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Determination of Appropriate Mix Proportions for the Kenyan Blended Portland Cement Concrete Production

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Abstract

The Kenya’s vision 2030 seeks to address the rising needs of its population through infrastructure development. Reinforced concrete being the most commonly used construction material forms an integral part of this development strategy. The direct substitution of the ordinary Portland cements with the cheaper, lower strength, locally available blended Portland cements could be responsible for the production of poor quality concrete and contribute to the failure of several concrete buildings in the country. This paper presents findings of an experimental investigation on the appropriate mix proportions for the Kenyan blended Portland cement concrete. Key variables used in this study included the water/ cement ratio (x_1), the cement/ total aggregates ratio (x_2) and the fine aggregates/ coarse aggregates ratio (x_3). The response was measured in terms of slump, compressive strengths at 7days, 14days and 28 days and density. Minitab 17 software was used in the design of experiments and results analysis based on Central Composite Design method. The investigation revealed that for a workable concrete with slump of ≥ 30mm, the appropriate mix ratios for the Kenyan blended Portland cement concrete are: 1:2.2:3.4 (w/c 0.6) for strength class C15 and 1:1.3:2.2 (w/c 0.5) for strength class C20. It was further noted that the different brands of blended Portland cement in the country had varying properties and thus produced concrete with different wet and hardened properties. None of the brands achieved the target design strength for strength class C25 and above. Therefore, the blended Portland cements may not be suitable for producing structural concrete strength class C 25 and above.

Keywords: Appropriate mix ratios; Blended Portland cement; blended Portland cement concrete; central composite design; concrete strength class; target design strength.

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1. Introduction

The construction industry influences the social-economic development of any nation. At present, the Kenyan urban housing sector is characterized by inadequacy of affordable and decent housing, low level of urban home ownership, extensive and inappropriate dwelling units including slums and squatter settlements. Informal settlements house 60% of the urban population. To satisfy the urban housing needs, it is estimated that a total 200,000 housing units are required annually, yet only an estimated 35,000 units are produced [1].

Developers seek to meet this ever increasing demand for decent housing through constructions that include reinforced concrete residential buildings. However, in most cases, no difference is made in cement strengths resulting in the use of same mix proportions irrespective of the cement type and strength. Further, quality assurance/control mechanisms are often overlooked and so the quality of concrete produced may not be as designed. The inappropriate mix ratios, coupled with lack of trial mixes leads to production of concrete that do not meet the designed target strengths [2, 3]. This scenario is however different for the few developers (public and private) who employ qualified professionals to design, construct and supervise their buildings.

Concrete mix design can be defined as the science of correct proportioning of concrete ingredients based on project requirements, to obtain the desired properties in plastic/wet as well in hardened stage [4]. Research has shown that the strength properties and other qualities of concrete depend on the mix design proportions; the type, content, and properties of ingredient materials, method of compaction, placing and curing [4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17]. When properly designed, mixed, placed, compacted and cured, concrete has good compression resistance and durability [6]. In the recent past, several reinforced concrete residential and commercial buildings have collapsed during construction and usage. This failure has been attributed to the poor quality of in situ concrete and the concrete technologies being implemented. [3, 5, 18].

All components within the mix design must be selected in such a way that the required properties of the final product are retained after the concrete mixture hardens [6]. In the fresh/ plastic state, workability is specified as the most important property while in the hardened state, compressive strength, density and durability are considered as the most important properties. The main parameters affecting the design of a concrete mixture are: type of cement, water/cement ratio, coarse aggregate/total aggregate ratio and total aggregate/cement ratio [7, 19]. Blended Portland cements exhibit a slower setting time and lower early strength development [20]. These cements however are the most commonly used type in Kenya and other developing countries due to their cheaper costs resulting from the local availability of the natural deposits of the pozzolanic materials used in their manufacture. Cement type and content, aggregate type and properties, age and curing conditions have also been reported to have a great effect on concrete strengths and durability [21]. Research has revealed that different mix design methods calculate the target mean strength and constituent ingredients mix proportions differently [22].

This experimental research was undertaken to determine the appropriate concrete mix proportions for blended Portland cement concrete production in Kenya. Locally available blended Portland cement concrete constituent materials were used during the study.

2. Materials and Methods

2.1. Materials Properties

2.1.1. Aggregates

Crushed stone aggregates from the Mlolongo quarry and ordinary river sand from the banks of river Ewaso Nyiro in Meru were used as coarse aggregates (CA) and fine aggregates (FA) respectively in the manufacture of concrete. The suitability of the aggregates for concrete production was ascertained through particle distribution in accordance to 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 812-102:1995), Bulk density (BS 812-2:1995), 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

SEIVE DESIGNATION	**WEIGT OF AGG. RETAINED**	**% WEIGHT RETAINED**	**CUMMULATIVE % RETAINED**	**% PASSING**
mm	**g**	%	**%**	**%**
10	0	0	0	100.0
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			
Physical Properties				**FM=2.41**
Grading	Zone II			
Fineness Modulus	2.41			
Specific Gravity	2.63			
water absorption	0.91%			
Moisture Content	0.73%			
Bulk Density	1564kg/m^3			

The aggregates physical and mechanical properties tests were done at the Jomo Kenyatta University of Agriculture and Technology (JKUAT) Civil Engineering laboratories. The results in Table 1 and Table 2 show that the aggregates were suitable for concrete production. 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 [18].

Table 2: Coarse Aggregates Physical Properties

SEIVE DESIGNATION (SIZE)	**Weight Of Agg. Retained**	**Cumulative Wt. Retained**	**% Weight Retained**	**% Weight Passing**
mm	**g**	g	**%**	**%**
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
Physical Properties				FM=2.551
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			

2.1.2 Cement

Portland Pozzolana Cement (PPC) is a type of Blended Cement which is produced by either inter-grinding Ordinary Portland Cement (OPC) clinker along with gypsum and pozzolanic materials in certain proportions, or grinding the OPC clinker, gypsum and pozzolanic materials separately and thoroughly blending them in certain proportions when producing concrete. Constituent materials that are permitted in blended Portland cements are artificial pozzolans (blast furnace slag, silica fume, and fly ashes) or natural pozzolans (siliceous or siliceous aluminous materials such as volcanic ash glasses, calcined clays and shale).

In Kenya, Lime and natural pozzolanic materials such as volcanic ashes, tuffs and diatomaceous earths deposits are commonly used in the manufacture of blended Portland cements. The cement is produced in accordance to KS EAS 18-1: 2001 standard which is an adoption of the European Norm EN 197 cement standards [23]. The cements produced are blended cements in which cement replacement materials are added to the clinker at the time of grinding. The cements readily available in the Kenyan market are Portland Pozzolanic Cement (PPC) CEM II/B-P containing 21-35% natural pozzolana, Pozzolanic Cement (PC) CEM IV/A with 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 specific uses [18], [24]. Normal cements are denoted N while rapid strength development cements are denoted R.

Currently there are six cement manufacturing companies in Kenya producing different brands of blended Portland cements. The six companies have been coded in this study as company A to F. Company A and company D each produce two brands of blended Portland cements coded as A1 and A2 and D1 and D2 respectively. The cements setting time, compressive strength and consistency tests were based on BS EN196:2010 while the fineness tests were done using the Blaine apparatus and the 32 Micron residue methods. The tests were done at the Kenya Bureau of Standards Laboratories and the properties of the locally available blended Portland cements have been summarized in Tables 3.

