A QUALITY CONTROL SCHEME FOR A COMMERCIAL POZZOLANA PLANT: A CASE STUDY OF POZZOLANA GHANA LTD

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Abstract

A Quality control scheme was developed for a 200 ton per day commercial pozzolana plant. The scheme was evaluated for the first 34 days of production. Statistical Process Control techniques were specifically applied to the mechanical properties of setting times and compressive strength. Results obtained showed that pozzolana samples tested were chemically suitable with total SiO_2, Al_2O_3 and Fe_2O_3 content $\geq$ 70%. Mechanical tests performed were mostly under control and when out-of-control, they gave valuable indication to plant malfunction or operator errors which were promptly corrected. The results of mechanical properties tested against the three major brands of cement on the Ghanaian market showed that pozzolana gave highest compressive strengths with Dangote CEM I 42.5R ranging between 21.3 MPa - 36.3 MPa at 7 days and 33.8 MPa - 45.1 MPa at 28 days whilst lowest compressive strengths were obtained with Ghacem CEM II B-L 32.5R cement ranging between 16.3 MPa – 23.6 MPa at 7 days and 23.3 MPa – 30.7 MPa at 28 days. Compressive strengths obtained with Diamond CEM II B-L 42.5N cement were average. A mean compressive strength for all brands of cement of 25.2 MPa and 33.6 MPa at 7 days and 28 days respectively were obtained.

Keywords: Pozzolana cement, statistical process control, Shewhart chart, compressive strength, setting time

Introduction

Ghana's housing construction sector has been plagued by high cost of imported inputs-especially Portland cement and its derivatives (Sarfo-Ansah *et al.,* 2009). Several locally developed materials have been proposed as alternatives and partial replacement of Portland cement. Such materials include burnt bricks (Obeng, 1993), compressed lateritic blocks (Gidigasu & Bawa, 1965), lime (Hagan, 1988) and pozzolanas - from bauxite waste (Hammond, 1974) and clay (Atiemo, 2005).

Clay pozzolana in particular has received much attention due to the widespread availability of clay, the main raw material for its production nationwide (Kesse, 1985). After 30 years of research and field trials into clay pozzolanas, the Building and Road Research

Institute (BRRI) of the Council for Scientific and Industrial Research (CSIR-Ghana) transferred the clay pozzolana production technology to PMC Global Inc. who subsequently established a 200 ton per day pozzolana plant – Pozzolana Ghana Ltd at Gomoa Mprumem in the Central region of Ghana to commercialize clay pozzolana. For such an entry level product as clay pozzolana on the Ghanaian market, there was a need to develop an effective and easily adaptable quality control scheme to ensure high quality standards of the product and optimal productivity levels of the plant. Quality control in manufacturing describes the individual measures which relate to the monitoring and control of particular production processes geared at ensuring the totality of features and characteristics of a product that bears on its ability to satisfy given needs (American Management System, 2010). Tools and techniques employed to control quality include statistical techniques such as Design of Experiments (DoE), Taguchi methods, Failure Mode Experimental Analysis (FMEA) and Statistical Process Control (SPC) (Hairulliza *et al*., 2009). SPC is the most employed quality control tool in manufacturing due to its easy adaptability (McAvoy, 2002).

SPC uses statistical concepts of the mean $\bar{x}$ and the standard deviation, σ, to characterize a normal distribution of the measured variable (Edgar *et al*., 1999) by isolating the assignable variability of the system from the inherent variability or noise of the system (Berthouex, 1989). Improved process operation then results from correcting the abnormal assignable variability (McAvoy, 2002). One way of achieving this is through the use of control charts such as the Shewhart chart. A control chart is a graphical representation on which values of quality characteristics under review are plotted sequentially based on a tar-

get value and quality limits. Two quality limits are of particular significance on a Shewhart chart – the warning limits defined as $\bar{x} \pm 2\sigma$ and action limits defined as $\bar{x} \pm 3\sigma$ (Koech, 2010).

Control charts are applied in SPC for two reasons. First, in indirect control, to help bring a process for which very little information exists into a state of statistical control and second, in direct control, by keeping variation about a target level to the barest minimum for a process which is already in a state of statistical control (Berthouex, 1989). In manufacturing, control charts are applied more especially for the latter reason (Hairulliza *et al*., 2009) with the basic assumption that typical process performance is defined by a constant value and the residuals about this level are random, independent and of a constant variance (Berthouex, 1989). Shewhart charts also find applicability in clinical chemistry (Westgard *et al*., 1981), analytical chemistry (Taverniers *et al*., 2004) and waste water treatment (Berthouex, 1981).

