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The Structural Integrity of Concrete Quarry Dust Blocks (CQDB) Manufactured in Matsapha, Swaziland

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Abstract

Concrete quarry dust blocks (CQDB) are manufactured from a mixture of cement: sand: quarry dust. A descriptive study using structured questionnaires and Laboratory test procedures was conducted to determine the structural integrity of CQDB in Matsapha, Swaziland. The companies; [CM concrete (CM), Nkwality Bricks and Pavers (N), Roots (R), Dlamini Block Yard (D), Santos Block Yard (S) and Toepfer and Sons (T and S)] that used quarry dust to produce concrete blocks were studied. Five load bearing CQDB were purchased from each company. A thin film of plaster of Paris was applied prior to load testing using a compression load testing machine at a rate of 100 kN per minute. The results reflected that CM concrete, N, D, Roots, Toepfer and Sons as well as Santos produced CQDB with compressive strengths of 5.55 N/mm^2, 3.39 N/mm^2, 1.68 N/mm^2, 1.24 N/mm^2, 3.02 N/mm^2, and 1.92 N/mm^2, respectively. Only CM concrete manufactured CQDB that met the standard 4.0 N/mm^2 mean compressive strength of 5 units. The CQDB manufactured by the other five companies were even below the standard 3.0 N/mm^2 unit block compressive strength. The CQDB were fabricated using the mixtures; 1:2:3, 1:1:4, and 1:3:2. The mix 1:2:3 was used by CM concrete, D and N. Roots, T and S, used the mix 1:1:4 and S used the 1:3:2 mix. All the CQDB companies in Matsapha used the curing period of 7 days except for D and R which used curing periods of 3 and 4 days, respectively. It was concluded that the structural integrity of the CQDB manufactured in Matsapha was not of acceptable quality. This was evident from the compressive strengths attained by the CQDB manufactured. CM concrete was the only company in Matsapha that manufactured CQDB that met the 4.0 N/mm^2 mean compressive strength of five (5) concrete block units enshrined in the South African National Standards (SANS 1215).

Keywords

Structural Integrity, Quarry Dust, Concrete Blocks, Matsapha, Swaziland

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1. Introduction

Concrete is one of the important construction materials used in the world of all engineering works including the infrastructure development and its constituents are widely available in nature (Madhayi, *et al*, 2016). Concrete is the most commonly used building material in the construction industry in Swaziland. It is essentially made of Portland cement, water and aggregates (fine and coarse). Sand is the widely used fine aggregate, which is slowly being replaced by quarry dust (Koganti, and Chappidi, 2016).

Rapid increase in construction activities leads to acute shortage of conventional construction materials (Balamurugan, and Perumal, 2013). Construction materials such as quarry dust have been used to alleviate such shortages in different parts of the world. Quarry dust has been used for different activities in the construction industry, such as road construction and the manufacture of building

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materials, such as lightweight aggregates, bricks, tiles, and autoclave blocks (Sivakumar and Prakash, 2011; Rai *et al*, 2014).

Quarry dust is a waste product obtained during the process of quarrying. It is available abundantly from rock quarries at low cost in many areas and may be an economical alternative to river sand. It is fine rock particles formed when boulders are broken into small pieces. It is gray in color and a fine aggregate. According to Krishnamoorth and Aswini (2015) the physical properties of quarry dust includes specific gravity, fineness modulus and water absorption, which were documented as 2.55, 3.0% and 3.8, respectively.

Researchers and practitioners in the construction industry have identified quarry dust as an alternative to river sand. In Nigeria the increasing use of quarry dust to replace river sand in concrete and block production was reported by Ukpata and Ephraim (2012). The use of quarry dust as a partial replacement of river sand in the production of hollow concrete blocks in India was documented by Ambarish, *et al*., (2011). Lahani *et al* (2012) concluded that crushed rock aggregates are more suitable for the production of high strength concrete compared to natural gravel and sand. Quarry dust was also recommended by Khamput (2006) as a replacement for sand in conventional concrete structures. However, Raman, *et al*., (2007) concluded that quarry waste caused a slight reduction in the compressive strength of concrete blocks due to excessive flakiness and greater weakness to crushing. Sivakumar and Prakash (2011) concluded that quarry dust may be used as an effective replacement material for natural river sand. The optimum replacement of sand with granite quarry dust as fine aggregates should be 15% of the sand fraction in hollow building concrete blocks of the size and mix ratio adopted herein (Osuji and Egbon, 2015). According to Anzar, (2015) the compressive strength of quarry dust concrete continues to increase with age for all the percentage of quarry dust contents.