Table 3: Blended Portland Cement Physical and Mechanical Properties

BLENDED PORTLAND CEMENT TYPE		**CEMENT FINENESS**		**COMPRESSIVE STRENGTH (MPa)**			**CONSISTENCY AND SETTING TIME (MIN)**		
Cement Type	**Cement Brand**	**Residue (32 Microns) %**	**Blaine (Cm^2/g)**	**2 Days**	**7 Days**	**28 Days**	**Consistency**	**Initial Setting Time**	**Final Setting Time**
CEM II/B-L 32.5R	CEM A1	17.41	3856	20.2	31.4	46.9	27.6	182	251
CEM IV/B-P 32.5N	CEM A2	16.58	3935	13.6	23.4	37.6	33.3	200	295
CEM IV/B-P 32.5N	CEM B	17.55	4471	12.1	23.9	32.6	34.9	230	319
CEM IV/B-P 32.5R	CEM C	21.98	4063	21.1	35.3	45.5	31.5	197	270
CEM II/B-P 32.5N	CEM D1	22.98	3191	13.2	26.6	43.8	29.7	251	393
CEM II/B-P 32.5N	CEM D2	21.86	3451	13.5	28.0	39.3	30.9	208	292
CEM II/B-P 32.5R	CEM E	28.03	3034	10.3	24.9	40.1	30.56	201	290
CEM IV/B-P 32.5N	CEMF	27.38	3918	14.0	25.0	32.3	30.2	215	319

The results indicate that other than CEM F which had a lower value of compressive strength <32.5MPa, and CEM B which exceeded the minimum requirement by only 0.1MPa, all the other brands of blended Portland cements met the requirements as stated in the KS EAS 18-1: 2001 Standard. CEM C had the best combination of ultimate compressive strength and fineness and thus was used during the study to develop the mix design proportions since cement strength and fineness influence the strength development of concrete.

2.1.3 Water

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

2.2. Design of Experiments and experimentation

Central Composite Design (CCD) is a classified design for Response Surface Method (RSM) which is especially useful in sequential experiments because it is built on previous factorial experiments by adding axial and center points. CCD enables estimation of the regression parameters for second- order polynomial regression model for the response. They consist of cube points, center points and axial points. A factorial or fractional factorial design (2k or 2k-1 factorial points, where k is the number of factors) allow for the estimation of linear and interaction effects. Center points are used to check for curvature while axial (or star) points are used to estimate quadratic terms. Alpha (α) for axial points is the distance of each axial point from the center calculated by $\alpha = 2^{k/4}$ [25, 26, 27].

In this study, CCD was used to determine a quadratic response surface which has curvature and to predict factor levels that produce maximum or minimum response values for the composite material concrete. MINITAB 17 software was used to generate the concrete mixture proportions for experiments based on the Central Composite Design (CCD) method. Three variables namely; (i) Water/ Cement ratio as x_1, [0.4, 0.5, 0.5], (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. The variables were mixed randomly to obtain a full factorial design at three levels and repeated three times yielding a total of 60 runs with 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 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 4.

Table 4: Design of Experiment based on CCD and Results of the experiments

Run Order	**Pt Type**	**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	-1	3	0.5	0.28532	0.6	119	17.6843	20.6667	24.8307	2426
2	0	3	0.5	0.22	0.6	5	25.3947	28.2600	32.8633	2466
3	-1	3	0.3367	0.22	0.6	0	31.8893	33.7037	37.5653	2425
4	0	3	0.5	0.22	0.6	60	17.7593	21.1257	26.6777	2436
5	-1	3	0.5	0.22	0.53468	20	19.4903	23.3520	25.6027	2432
6	-1	3	0.5	0.22	0.66532	16	24.7543	28.0393	31.9137	2471
7	-1	3	0.6633	0.22	0.6	178	9.5227	12.1453	13.8743	2403
8	0	3	0.5	0.22	0.6	22	20.3303	24.6477	28.3687	2451

9	-1	3	0.3367	0.22	0.6	0	14.7980	16.8950	22.2483	2297
10	-1	3	0.6633	0.22	0.6	145	10.0233	13.6190	16.8733	2395
11	-1	3	0.5	0.15468	0.6	0	22.1967	26.9337	30.7127	2449
12	-1	3	0.5	0.22	0.53468	46	18.1250	22.9447	26.9840	2437
13	-1	3	0.5	0.28532	0.6	79	21.5290	26.7977	29.3450	2418
14	-1	3	0.5	0.22	0.53468	25	21.3067	25.4707	29.0913	2479
15	0	3	0.5	0.22	0.6	40	22.5180	27.0080	28.6100	2442
16	0	3	0.5	0.22	0.6	34	20.9717	26.2637	28.3360	2449
17	-1	3	0.5	0.22	0.66532	17	24.2600	27.0837	31.2523	2469
18	-1	3	0.5	0.15468	0.6	0	27.6507	32.0383	32.9640	2475
19	-1	3	0.5	0.22	0.66532	19	22.2050	26.2387	29.2247	2451
20	-1	3	0.5	0.15468	0.6	0	22.5987	25.9257	28.5010	2507
21	-1	3	0.5	0.28532	0.6	48	22.5260	26.4633	28.9590	2165
22	0	3	0.5	0.22	0.6	36	18.1237	23.6153	26.4823	2483
23	-1	3	0.3367	0.22	0.6	0	21.0787	34.3950	40.2660	2405
24	-1	3	0.6633	0.22	0.6	127	11.7603	14.1250	16.2230	2419
25	0	1	0.5	0.22	0.6	19	20.0800	25.3320	28.0543	2459
26	1	1	0.4	0.26	0.64	0	30.0670	36.2663	40.0590	2471
27	1	1	0.6	0.26	0.56	179	13.3357	16.4277	20.3050	2329
28	1	1	0.6	0.18	0.64	54	18.0570	19.8903	24.6177	2458
29	1	1	0.4	0.18	0.56	0	37.0520	38.8603	45.0367	2497
30	1	1	0.4	0.26	0.64	0	35.4320	41.7900	44.2050	2491
31	0	1	0.5	0.22	0.6	29	17.7777	22.1710	26.6133	2426
32	0	1	0.5	0.22	0.6	24	21.4933	25.6683	31.0600	2444
33	0	1	0.5	0.22	0.6	26	22.2083	28.6603	31.9413	2437
34	1	1	0.6	0.18	0.64	59	17.0493	18.9420	22.9697	2458
35	0	1	0.5	0.22	0.6	15	21.6350	26.5200	30.2403	2469
36	1	1	0.6	0.18	0.64	47	20.8780	24.3963	25.9997	2463
37	1	1	0.6	0.26	0.56	162	14.2423	17.6640	22.1520	2404
38	1	1	0.4	0.18	0.56	0	31.3223	34.2660	37.1040	2484
39	1	1	0.4	0.26	0.64	0	34.0237	37.1100	41.8920	2504
40	1	1	0.4	0.18	0.56	0	31.1180	37.7493	40.6843	2484
41	1	1	0.6	0.26	0.56	171	16.4057	19.1530	20.7490	2451
42	0	1	0.5	0.22	0.6	16	21.9257	27.7750	30.0290	2458
43	0	2	0.5	0.22	0.6	9	25.3853	30.0360	31.4287	2467
44	0	2	0.5	0.22	0.6	16	23.3377	26.7687	30.4777	2465
45	1	2	0.6	0.26	0.64	189	13.3767	15.6147	19.7300	2431
46	0	2	0.5	0.22	0.6	15	25.0243	28.9647	31.9650	2489
47	0	2	0.5	0.22	0.6	11	24.5367	28.6610	31.9650	2474

48	1	2	0.6	0.18	0.56	39	14.5397	18.0910	21.4490	2411
49	1	2	0.4	0.26	0.56	0	29.8100	34.5507	40.1690	2502
50	1	2	0.6	0.26	0.64	173	14.0673	17.2430	21.1427	2377
51	1	2	0.6	0.18	0.56	92	12.2783	15.1760	18.6677	2389
52	1	2	0.6	0.26	0.64	192	11.3460	15.3810	16.5090	2372
53	1	2	0.4	0.18	0.64	0	32.2370	34.1743	39.7800	2457
54	1	2	0.4	0.26	0.56	2	32.5597	36.6003	45.5950	2488
55	0	2	0.5	0.22	0.6	15	25.7463	27.8867	32.0750	2467
56	1	2	0.4	0.26	0.56	9	29.9810	33.5277	40.3447	2466
57	1	2	0.4	0.18	0.64	0	32.7410	36.2083	38.9030	2471
58	0	2	0.5	0.22	0.6	12	18.1333	23.4363	29.1447	2459
59	1	2	0.4	0.18	0.64	0	30.7233	35.6497	39.7387	2463
60	1	2	0.6	0.18	0.56	53	15.9157	16.6587	20.6830	2451

2.3. Instrumentation and Testing

Nine (9) 150mm by 150mm by 150mm concrete cubes were cast for each of the sixty (60) runs and slump test was used to evaluate the wet concrete response properties while three cubes were tested at 7, 14 and 28 days of curing each to evaluate the compressive strength development of the concrete and the density of the concrete. The compressive strength of concrete was investigated at 7, 14 and 28 days using the Universal Testing Machine with a loading capacity of 1500kN in accordance to BS 1881-116: 1983 as illustrated in Figure 1.