Experimental

A 200 TPD (tonnes per day) commercial pozzolana plant of Pozzolana Ghana Ltd, located at Gomoa Mprumem was used for the study. Production of pozzolana started at the plant on 18th April, 2011. Fig. 1 shows the flow chart for the 200 TPD plant. A scheme of sampling was developed for the pozzolana production process as shown in Fig. 2. The hourly milled pozzolana samples taken were formed into a daily composite sample to determine the mechanical and chemical properties of the pozzolana. The pozzolanas were tested for mechanical and chemical properties with the three main brands of Portland cement on the Ghanaian market – Ghacem CEM II B-L Class 32.5R, Diamond CEM II B-L Class 42.5N and Dangote CEM I Class 42.5R cements – by replacing 33% of the cements with pozzolana.

Test methods for mechanical properties of the pozzolana cement were based on the Ghana Standards, GS C 311-05 and where necessary on EN 196:1-4. Chemical tests were based on gravimetric methods stipulated in ASTM C 150. Internally adopted criteria were developed for sorting of the calcined nodules. These tests were compiled into a set of Standard Operating Procedures (SOPs) for easy use by laboratory technicians. As much as possible, the laboratory applied the principles enshrined in ISO 17025 standards. In conformity with that, a draft quality manual was produced and adopted for use in the laboratory. Test results for mechanical properties were developed into Shewhart charts to ascertain the quality control dynamics of the production process.
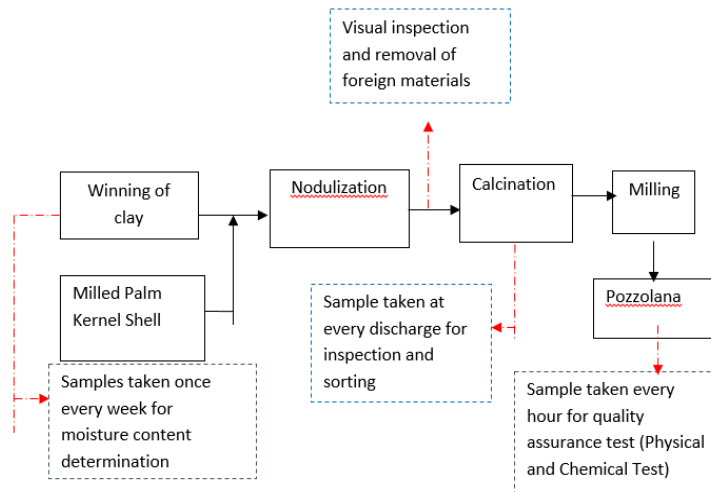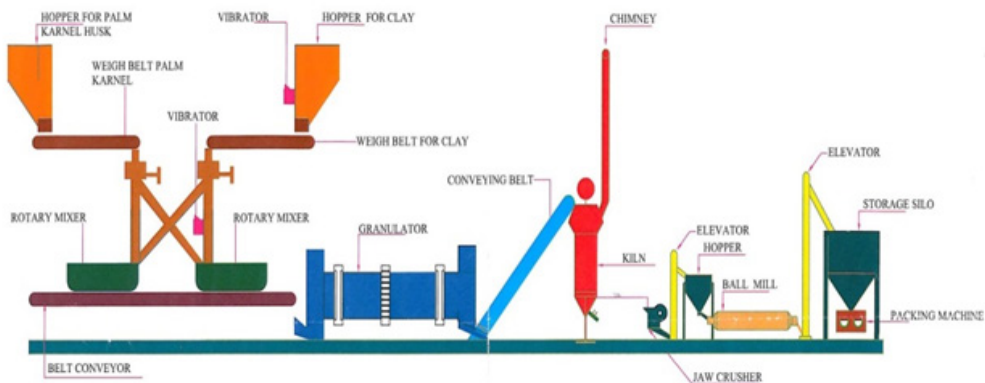
Fig. 1: Flow chart for 200 TPD plant.

Fig. 2: Schematic representation of production process showing sampling points for quality control.

