Cement Performance in Sand Cement Blocks – A Case Study from Dar es Salaam, Tanzania

Alex L. Mrema ¹, Raine Isaksson ²

¹ Department of Structural and Construction Engineering, College of Engineering and Technology, University of Dar es Salaam, P.O. Box 35131, Tanzania.
² Department of Engineering Sciences, Industrial Engineering & Management, Campus Gotland Uppsala University, 621 67 Visby, Sweden – raine.isaksson@angstrom.uu.se

Abstract
In Tanzania a large part of the building material products, especially in Dar es Salaam, consist of solid sand cement blocks - sandcrete. The objective of the investigation was to determine cement performance in these sandcrete blocks and to relate results to a defined best performance. The purpose was to assess how well the cement compressive strength potential has been utilised and to identify factors affecting the performance. Results indicate that only about 30% of the inherent cement compressive strength potential is used and that the main problem is the design of the sandcrete blocks. Mostly solid six-inch blocks consisting of cement sand and water are used in Dar es Salaam. The compressive strength requirement is relatively low which leads to a low cement content. Proper compaction of the sand cement blocks requires high amounts of water leading to high water cement ratios with these often being over 1. This then leads to that only about 30% of the cement building potential is used. Since cement drives price and the carbon footprint the situation is far from ideal. One possible improvement would be to change from solid to hollow blocks, which would enable a lower water to cement ratio.

Keywords: Sandcrete, sand cement blocks, water to cement ratio, carbon footprint, sand quality, compressive strength, sand bulk density.

Corresponding author’s email: alex.mrema@yahoo.com
Introduction

In many concrete applications cement is often the main driver of costs. This is particularly true in African countries where salaries generally are low and where a lot of the work can be carried out manually. Cement is also the driver for carbon footprint in building materials. Cement prices however are on international level or even higher for quality that could be below average [1]. The consequence is that cement price probably forms a larger part of the building investment in African countries, compared to the situation in the industrialized world. This highlights the challenge of making best use of cement in order to provide affordable buildings. Multinational companies often manage cement plants. The routines of cement manufacturing control are well established with many companies having external certification and follow up carried by national authorities. This means that the structure of control and the adherence to standards are reasonably good supporting a common saying within building manufacturing that cement is the least variable material in concrete. Preliminary indications from the Dar es Salaam market, which is believed to be typical for Sub Saharan Africa, is that the performance in cement applications has a high variation and that cement is not used to its full potential [2], [3]. This indicates that focus on the use of cement and the performance of the cement in applications is of interest. In many Sub Saharan countries one-family houses are common. Often cement-based blocks are used for these constructions. Solid six-inch blocks, like those used in Tanzania and in Dar es Salaam are low cement concentration applications with about 5% cement. These blocks are normally made out of local sand, cement and water. The cement performance seems to be particularly low in this type of applications. The performance indicator studied was the block compressive strength in MPa (N/mm$^2$), which could be seen as the main quality parameter. The objective of the investigation was to determine cement compressive strength performance in the typical applications and how this performance is affected by cement and water content. The research questions for this paper are:

RQ1: How is the relative cement compressive strength performance in the sandcrete applications in Dar es Salaam compared to a defined benchmark?
RQ2: How do water and cement content affect the sandcrete products in Dar es Salaam?

Methodology

The higher the cement compressive strength is the better it is for the customer who with the cement can create more building value. Building value for the customer could be seen as m$^2$ of living space built for the cement used. Block compressive strength performance in MPa should correlate positively with the customer building value. To be able to measure the block performance we have chosen an indicator of compressive strength times weight of material produced defined as MPa*tons [4]. This indicator can be used to monitor how well block producers make use of the cement. In order for this to correlate with customer utility the compressive strength performance has to be on the level, which ensures a safe and durable building but without producing excessive compressive strength. We used a proposed benchmark of 250 MPa*tons [4] based on best value achieved with standard mortar in cement compressive strength testing (22% of cement with 55 MPa on 28 days 55/0.22 = 250 MPa*tons). The relationship between actual performance of cement in the application and the benchmark results in a relative value expressed in %. The RQ1 is answered using data collected from the University of Dar es Salaam (UDSM) materials testing laboratory. The problem here is that the exact recipes are not normally known. Based on information collected from the market on typical cement content in the sandcrete applications we can assess the
magnitude of the cement performance. For answering RQ2 we have carried out laboratory tests using typical local sand for the mixes with varying cement and water-cement ratios. In Table 1 the final test set up is described.

Table 1: Testing plan for producing mortar bars based partly based on EN 196-1.