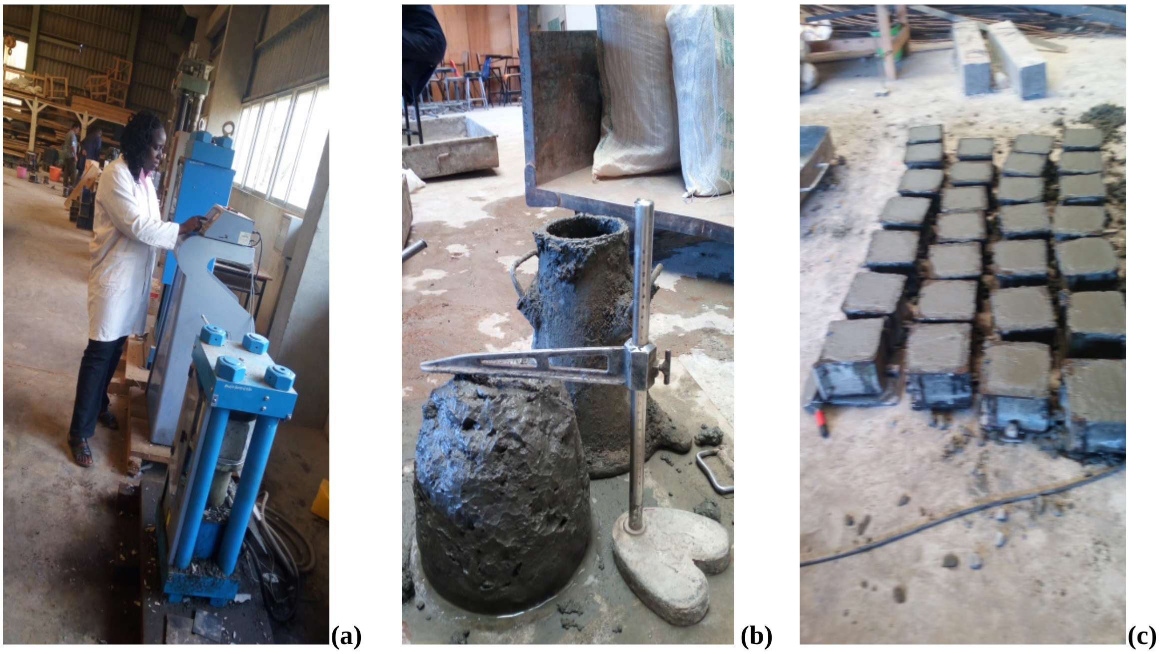


Figure 1: (a) Compressive strength testing machine, (b) slump test cones and (c) casted concrete cubes

3. Results and Discussion

The analysis of the response based on the 60 runs of experiments carried out was done using Minitab 17 software. Each response was analyzed independently and the interaction effects of the various variables were also investigated.

3.1. The Effect of water /cement ratio (x_1), the cement/ total aggregates ratio (x_2) and fine aggregates/ coarse aggregates ratio (x_3) variables on the Slump (Y_1)

The experiment resulted in slump values ranging from 0mm to 195 mm as shown in Table 4. The response was then analyzed to evaluate the influence of the different variables and their interactions on the slump of the concrete. The interaction effects of the different variables on the slump was also investigated and the results show that the interaction between the water /cement ratio (x_1) and the cement/ total aggregates ratio (x_2) had a significant effect in the slump while their interaction with the fine aggregates/ coarse aggregates ratio (x_3) did not have a significant effect on the slump as shown in Figure 2.

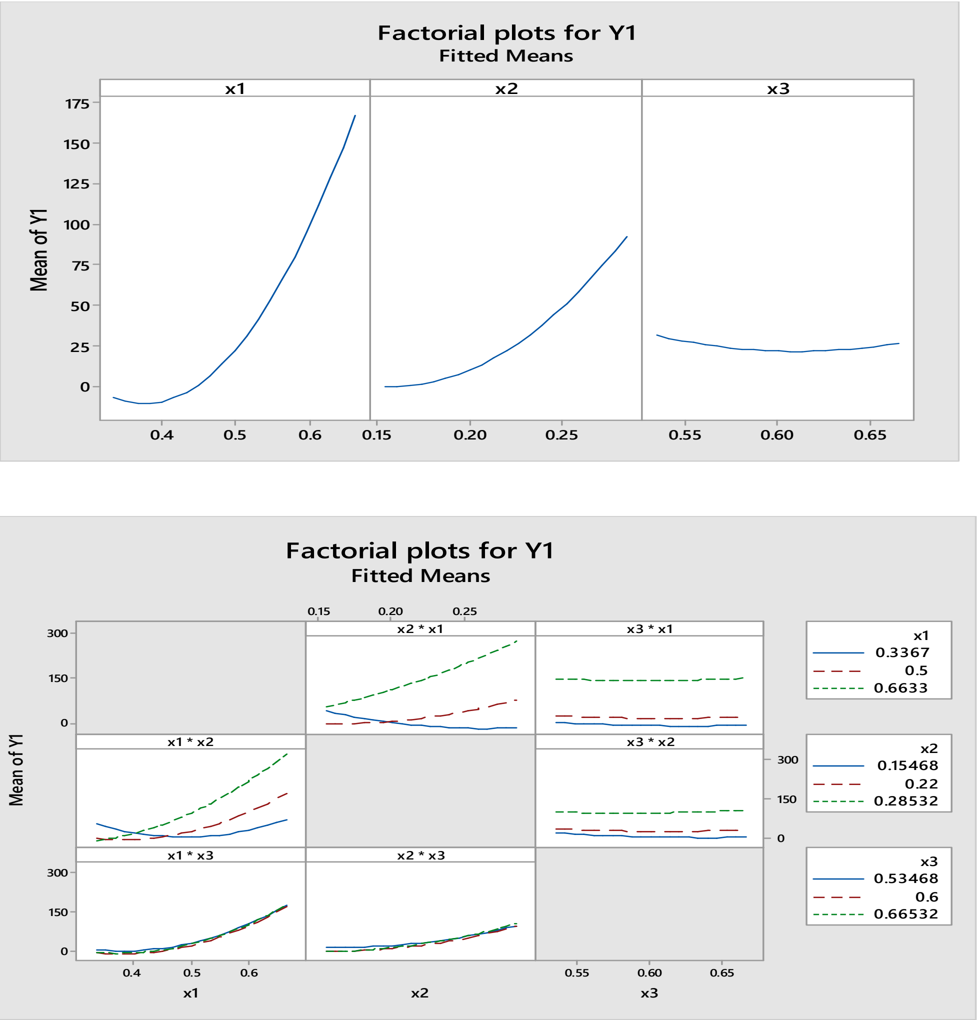


Figure 2: Effect of water /cement ratio (x_1), the cement/ total aggregates ratio (x_2) and fine aggregates/ coarse aggregates ratio (x_3) variables on the Slump (Y_1)

The results were further analyzed to obtain the residual plots and the quadratic model for the effect of the three variables x1, x2 and x3 on the blended Portland cement slump and the results were as shown in Figure 3.