In Swaziland, hollow concrete blocks are used in the construction industry, both in the rural and urban areas. However, it is worth noting that the construction industry is regulated in the urban areas, but not in the rural areas. Concrete blocks in the country are available in two different grades; the load bearing (6 inch and 9 inch) and the non-load bearing (4.5 inch) for various purposes. They are widely used in the construction of multi-storey residential buildings, industrial and other buildings mainly for infill wall masonry.

In Swaziland, where this study was conducted, the local building construction industry adds quarry dust to the mixture of Portland cement and fine aggregate (sand) to produce concrete quarry dust blocks (CQDB). Despite this unconventional concrete block mix, the structural integrity of such blocks has not been established, hence this study.

The objective of the study was to determine the structural integrity of CQDB fabricated in Matsapha, Swaziland.

2. Methodology

The study was descriptive in nature using questionnaire survey techniques and Laboratory structural integrity test procedures. The questionnaire was used to establish the properties (i.e. mixture and curing period) of the hollow concrete quarry dust blocks made in Matsapha. These were compared to the compressive strength of the load bearing quarry dust blocks made from the above properties. The results were then compared to the South African National Standards (SANS1215, 2008).

2.1. Sampling Procedure

All the six companies that used quarry dust to fabricate concrete blocks in Matsapha formed the sampling frame for the study. These were; Roots (R), Toepfer and Sons (T and S), CM concrete (CM), Bricks and Pavers (N), Santos Block Yard (S) and Dlamini Block Yard (D). Five load bearing CQDB were purchased at random from each company and transported to the laboratory for compressive strength load testing. They were coded according to the first letter of the company name for identification. The five hollow CQDB purchased from each company formed the sample size.

2.2. Data Collection and Analysis

Primary data were collected through desk search and secondary data were collected using structured questionnaire survey procedures to establish the properties of CQDB made in Matsapha. The data collected from the questionnaires was analysed using Statistica computer software. These results were compared with the compressive strength of the load bearing CQDB purchased from the CQDB companies in Matsapha. The resultant means of the concrete block compressive strengths were separated using the LSD test.

2.3. Compressive Strength Test

The purchased CQDB were tested for structural integrity using a compression load testing machine (Pro-Ikon Cube Press). A thin film of calcium sulphate (Plaster of Paris) was pasted on the blocks before testing to provide an even platform for loading. A metal plate of 3 mm thickness was fabricated specifically for the study using the dimensions of the concrete blocks. It was placed on top of the concrete blocks for uniform distribution of the load during testing. The Plaster of Paris was applied a week before the CQDB were tested. The thirty blocks were tested under the same environmental conditions for compressive strength using a concrete load testing machine at a rate of 100 kN per minute. The compressive strength was then calculated using equation 1.

$$\sigma_c = \frac{F}{A} \quad (1)$$

Where:

σ_c - Compressive strength (N mm^2)

F - Failure load (N)

A - Area of bed-face (mm^2)

3. Results and Discussion

The results indicated that four different concrete mixtures were used by the concrete block manufacturing companies in Matsapha. These were (cement: sand: quarry dust) 1:2:3, 1:1:4 and 1:3:2 (Table 1). The quarry dust concrete blocks were fabricated using a mixture of 1:2:3 by three block manufacturers (CM concrete, D and N). A 1:1:4 CQDB mixture was used by R as well as T and S block manufacturers. The remaining 1:3:2 CQDB mixture was used by Santos Block Yard (S).

Table 1. Concrete quarry dust blocks compressive strength test.

Company Code	Mixing Ratio	Sand (%)	Quarry Dust (%)	Curing Period (days)	Mean Compressive Strength (N/mm^2)
CM	1:2:3	40	60	7	5.55
D	1:2:3	40	60	3	1.68
N	1:2:3	40	60	7	3.39
R	1:1:4	20	80	4	1.24
S	1:3:2	60	40	7	1.92
T and S	1:1:4	20	80	7	3.02

CM concrete, Dlamini Block Yard and Nkwality Bricks and Pavers used the mixing ratio of 1:2:3 to make their CQDB. The mixture consisted of 40% sand and 60% quarry dust. Roots together with T and S both made their CQDB from a mixing ratio of 1:1:4 with 20% sand and 80% quarry dust. The mixing ratio of 1:3:2 was used by S to fabricate CQDB containing 60% sand and 40% quarry dust.