Chemical analysis

The quality benchmark for chemical suitability of pozzolanas produced was standard levels as stipulated in EN 197-1 and ASTM C 618. Table 1 shows chemical determinations of some pozzolana samples produced at the plant. All the pozzolana samples analysed within the period were found to be chemically suitable with total $SiO_2+Al_2O_3+Fe_2O_3$ contents higher than the minimum 70% required in ASTM

C618. The SiO_2 content of all the pozzolanas exceeded the minimum limit of 25.0% (averaging 63.36%) as prescribed by EN 197-1. The loss on ignition figures determined were also below the maximum limit of 5.0% with an average of 3.45%; the chloride contents were less than 0.1% and the sulphate contents (determined as SO_3) were less than 3.5% required of pozzolanas as specified in EN 197-1.

TABLE 1

Chemical properties of samples of pozzolana produced between April-August, 2012

DATE	LOI	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Cl	Insoluble Residue	SO_3
2012	%	%	%	%	%	%	%A	%	%
26/4	3.72	63.80	18.93	5.41	0.18	1.08	0.01	1.42	2.02
28/4	4.02	63.43	18.06	5.51	0.10	1.12	0.01	1.36	1.18
30/4	3.88	62.98	18.84	5.19	0.14	1.24	0.01	1.44	2.01
2/5	3.85	62.69	17.93	5.86	0.11	1.04	0.01	1.31	1.15
3/5	3.61	63.92	17.82	5.18	0.10	1.14	0.01	1.29	1.19
5/5	3.92	63.88	18.15	5.78	0.18	1.06	0.01	1.40	2.01
7/5	3.55	62.96	19.04	5.49	0.20	1.30	0.01	1.20	2.04
8/5	3.71	63.00	19.11	4.97	0.09	1.16	0.01	1.32	2.00
9/5	2.98	63.90	18.65	5.44	0.13	1.28	0.01	1.40	1.26
10/5	2.86	63.41	18.04	5.20	0.11	1.24	0.01	1.33	1.62
11/5	3.27	62.95	18.62	5.18	0.16	1.08	0.01	1.30	1.18
27/6	2.99	63.97	18.01	5.68	0.13	1.14	0.01	1.34	2.03
28/6	3.42	63.41	18.18	5.10	0.18	1.12	0.01	1.41	1.84
5/8	3.51	63.00	18.92	4.96	0.12	1.16	0.01	1.36	1.91
6/8	3.88	63.11	18.04	5.32	0.14	1.20	0.01	1.30	1.52
7/8	2.85	63.91	18.65	5.56	0.18	1.28	0.01	1.42	1.62
8/8	3.07	62.89	19.02	5.48	0.16	1.24	0.01	1.28	1.36
9/8	3.00	63.19	18.94	5.39	0.16	1.18	0.01	1.33	1.64
10/8	2.83	62.54	18.34	5.35	0.14	1.04	0.01	1.30	1.52
14/8	3.04	63.54	18.45	5.63	0.13	1.12	0.01	1.34	1.62
15/8	2.65	63.24	18.05	5.24	0.16	1.05	0.01	1.29	1.43
4/9	3.65	63.14	18.54	5.26	0.16	1.06	0.01	1.36	1.37
6/9	3.55	62.65	18.26	5.26	0.13	1.12	0.01	1.42	1.42
8/9	3.23	63.04	18.59	5.28	0.09	1.06	0.01	1.36	1.64
12/9	3.14	62.36	18.31	5.31	0.12	1.09	0.01	1.44	1.15
18/9	2.85	63.53	18.39	5.76	0.15	1.24	0.01	1.42	1.23
21/9	3.04	62.37	18.32	5.64	0.12	1.27	0.01	1.28	1.23
22/9	2.86	63.64	18.35	5.12	0.16	1.05	0.01	1.33	1.15
23/9	3.12	63.75	18.35	5.54	0.09	1.25	0.01	1.32	2.03
4/10	3.31	63.84	18.32	5.23	0.16	1.26	0.01	1.40	1.84
6/10	3.18	63.36	18.27	5.63	0.13	1.06	0.01	1.34	2.02
8/10	2.86	62.86	18.49	5.34	0.12	1.15	0.01	1.41	1.18
16/10	3.42	62.95	18.84	5.24	0.16	1.18	0.01	1.33	2.01
17/10	2.87	63.42	18.13	5.24	0.15	1.15	0.01	1.32	1.45
Average	**3.29**	**63.25**	**18.44**	**5.38**	**0.14**	**1.15**	**0.01**	**1.35**	**1.58**