From the results, as expected, slump was affected by both the water/ cement ratio and the cement/ total aggregates ratio in that in both cases, the higher the water/ cement ratio and cement content, the higher the slump and vice versa. The fine aggregates/ coarse aggregates ratio however had very minimum effect on the slump as the value of the slump remained almost constant at the different values of the aggregates ratios investigated. The contour plots for the three variables was then plotted to be used to derive the mix design ratios for the different values of slump for the blended Portland cement concrete production as shown in Figure 4.

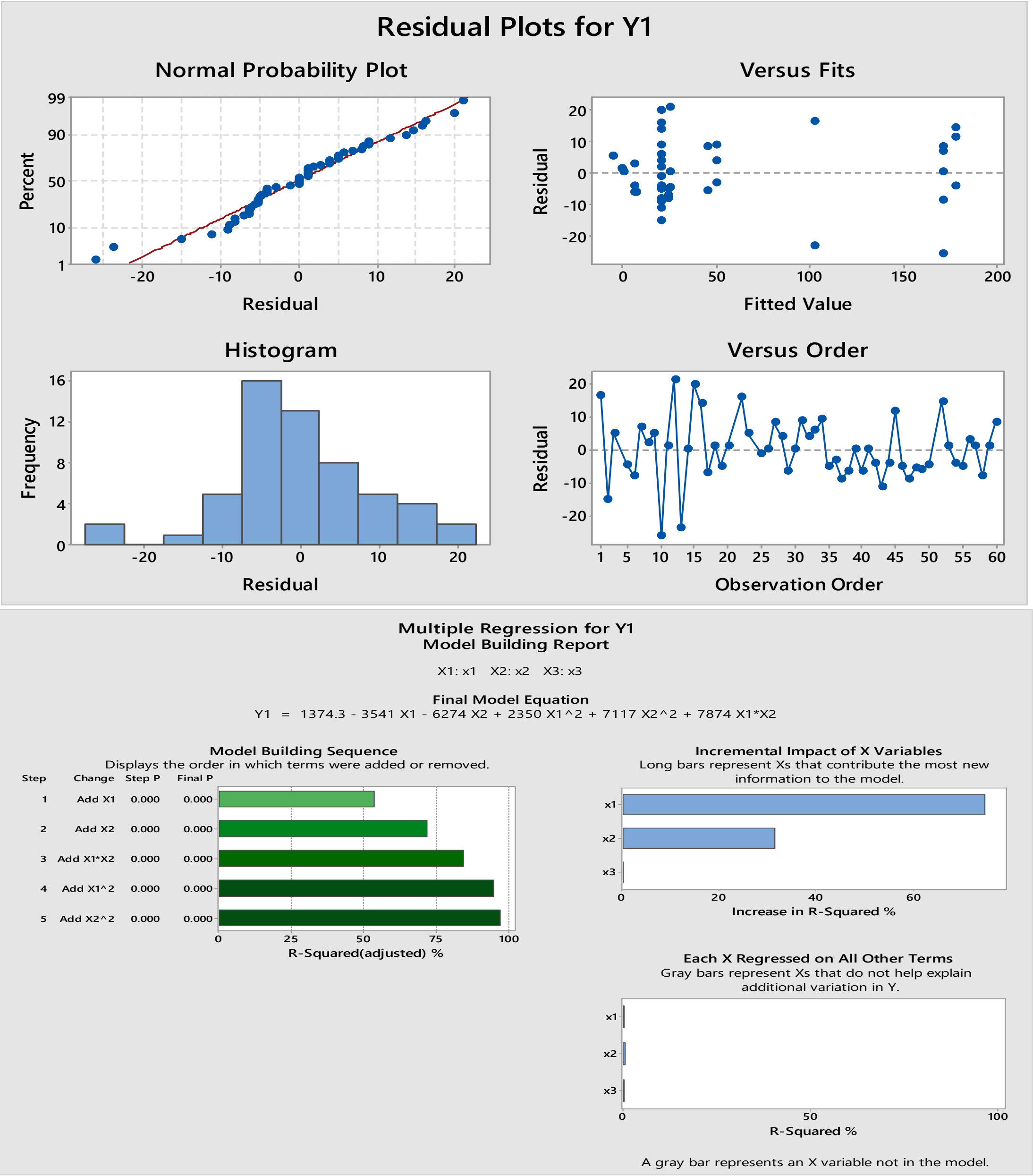


Figure 3: Residual plots and Model Building Report for the effect of the variables on the Slump Y_1

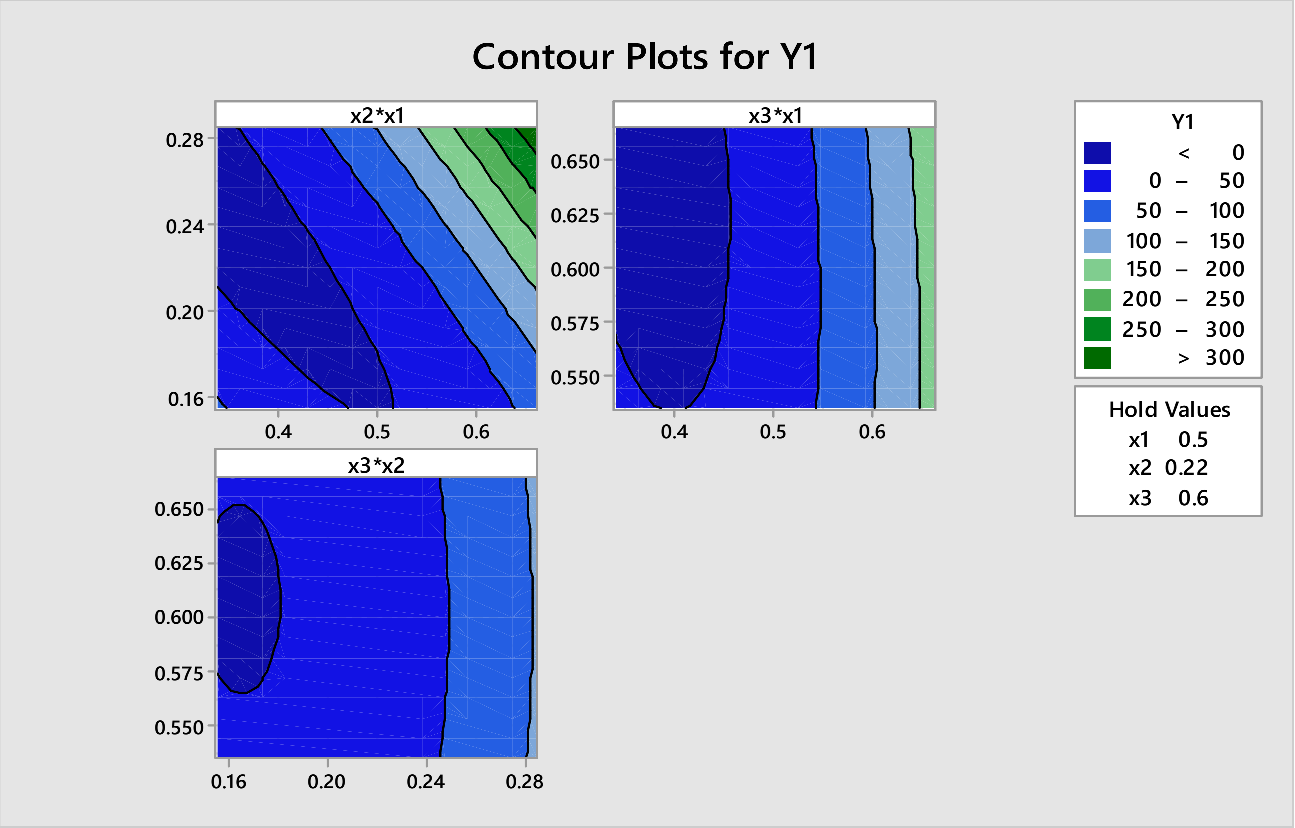


Figure 4: The Interaction Effect of water /cement ratio (x_1), the cement/ total aggregates ratio (x_2) and fine aggregates/ coarse aggregates ratio (x_3) variables on the Slump (Y_1)

3.2. The Effect of water /cement ratio (x_1), the cement/ total aggregates ratio (x_2) and fine aggregates/ coarse aggregates ratio (x_3) variables on the Early (7-Days) Compressive Strength (Y_2)

The experiment resulted in 7 days compressive strength values ranging from 9MPa to 34MPa as shown in Table 4. The response was then analyzed to evaluate the influence of the different variables and their interactions on the early strength gain of the blended Portland cement concrete as shown in Figure 5.

