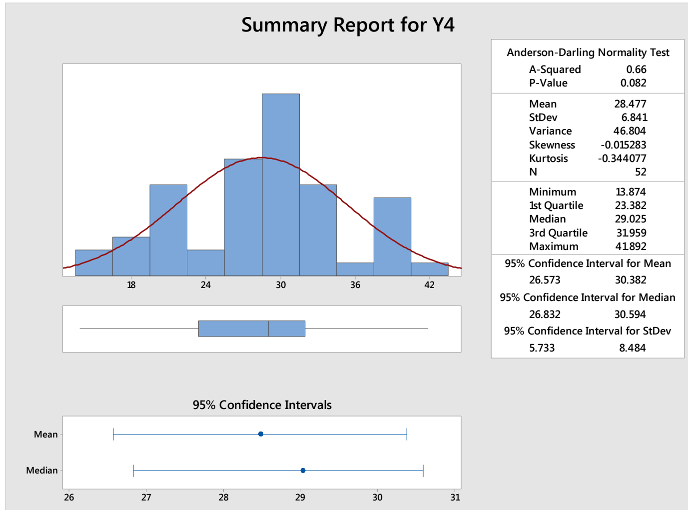

Fig. 9. Blended Portland cement concrete statistical analysis

4. Conclusions

Based on the results of this study, the following conclusions have been made:

1. The Kenyan Blended Portland cements have varying chemical, physical and mechanical properties. This can be attributed to the difference in manufacturing processes and the types and quantities of blends added to the cements.
2. Two out of the six blended Portland cement brands (Blue Triangle cement and Simba cement) did not meet the minimum compressive strength requirements at 28 days thus compromising the quality of the concrete produced using the two brands as evidenced in the compressive strength of concrete produced by the two brands which did not meet the target strengths.
3. The mix design curves used to come up with the mixture proportions led to the production of concrete that met the target compressive strengths at 95% confidence limit when the same cement brand (Savannah cement) used to generate them was used to cast the concrete thus proving their validity and accuracy.
4. The blended Portland cements may not be suitable for producing structural concrete strength class C 25 and above since none of the cement brands achieved

the target compressive strength of 36.22MPa at a workable slump of ≥25mm.

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