<table>
<thead>
<tr>
<th>W/C Ratio</th>
<th>Cement Cont. 5%</th>
<th>Cement Cont. 7%</th>
<th>Cement Cont. 9%</th>
<th>Cement Cont. 12%</th>
<th>Cement Cont. 15%</th>
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The testing method applied deviated from the testing standard EN 196-1 at a number of points. The major issues were that local sand was used instead of the standardized one. Curing was not done under water but under a wet cloth where temperatures were higher than the 20°C indicated in the standard. There were also some other minor differences from the standard such as with mixing, placing and vibrating. The procedure applied is much closer to how production is done by the manufacturers than what the standard EN 196-1 procedure is. We therefore expect to obtain compressive strengths in the same range as the manufacturers. For all the tests, cement coming from the same bag of a Twiga Plus, Portland limestone cement of 42.5 class was used. Based on the standard the limestone content is between 6-20%. This brand is commonly used in the Dar es Salaam market. After analysing the first results we needed to verify two aspects, which were how sand compaction was affected by the level of moisture and how compressive strength would vary as function of water content with a fixed cement content.

Theoretical background

It is common knowledge that concrete compressive strength is strongly influenced by the water to cement ratio, see Figure 1.

The lower the w/c ratio is the higher the compressive strength should be. However, this is on the condition that concrete can be compacted. On the other hand mixing requires a certain amount of water to wet and mix the material. Mixes with low cement content are very difficult or impossible to mix properly which leads to loss of compressive strength. Ordinary concrete contains about 250-450 kg of cement per m³. By weight this corresponds to some 10-20%. In many Sub Saharan countries and particularly in Tanzania typical concrete applications consist of sand cement blocks – sandcrete - with a cement content that is down to 5%.
Results

Examples from block making

Block production in Dar es Salaam is in many cases simple and none of the visited block manufacturers measure moisture in the sand added. This increases the risk of varying the w/c ratio, which will cause variations in the cement compressive strength. The most common product is the 6-inch solid block. Out of the 165 individual blocks tested in the University of Dar es Salaam (UDSM) materials testing laboratory 83% were of this type. Blocks have been tested both at 7 days and at 28 days. In most cases private house builders do not test cement compressive strength. It is also rare that block producers measure compressive strength. Instead customers judge by looking, kicking and dropping the blocks if they are good enough. However, professional users and projects that need to comply with standards and specifications send blocks for testing.

In Figure 2 it can be seen that even among what can be seen as top users the performance often is below the lowest class in the Tanzania block standard TZS 283:2002, which stipulates a minimum of 3.0 MPa for individual blocks. Compressive strength results and information from mix results indicate that cement content normally is low and at about 5% corresponding to 30-35 blocks made per 50 kg bag of cement. Data in Figure 2 has been used to assess an average compressive strength performance. For this the outliers with compressive strengths of more than 8 MPa have been excluded. These results are assumed to belong to blocks produced to
meet with the requirements in the second compressive strength class of 7 and where the expected average is min 8 MPa. For these blocks the cement percentage would have been higher. The average for the remaining 82 blocks is 3.8 MPa. If an average cement content for these of 5% is assumed this results in 75.5 MPa*tons, which is only about 30% of the benchmark of 250 MPa*tons indicating that cement is not used effectively. It is possible that some of the producers have used up to 6-7% cement, which would still reduce the MPa*tons performance.

**Mechanisms affecting the compressive strength**

It seems that the bulk density of blocks is a reasonable indicator of the expected compressive strength (see Figure 3).

![Figure 3: Compressive strength (MPa) for sand cement blocks at 28 days as a function of bulk density (ton/m³) for samples from the market taken for testing to UDSM materials laboratory.](image)

The benchmark bulk density achieved using standard sand in the mortar compressive strength testing is 2.3 tons/m³ (with 22% cement and the 28 days compressive strength of 55 MPa). It could be taken as a hypothesis that provided compaction resulting in the same bulk density, the compressive strength would be proportional to the cement content. This would mean that the MPa*tons would be constant. However, when maximum compaction is not achieved, the compressive strength drops. In Figure 3 the 82 values (without outliers) used to calculate the average compressive strength have been compared with the bulk density, which is determined by weighing the block and measuring its dimensions. In Figure 3 there is a cluster of outliers with high density but with relatively low compressive strength. The blocks are classified sand cement as the others, but have apparently been compacted very well using appropriate sand. Provided the same recipe is used the correlation should be better. The results indicate that block weight could be used as a quality indicator. The bulk density is affected by compaction, but also by compactability, which depends on the sand used, amount of water and amount of cement used.