From the results, the early strength gain was significantly affected by the water/ cement ratio (x_1). The lower the water cement ratio, the higher the early compressive strength. The cement/ total aggregates ratio (x_2) and the fine aggregates / coarse aggregates ratio (x_3) on the other hand had a slight effect of the early strength gain. Between 0.2 to 0.25 cement / total aggregates ratio (x_2), there was no effect on the 7 days strength while below 0.2, the strength increased with decrease in the ratio and above 0.25 the strength increased with increase in the ratio. There was, however, slight increase in strength with the increase in the fine aggregates/ coarse aggregates ratio (x_3) as shown in Figure. 5.

The interaction effects of the different variables on the 7 days compressive strength was also investigated and the results show that the interaction between the water /cement ratio and the cement/ total aggregates ratio and that of the cement/ aggregates ratio and the fine aggregates/ coarse aggregates ratio had an effect in the 7 days compressive strength while the interaction between the fine aggregates/ coarse aggregates ratio and the water cement ratio did not have a significant effect on the 7 days compressive strength as shown in Figure. 5. The results were then used to generate contour plots for the determination of the blended Portland cement concrete ratios as shown in Figure 6.

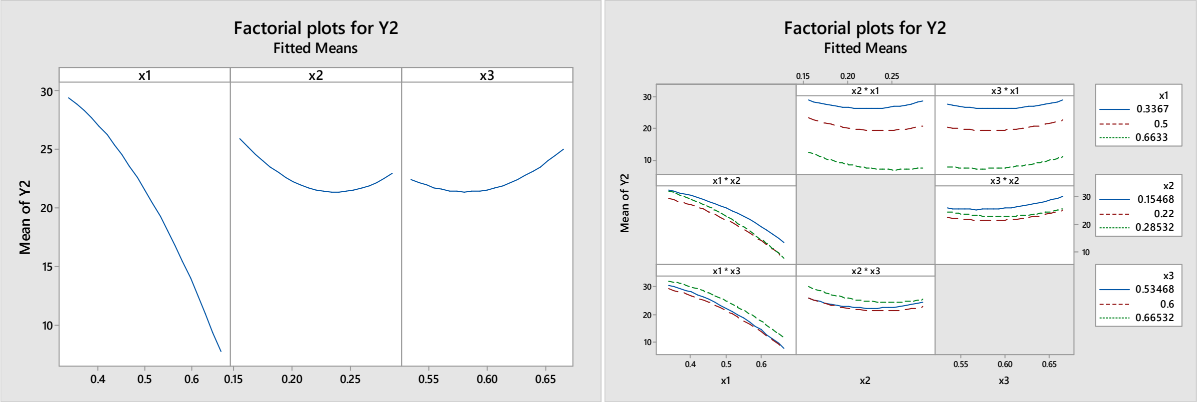


Figure 5: Effect of water /cement ratio (x_1), the cement/ total aggregates ratio (x_2) and fine aggregates/ coarse aggregates ratio (x_3) variables on the 7 Days Compressive Strength (Y_2)

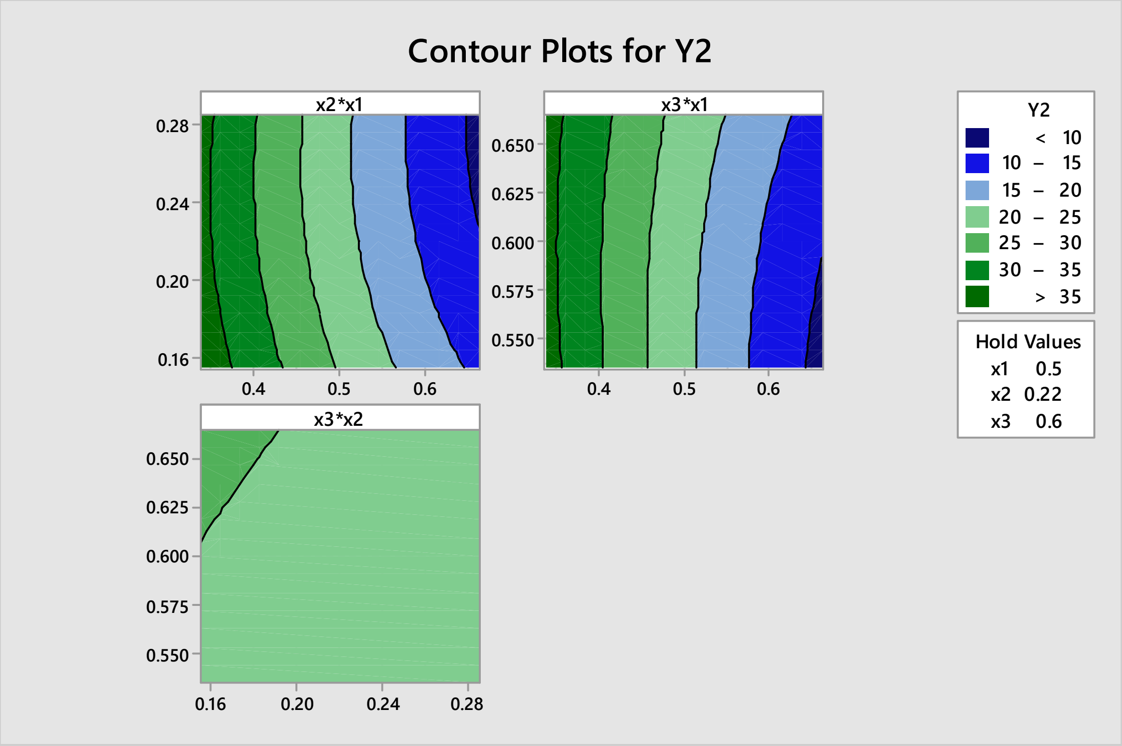


Figure 6: The 7 days contour plots for the Interaction Effect of water /cement ratio (x_1), the cement/ total aggregates ratio (x_2) and fine aggregates/ coarse aggregates ratio (x_3) variables on the 7 Days Compressive Strength (Y_2)

3.3. The Effect of water /cement ratio (x_1), the cement/ total aggregates ratio (x_2) and fine aggregates/ coarse aggregates ratio (x_3) variables on the Ultimate compressive strength at 28 days (Y_4)

The experiment resulted in 28 days compressive strength values ranging from 13MPa to 45MPa. The response was then analyzed to evaluate the influence of the different variables and their interactions on the 28 days strength gain of the concrete. From the results, as expected, the ultimate strength gain is highly affected by the water/ cement ratio (x_1) as shown in Figure 7. The lower the value of the water cement ratio, the higher the value of the ultimate compressive strength. The cement/ total aggregates ratio and the fine aggregate / coarse aggregates ratio had a slight effect of the ultimate compressive strength gain.