Setting times

Figs. 3 and 4 are shewhart charts showing the initial setting times and final setting times of the pozzolanas tested within the period. Pozzolana set quickest with DC than other cement brands on the market. DM based pozzolana cement set between DC and GC based pozzolana cement with GC based pozzolana cement setting as an average of the three brands of the cement. The effect of limestone in GC and DM on the pozzolanic reaction results in their slow rate of setting. All the samples tested passed

the GS 803 standard of 60 min for initial setting time and 600 min for final setting time. On occasions when the pozzolana cement samples set quicker than the lower warning limit with DC, investigations with production team showed that the mill was being underfed due to a faulty ratchet feeder leading to increased pozzolana fineness. The mill was shut down for corrective maintenance on the ratchet feeder. This helped in controlling the energy expenditure of the mill.

The reduced setting times also gave an earlier indication of the problem associated with the mill than the compressive strength determinations which would only be due after 7 and 28 days. Thus, problems with production could be more promptly attended to.

Compressive strengths

Fig. 5 and 6 show the 7-days and 28-days compressive strengths of the pozzolanas produced within the period. Generally, all pozzolana samples tested satisfied the 7-day minimum requirement of 16 MPa stipulated in GS 803:2000 and EN 197:2000. None of the samples tested fell below the lower warning or action limits which would require corrective measures to be taken. Whenever compressive strengths fell below the lower warning limit as on 3/5/12 and 15/8/12 respectively for 28-days strength (Fig. 6), the tests were repeated

for confirmation and production staff notified accordingly to maintain best production standards.

Strength gains were lowest for Ghacem CEM II B-L Class 32.5R based pozzolana cements, followed by Diamond CEM II B-L Class 42.5N based pozzolana cement samples whilst Dangote CEM I Class 42.5R based pozzolana cement samples attained the highest compressive strengths. Diamond CEM II B-L class 42.5N based samples performed usually as average cement.

The lower strengths attained by the CEM II B-L samples is mainly due to part of the cements already substituted an inert filler – limestone. This limits the amount of free calcium hydroxide available for the pozzolanic reaction to take place and hence negatively imparts the strength development. This low strength development was also evidenced by a higher level of customer complaints received by the laboratory from customers who used the product with Ghacem CEM II B-L 32.5R especially. More significantly, Pozzolana cement samples prepared with Ghacem CEM II B-L 32.5R failed to meet the GS 803:2000 and the EN 197-1:2000 requirements as shown in Fig. 3 for all samples tested. Customers were often advised to use either Dangote CEM I class 42.5R or Diamond CEM I class 42.5N as much as possible.
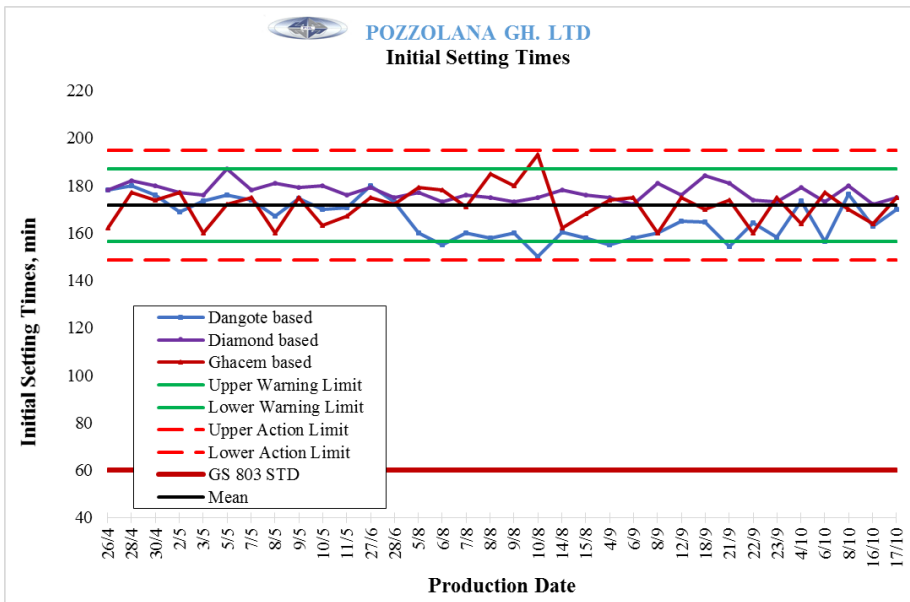
Fig. 3: Shewhart chart showing initial setting times of some pozzolana samples produced between April-October, 2012 with major brands of cement.
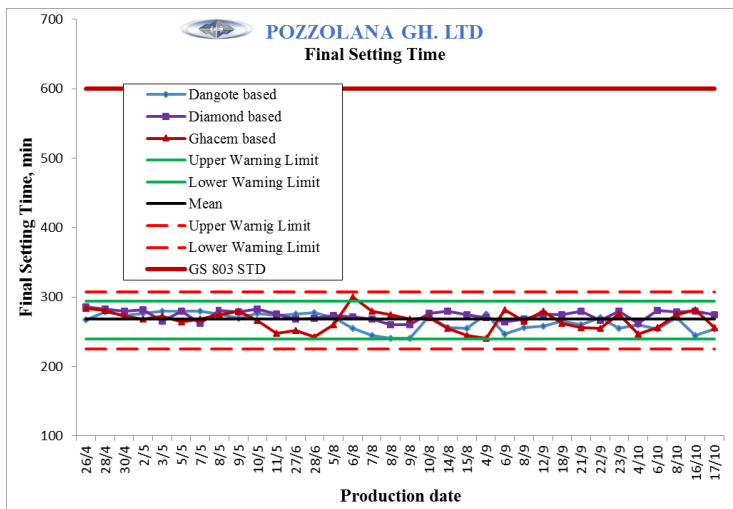