Dlamini Block Yard and Roots were the only companies that manufactured CQDB that were cured for a period of less than 7 days. Dlamini Block Yard had the lowest CQDB curing period of 3 days, while R cured CQDB for a period of 4 days. The remaining 4 companies (CM concrete, N, S and Toepfer and Sons) cured their CQDB for a period of 7 days.

CM concrete Block Yard produced CQDB with the highest (5.5 N/mm^2) mean compressive strength followed by N with a mean compressive strength of 3.39 N/mm^2. Toepfer and Sons produced CQDB that had a mean compressive strength of 3.02 N/mm^2. Dlamini Block Yard, Santos Block Yard and Roots were the only companies that produced CQDB with a mean compressive strength that was less than 2 N/mm^2. Dlamini Block Yard's CQDB had a mean compressive strength of 1.68 N/mm^2, while Santos's CQDB had a mean compressive strength of 1.92 N/mm^2 and Roots' CQDB had the lowest (1.24 N/mm^2) mean compressive strength. It is worth noting that all the other CQDB manufacturing companies in Matsapha made CQDB that had compressive strengths that were less than the 3.0 N/mm^2 unit concrete block mean compressive strength as documented by SANS2015 (2008).

The concrete blocks were manufactured from different mixing ratios and cured for different periods, hence, the different mean compressive strengths achieved. Even the CQDB manufactured from the same mixture attained different compressive strengths. CM concrete Block Yard and Nkwality Bricks and Pavers were all used the same mixing ratio of 40% sand with 60% quarry dust to produce their CQDB. They all had different mean compressive strengths, which was unexpected. Dlamini Block Yard's CQDB had lower mean compressive strengths of 1.7 N/mm^2 at 60% quarry dust. This however, could be attributed to the curing period of 3 days which, was less than that of the other companies (CM concrete and N). Concrete blocks are usually cured for a period in multiples of 7 days; i.e. 7 days, 14 days, 21 days or more. Moreover, research has shown that compressive strength does increase with an increasing curing period (Sachin, *et al*., 2012).

Roots as well as Toepfer and Sons' CQDB were also manufactured from the same mixing ratio of 20% river sand with 80% quarry dust. However, both companies had CQDB of different mean compressive strengths. The CQDB manufactured by Toepfer and Sons had a mean compressive strength of 3.02 N/mm^2, whereas R produced CQDB with a mean compressive strength of 1.24 N/mm^2. This could be attributed to the differences in the curing period since the CQDB manufactured by R were cured for 4 days, while T and S cured CQDB for 7 days.

Santos made CQDB that attained a compressive strength of 1.92 N/mm^2 at 40% quarry dust. According to SANS1215 (2008), the mean compressive strength of 5 units should range between 4.0 N/mm^2 and 23.5 N/mm^2. CM concrete was the only CQDB manufacturing company that fabricated CQDB that met the above standard. The other five companies manufactured CQDB with lower (less than 4.0 N/mm^2) mean compressive strengths. This reflected that quarry dust does improve the compressive strength of concrete blocks when added partially to sand. It is worth noting that as the quarry dust exceeds 60%, the amount of fines in the concrete increases. The amount of fines increase such that, there is not enough cement paste to bond all the coarse and fine aggregate particles, which consequently leads to a decrease in the compressive strength.

The mean compressive strength results in Figure 1 indicated that CM concrete produced CQDB that had average compressive strengths that were significantly different (P< 0.05) from the other six CQDB manufacturers. Nkwality Bricks and Pavers as well as T and S's CQDB mean compressive strengths were not significantly different (P>0.05) from each other. This trend was observed with CQDB manufactured by D and S, which had mean compressive strengths that were not significantly different (P>0.05). The CQDB manufactured by Dlamini Block Yard had mean compressive strengths that were not significantly different (P>0.05) from the CQDB mean compressive strength fabricated by S and R.