The interaction effects of the different variables on the 28 days compressive strength was also investigated and the results show that the interaction between the water /cement ratio and the cement/ total aggregates ratio and that of the cement/ aggregates ratio and the fine aggregates/ coarse aggregates ratio had a significant effect in the 28 days compressive strength while the interaction between the fine aggregates/ coarse aggregates ratio and the water cement ratio did not have a significant effect on the 28 days compressive strength as shown in Figure 7.

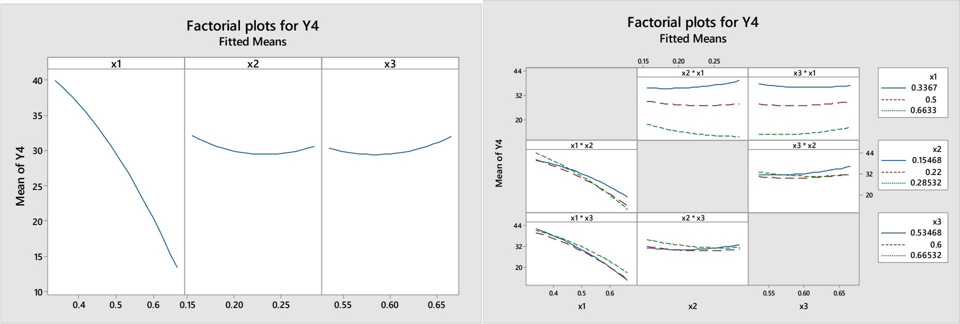


Figure 7: Effect of water /cement ratio (x_1), the cement/ total aggregates ratio (x_2) and fine aggregates/ coarse aggregates ratio (x_3) variables on the 7 Days Compressive Strength (Y_4)

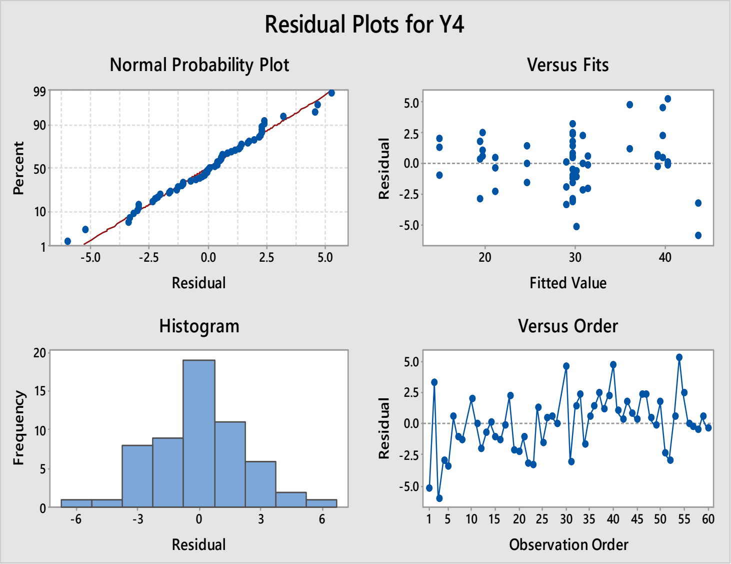
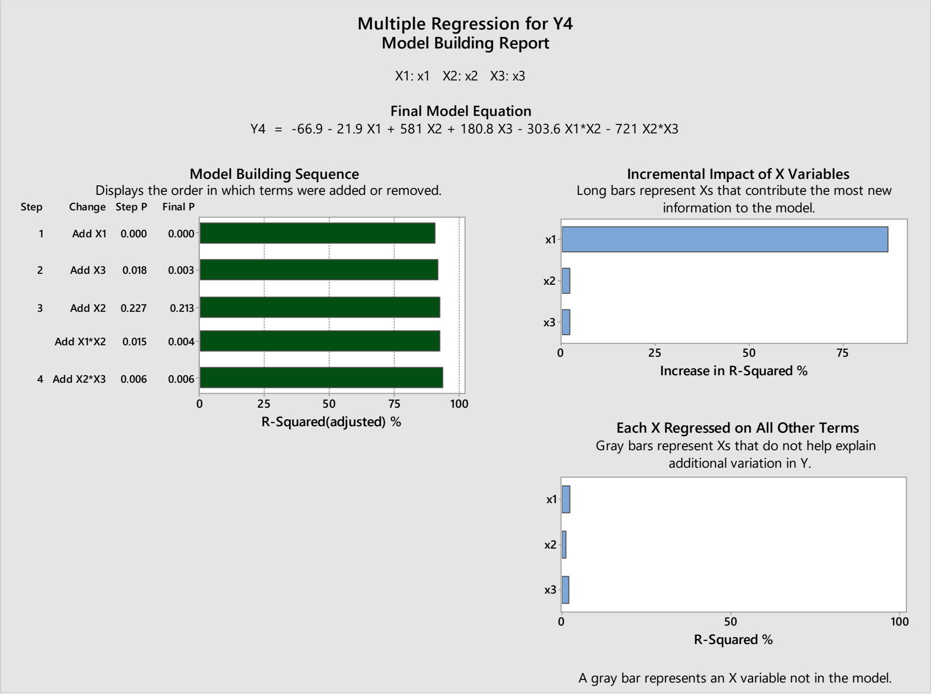


Figure 8 (a): The ultimate compressive strength residual plots



Multiple Regression for Y4
Model Building Report

X1: x1 X2: x2 X3: x3

Final Model Equation
Y4 = -66.9 - 21.9 X1 + 581 X2 + 180.8 X3 - 303.6 X1*X2 - 721 X2*X3

Model Building Sequence
Displays the order in which terms were added or removed.

Step	Change	Step P	Final P
1	Add X1	0.000	0.000
2	Add X3	0.018	0.003
3	Add X2	0.227	0.213
	Add X1*X2	0.015	0.004
4	Add X2*X3	0.006	0.006

Incremental Impact of X Variables
Long bars represent Xs that contribute the most new information to the model.

Each X Regressed on All Other Terms
Gray bars represent Xs that do not help explain additional variation in Y.

A gray bar represents an X variable not in the model.

Figure 8 (b): The Ultimate Compressive Strength Model Building Report

The results were then used to plot the residual plots for the ultimate compressive strength at 28 days and to generate the mathematical model for the ultimate compressive strength of the blended Portland cement concrete production as shown in Figure 8. The results were further used to plot the contour plots for the generation of the concrete mix design ratios for the different target compressive strengths at 28 days given in Figure 9.

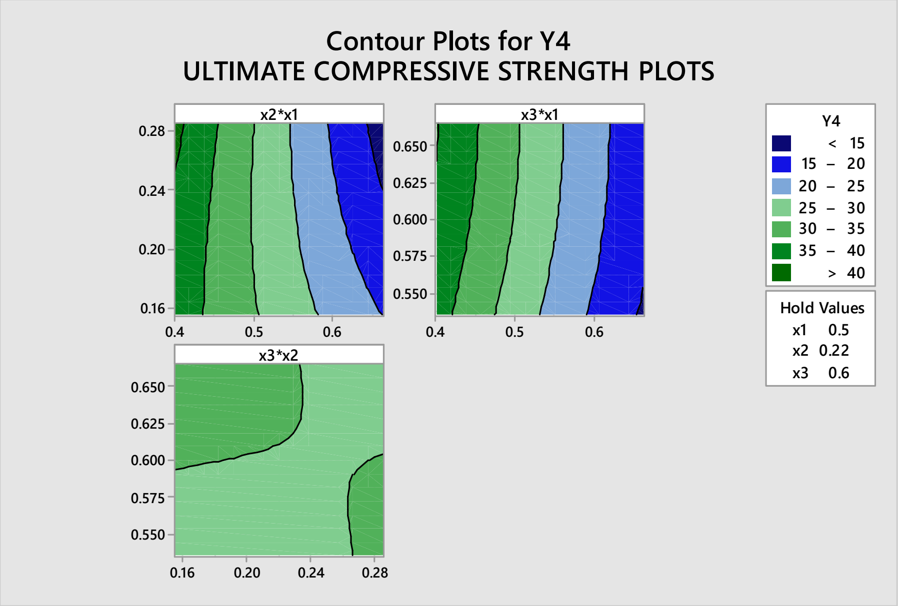


Figure 9: The 7 days contour plots for the Interaction Effect of water /cement ratio (x_1), the cement/ total aggregates ratio (x_2) and fine aggregates/ coarse aggregates ratio (x_3) variables on the 28 Days Compressive Strength (Y_4)

3.4. The Effect water /cement ratio (x_1), the cement/ total aggregates ratio (x_2) and fine aggregates/ coarse aggregates ratio (x_3) variables on the Average Density of blended Portland cement concrete (Y_5)

The experiment resulted in average density values ranging from 2100kg/m3 to 2500kg/m3 as shown in Table 4. The response was then analyzed to evaluate the influence of the different variables and their interactions on the density of the concrete as shown in Figure 10.