Fig. 4: Shewhart chart showing final setting times of some pozzolana samples produced between April-October, 2012 with major brands of cement.
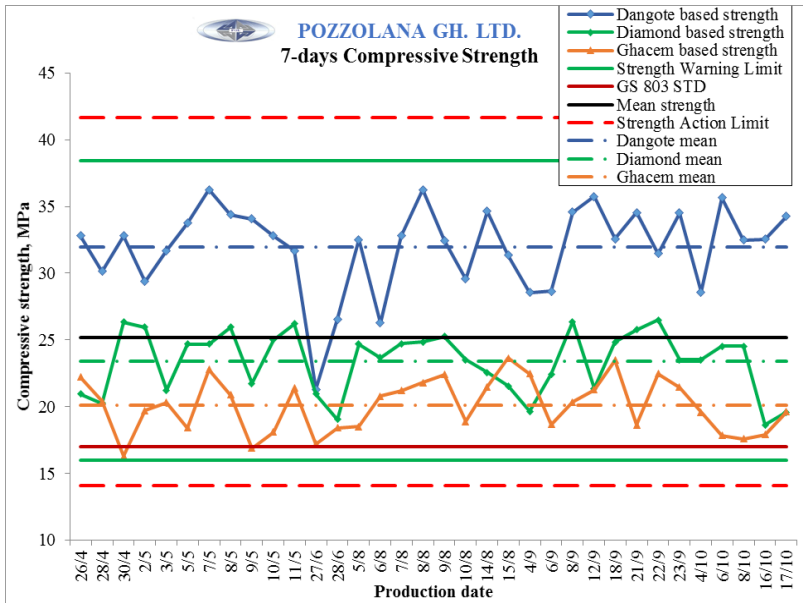
Fig. 5: Shewhart chart showing 7day compressive strengths of some pozzolana samples produced between April – October, 2011 with major brands of cement.
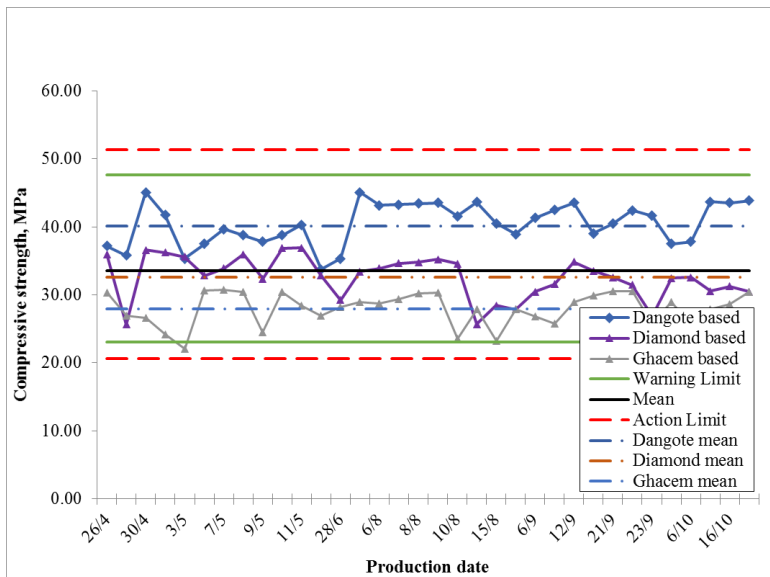

Fig. 6: Shewhart chart showing 28-day compressive strengths of some pozzolana samples produced between April –October, 2011 with major brands of cement.