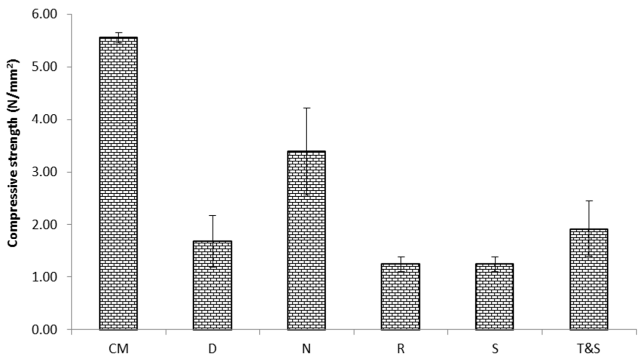

Figure 1. Mean compressive strength of CQDB made by companies in Matsapha.

There was at least one significant difference (P < 0.05) in the mean compressive strength of the CQDB manufactured by companies, thus a mean separation test was performed which marked significant differences at P < 0.05 (Table 2). Upon separating the means using the Least Significant Different test, companies were found to have produced CQDB that were significantly different from each other. CM concrete produced CQDB that were significantly different from the other CQDB manufacturing companies. Nkwality Bricks and Pavers made CQDB that were significantly different from the other CQDB manufactured by the other companies except for the ones from T and S.

Table 2. LSD mean compression strength test.

Company Code	C.M.(1)	(2)	(3)	(4)	(5)	(6)	(7)
C.M. (1)	-	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
D (2)	0.000000	-	0.000003	-	-	0.000092	0.014280
N (3)	0.000000	0.000003	-	0.000000	0.000030	-	0.000000
R (4)	0.000000	-	0.000000	-	0.029240	0.000002	-
S (5)	0.000000	-	0.000030	0.029240	-	0.000852	0.001851
T and S (6)	0.000000	0.000092	-	0.000002	0.000852	-	0.000000

Marked differences are significant (P < 0.05). - Not significant (P>0.05).

Dlamini Block Yard and Santos Block Yard fabricated CQDB that had mean compressive strengths that were also not significantly different (P>0.05) from each other. The same was true for the compressive strengths of the CQDB manufactured by D and R (Table 3).

Table 3. Mean separation test (P > 0.05).

Company code	Mean compressive strength (N/mm^2)[1]
CM concrete	5.55^{a}
N	3.39^{b}
T	3.02^{b}
S	1.92^{c}
D	1.68$^{c\,d}$
R	1.24$^{d\,e}$

Companies with the same letter had CQDB that were not significantly different from each other.

4. Conclusions

The structural integrity of CQDB in Matsapha was not of acceptable quality. This was evident from the compressive strengths attained by the CQDB manufactured. CM concrete was the only company in Matsapha that manufactured CQDB that met the standard 4.0 N/mm^2 mean compressive strength of five (5) concrete block units.

Dlamini Block Yard (D), R and S manufactured CQDB that had mean compressive strengths of 1.68 N/mm^2 (60% quarry dust), 1.24 N/mm^2 (80% quarry dust) and 1.92 N/mm^2 (40% quarry dust), respectively. These were even below the standard 3.0 N/mm^2 unit concrete blocks compressive strength.

The concrete mixtures (cement: sand: quarry dust) of the CQDB manufactured in Matsapha were 1: 1:4, 1:2:3 and

1:3:2. Roots as well as T and S block manufacturers used concrete mixtures of 1:1:4 to make their CQDB. CM concrete, Dlamini Block Yard and Nkwality Bricks and Pavers used concrete mixtures of 1:2:3 to make their CQDB. Santos Block Yard was the only company in Matsapha that fabricated CQDB using a concrete mixture of 1:3:2.

The mixing ratio 1:1:4 used by CM concrete, D and N resulted in CQDB with different mean compressive strengths. Amongst these companies CM concrete's CQDB attained the highest (5.55 N/mm^2) mean compressive strength and D's CQDB had the lowest (1.68 N/mm^2) mean compressive strength. This could be attributed to the curing period of 3 days used by D. Out of the six CQDB manufacturing companies in Matsapha the CQDB manufactured by R attained the lowest (1.24 N/mm^2) mean compressive strength which was a product of a mix of 1:3:2 and a curing period of 4 days. The mix used by R was the same as that used by T and S to produce CQDB which had the third highest mean compressive strength of 3.02 N/mm^2. It could be concluded that the curing period of 4 days used by R was responsible for this difference in mean compressive strength.

The curing period used to fabricate the load bearing CQDB in Matsapha was 3 days for D and 4 days for R. The other four companies (CM concrete, N, S as well as T and S) cured their CQDB for 7 days.

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