From the results, it was clear that the density is highly affected by the water/ cement ratio (x_1) and the cement/ total aggregates ratio (x_2) while the fine aggregates / coarse aggregates ratio had a slight effect of the average density.

The higher the value of the water / cement ratio, the higher the value of the density up to 0.5 above which the higher the water/ cement ratio, the lower the density.

The cement/ total aggregates ratio on the other hand affected the density in that the higher the ratio, the lower the density.

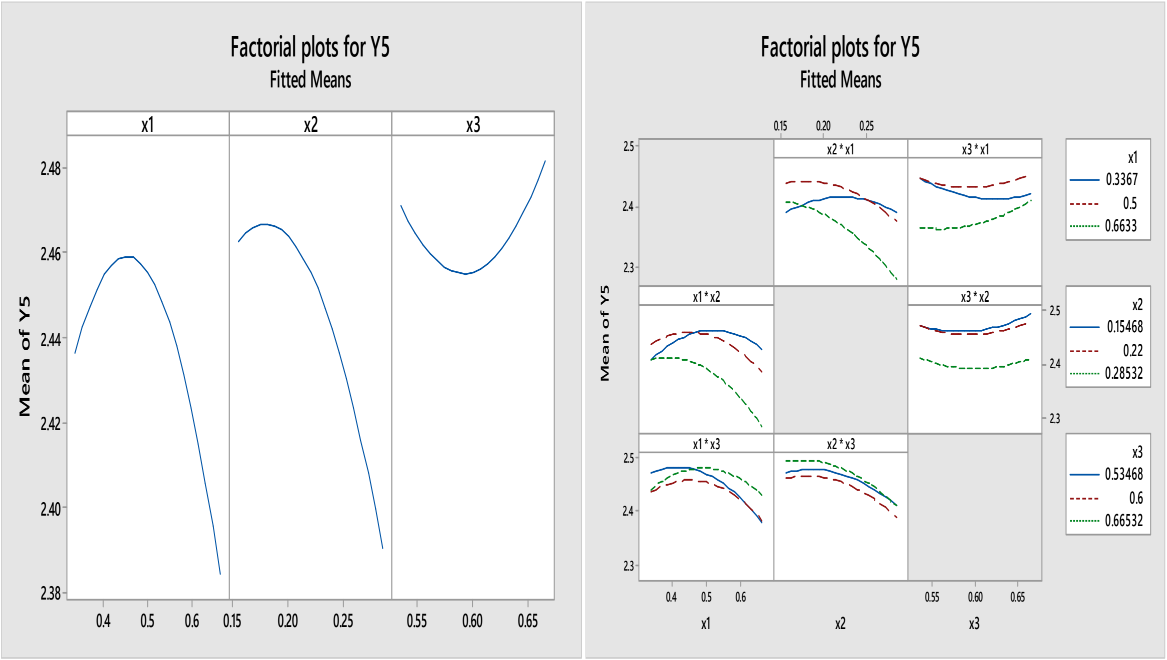


Figure 10: Effect of water /cement ratio (x_1), the cement/ total aggregates ratio (x_2) and fine aggregates/ coarse aggregates ratio (x_3) variables on the 7 Days Compressive Strength (Y_4)

3.5. Model validation

Model validation was done through repeat tests on the 28 days compressive strength with various target strengths.

The same type of aggregates and CEM C cement was used to cast 20 runs repeated three times at different times and the results were as shown in Table 5.

Table 5: 28 day's compressive strength model validation test results for Blended Portland cement (CEM C)

RUN	x_1	x_2	x_3	Cement	Water	Fine Aggregates	Coarse Aggregates	SLUMP Y_1 (mm)	7 days (Y_2)	28 days Strength (Mpa) Y_4	
				kg	**kg**	**kg**	**kg**	**mm**	**Mpa**	**ACTUAL Mpa**	**TARGET Mpa**
1	0.5	0.3	0.7	491.3	236.9	687.9	1033.9	86.0	22.5	30.1	**30.0**
2	0.5	0.2	0.6	405.3	202.6	690.8	1151.3	23.0	23.0	29.3	**29.9**
3	0.5	0.2	0.5	405.3	202.6	641.8	1200.3	37.0	23.4	30.9	**28.5**
4	0.5	0.3	0.6	489.5	244.8	643.4	1072.3	88.0	22.6	30.1	**29.7**
5	0.5	0.2	0.7	405.3	202.6	735.9	1106.2	35.0	24.4	33.0	**31.4**
6	0.5	0.2	0.5	432.4	216.2	627.6	1173.8	31.0	20.5	29.2	**25.0**
7	0.6	0.2	0.6	342.4	205.4	742.3	1159.9	34.0	16.7	25.0	**24.4**
8	0.5	0.2	0.5	405.3	202.6	641.8	1200.3	30.0	22.2	32.2	**28.5**
9	0.5	0.3	0.6	489.5	244.8	643.4	1072.3	92.0	21.3	29.1	**29.7**
10	0.5	0.2	0.6	405.3	202.6	690.8	1151.3	21.0	21.7	29.2	**29.9**
11	0.6	0.2	0.5	304.5	177.0	685.8	1282.7	11.0	19.4	25.1	**20.0**
12	0.6	0.3	0.6	449.9	269.9	621.1	1109.1	122.0	16.0	20.0	**20.0**
13	0.6	0.2	0.6	342.4	205.4	682.8	1219.3	33.0	16.0	20.5	**20.3**
14	0.6	0.3	0.6	449.9	269.9	675.2	1055.0	137.0	15.1	20.9	**19.4**
15	0.6	0.2	0.6	342.4	205.4	742.3	1159.9	40.0	12.5	20.3	**24.4**
16	0.7	0.2	0.5	301.8	197.3	679.7	1271.2	22.0	13.0	16.8	**15.0**
17	0.6	0.3	0.6	449.9	269.9	1730.2	1055.0	133.0	12.4	17.7	**19.4**
18	0.6	0.3	0.6	**449.9**	269.9	1730.2	1109.1	119.0	12.2	18.0	**20.0**
19	0.6	0.2	0.6	**342.4**	205.4	1902.2	1219.3	31.0	13.9	18.9	**20.3**
20	0.6	0.2	0.6	**342.4**	205.4	1902.2	1159.9	27.0	16.5	22.0	**24.4**

The same mix ratios for the 20 runs were then used to cast concrete using the same aggregates but varying the brands of blended Portland cements.

Cements from all the six local cement companies were used to evaluate the suitability of the mix proportions.

The results were then compared with the target 28 days compressive strength generated through the model and the results were as shown in Table 6.