Clay moisture content and kiln product quality

TABLE 2
Clay moisture content and kiln discharge sorting analysis

DATE	DISCHARGE SAMPLE TIME (GMT)	TOTAL MASS g	MASS REJECT g	% REJECT ≤ 40	ACTION TAKEN	MOISTURE CONTENT (%) ≥15
26/4/11	14:50	1263	131	10.37		
	16:35	1220.5	192	15.73		
28/4/11	9:20	1155	232	20.09		18.60
	10:30	1133.5	383	37.79	Milled	
	12:40	1792	471.2	36.29	Milled	
	15:40	1221	577.3	37.28	Milled	
30/4/11	11:30	938	305	32.52		
	14:00	1146	232	20.24		
	15:50	1472	657	44.63	Product rejected	
02/05/11	9:15	1462	273.5	18.71		15.20
	10:40	1184	203	17.15		
	13:00	1336.5	311	23.27		
03/05/11	8:40	1478.5	232	15.69		
	10:00	1647	110.5	6.71		
	11:30	1786	248.5	13.91		
	13:05	1258	205	16.30		
	14:24	1488	224	15.05		
	15:40	1364	215	15.76		
05/05/11	9:10	2235	426	19.06		
	11:55	1434	306	21.34		
	13:05	1227	346	28.20		
	14:30	1134.5	301	26.53		
	16:05	1164	251	21.56		
07/05/11	9:10	1632	408.0	25.00		
	10:30	1404.0	415.0	29.56		15.00
	12:00	1378.0	580.0	42.09	Product rejected	
	13:10	1198.0	344.0	28.71		
	15:30	1288.0	432.0	33.54		

Table 2 shows data of some kiln output analysis and clay moisture content determinations made during the period. Reject nodules from the kiln included under burnt and over burnt nodules from the kiln. On occasions when the percentage of reject product exceeded 40%, the product was rejected and thrown away. Production team were informed of the rejected product and stricter control of the kiln fire and palm kernel shell content in raw meal was enforced. The maintenance team was also tasked to ensure optimum performance of kiln blowers. On 28/4/11 the percentage rejects were high but the material was not rejected. This led to lower 7-day and 28-day compressive strengths with all brands of cement as shown on Figs. 4 and 5. The moisture content informed production team on right quantity of palm kernel shells to be added to the clay for effective firing. When the moisture content of the raw clay was lower than 15%, water was added at the nodulization stage to ensure proper mixing and nodules formation.

Conclusion

The quality control scheme employed for the pozzolana plant covered most major production operations of the plant. Methods of analysis employed in the quality control process were standard and consistent with internationally accepted practices in cement plants. Chemical analysis showed that the products of the plant were chemically suitable as pozzolanas. All pozzolana samples tested set within the Ghana Standard GS 803 limits for initial and final setting times.

The 7-days and 28-days compressive strengths of pozzolana samples tested with the three major brands of Portland cement on the Ghanaian market indicated that pozzolana gave the highest compressive strengths when used with Dangote CEM I 42.5R cement with a mean 7-day compressive strength of 32.0 MPa and a mean 28-day compressive strength of 40.5 MPa. The lowest compressive strengths were always obtained by using pozzolana with Ghacem CEM II B-L 32.5R cement with a mean 7-day compressive strength of 20.1 MPa and a mean 28-day compressive strength of 28.0 MPa which is lower than the GS 803 minimum standard of 32.5 MPa. Compressive strengths obtained using pozzolana with Diamond CEM II B-L 42.5N were between those of Dangote CEM I 42.5R and Ghacem CEM II B-L 32.5R with mean 7-day strength of 23.4 MPa and 28-day strength of 32.6 MPa.

The quality control scheme also helped in early detection of mechanical malfunctions of key equipment such as the kiln and ball mill so that necessary repair works would be carried out in a timely manner. Operator errors were also brought to the fore as early as possible by the results of the quality control mechanism whilst customer complaints could be anticipated and handled more efficiently.

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