Table 6: 28 day’s compressive strength model validation test results for different brands Blended Portland cements

	SLUMP (mm)						**ACTUAL 28 DAYS COMPRESSIVE STRENGTH (MPa)**						**MPa**
RUNS	CEM A1	CEM B	CEM C	CEM D	CEM E	CEM F	CEM A1	CEM B	CEM C	CEM D1	CEM E	CEM F	PREDICTED
1	43	40	86	136	139	76	28.28	26.42	30.14	32.08	30.06	23.50	**30.00**
2	9	10	23	25	30	29	28.10	24.08	29.32	33.59	25.81	22.00	**29.91**
3	16	9	37	20	20	25	29.06	23.63	30.90	31.76	28.07	22.42	**28.47**
4	44	60	88	145	170	95	28.33	22.16	30.15	30.14	28.31	20.61	**29.70**
5	28	5	35	14	27	23	26.92	24.14	32.99	30.62	25.69	20.83	**31.36**
6	16	4	31	11	23	22	25.16	21.37	29.16	27.53	18.17	19.63	**25.00**
7	33	20	34	24	32	22	19.39	18.07	25.02	23.46	18.83	18.33	**24.42**
8	16	10	30	24	28	11	25.95	24.48	32.21	33.67	24.03	25.96	**28.47**
9	41	48	92	141	174	105	23.42	21.62	29.07	32.01	22.25	21.11	**29.70**
10	5	5	21	12	25	9	26.27	26.64	29.18	32.47	28.32	22.30	**29.91**
11	4	2	11	6	6	5	20.95	21.21	25.10	25.51	17.89	18.09	**20.00**
12	156	179	122	203	227	202	17.40	17.71	20.02	21.35	16.38	13.14	**19.97**
13	40	29	33	46	47	20	19.86	19.27	20.49	27.74	22.34	15.67	**20.35**
14	145	180	137	118	204	218	19.32	18.30	20.93	24.30	20.27	15.90	**19.42**
15	38	38	40	69	52	13	16.56	18.27	20.31	27.64	19.41	14.82	**24.42**
16	39	55	22	75	70	21	15.85	13.63	16.82	21.93	17.92	14.19	**15.00**

17	150	201	133	215	211	202	14.86	15.10	17.71	21.33	20.43	15.35	**19.42**
18	135	204	119	207	209	229	12.05	17.85	18.03	15.35	18.38	15.84	**19.97**
19	26	13	31	16	47	21	19.60	19.49	18.85	25.29	22.34	15.67	**20.35**
20	16	28	27	17	32	15	20.57	17.69	22.00	17.54	24.03	14.82	**24.42**

3.6. Determination of appropriate blended Portland cement concrete proportions

Due to the variability of concrete in production 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 where the terms are as illustrated in Table 7.

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

Table 7: Illustration of terms used in Equation 1 as given in BS 532828

Terms	**Meaning**	**Terms**	**Value**
f_m	The target mean strength	k for 10% defective	1.28
f_c	The specified characteristic strength	k for 5% defective	1.64
s	The standard deviation	k for 2.5 % defective	1.96
k	A constant	K for 1% defective	2.33

The standard deviation s for the 28 days compressive strength results was 6.841 as illustrated in Figure 11. 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.

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

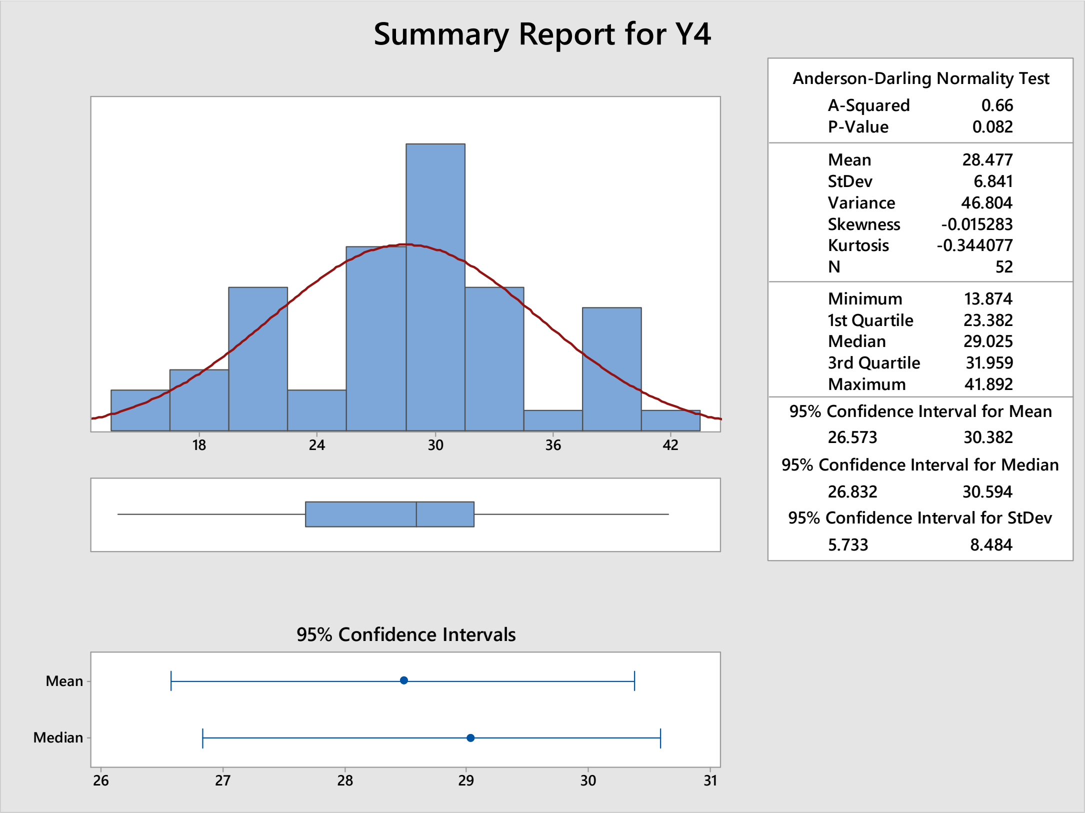


Figure 11: Statistical analysis of the 28 days compressive strength Y_4 results

Considering the results in Tables 5 and 6, 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 did not achieve the target 30MPa. Based on the calculated compressive strength margin of 11.22MPa, 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 for a workable concrete with a slump of ≥ 30mm that the most appropriate mix proportions for the blended Portland cement concrete were: : 1:2.2:3.4 (w/c 0.6) for strength class C15 and 1:1.3:2.2 (w/c 0.5) for strength class C20. It was further noted that none of the blended cement brands achieved the target design strength for strength class C25 and above. It was concluded that the blended Portland cements may not be suitable for producing structural concrete strength class C 25 and above.

4. Conclusion

Based on the experiments carried out and the results obtained, the following conclusions can be arrived at:

a) The different brands of blended Portland cements from the six different manufacturers have varying physical and mechanical properties which in turn affect the concrete produced when the different brands of cements are used. Other than one brand (CEM F), all the other five brands met the minimum physical and mechanical properties as stated in the Kenyan standards KS EAS 18-1:2001.

b) The appropriate concrete mix ratios for the Kenyan blended Portland cement concrete are as follows: Class C15 is 1:2.2:3.4 at a water/ cement ratio of 0.6, and C20 is 1:1.3:2.2 at a water cement ratio of

0.5. Since some cement brands do not meet the minimum characteristic strength of 25MPa required for class C 25, Kenyan Blended Portland cements should not be used to produce concrete of strength class C25 and above since the mix does not achieve the target compressive strength of 36.22MPa at 28 days when no additive is used.

c) The construction industry in Kenya should come up with policies to ensure that un qualified personnel do not design and supervise reinforced concrete structures to ensure that quality control measures are adhered to on site.

5. Limitations of the study

The main limitation of the study is the use of fine aggregates from the same river bank and coarse aggregates from the same quarry thus the influence of the difference in the properties of the aggregates on the quality of concrete was not investigated.

6. Recommendations

From the results of the experiments, the authors recommend that;

1. The blended Portland cements may not be suitable for the production of concrete class C25 and above.
2. Further research should be done to establish the influence of the difference in aggregates properties on the quality of blended Portland cement concrete in Kenya.

Acknowledgment

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