**Results from laboratory tests with varying w/c ratio**

Mortar bars of 4*4*16 cm have been prepared in the UDSM Materials laboratory using local sand from Mpiji and using a procedure based on EN 196-1. Compressive strength was tested at 1, 3, 7 and 28 days with varying cement and w/c ratio with the purpose of finding out effects on
cement effectiveness. In Figure 4 the resulting compressive strength as function of bulk density is presented. In spite of that age varies from 1 to 28 days and cement content from 5 to 15% there is an overall general correlation between the bulk density and compressive strength. The results further reinforce the importance of bulk density as an indicator of compressive strength.

In Figures 5-8 compressive strength results from the laboratory testing as function of age, w/c ratio and % cement are presented.

Figure 4: Compressive strength at 1-28 days as function of bulk density for all laboratory samples. Results are for ages that are varying from 1 to 28 days.

Figure 5: Compressive strength at 1 day in MPa at different w/c ratios with different cement content by weight.
Results in Figure 5 show that higher cement content results in higher compressive strength and that higher w/c-content reduces compressive strength as would be expected. The exception is the line with 5% of cement. However, the difference could probably be disregarded since compressive strengths were very low and handling was a problem.

The results in Figure 6 for the 3 days results show a similar pattern for the 1-day results. Again the highest value for 5% cement is around w/c = 1. This still could be a result of problems with the very low compressive strengths.

![Figure 6: Compressive strength at 3 days in MPa at different w/c ratios with different cement content by weight.](image)

The results in Figure 7 are different from the other ages. For cement content 9, 12 and 15% there seems to be an optimum w/c ratio.

![Figure 7: Compressive strength at 28 days in MPa at different w/c ratios with different cement content by weight.](image)
Based on an assessment of Figure 7 the optimum w/c ratios are:

- 15% cement – w/c – optimum = 0.93
- 12% cement – w/c – optimum = 0.95
- 9% cement – w/c – optimum = 1.1
- 7% cement – w/c – optimum = 1.4

One interpretation of the results could be that the sand matrix requires a certain amount of water to compact properly. The practice of using as much water as possible for sandcrete blocks is apparently standard practice in block making in South Africa. Based on course handouts for UDSM for sand bulk density there is a minimum at 5% water meaning that the compaction is at its worst when having 5% water. The theoretical foundations need to be looked further into in forthcoming research. In order to achieve some quick clarifications we decided to test how the bulk density of the sand we had used would behave at different additions of water. We developed a simple test with a metal cylinder and then mixed the test sand from Mpiji with different percentages of water. The mix was compacted using a standard compaction and the weight was recorded. Results in Figure 8 show a clear minimum at close to 5% moisture supporting the earlier information.

![Figure 8: Bulk density of the Mpiji sand used for laboratory testing as function of moisture.](image)

In order to test the effects of the water content in the mix we prepared mortar samples with 10% cement with different % of moisture and measured the 7 days compressive strength using the same sand as earlier. Results are presented in Figure 9. The optimum utilization of the cement compressive strength seems to take place at about 10% moisture. With 10% cement this means that the w/c ratio should be 1. With 5% cement it would be 2.
Discussion

We have not come across any block producers that measure sand moisture content. With occasionally large variations in the moisture content it will be left to the trained eye of the operator to add the correct amount of water. Without any targets or clear references the result could be that moisture contents in mixes vary considerably. This could be an important contribution to the large variation in compressive strength performance demonstrated in Figure 2. Our RQ1 was: How is the relative cement compressive strength performance in the sandcrete applications in Dar es Salaam compared to a defined benchmark? Based on Figure 2 we can see that even the more advanced producers taking their blocks for testing often fail to meet minimum compressive strength requirements. Assuming 5% cement addition we estimated that cement was used to 30% of its potential. In our RQ2 we asked: How do water and cement content affect the sandcrete products in Dar es Salaam? Here, we can see that in many cases water content could be more important than the w/c ratio. Difficulties to compact due to coarse sand and lack of water seem to reduce the bulk density more than excess water does up to a point. For our Mpiji sand the optimum amount of moisture content in the mix seems to be about 10%, which is high and which means that the w/c ratio will be high for the low amounts of cement normally used. This means that the currently used solid sandcrete blocks will never become products where cement is used optimally. Increasing the amount of cement in the current products does not make sense since the market is not asking for the additional compressive strength. The only way to use cement building potential better seems to be changing the products used. One way of enabling more cement in order to reduce the w/c and increase compressive strength potential would be to change from solid to hollow blocks.

Conclusions

Cement compressive strength potential in the currently favoured solid sandcrete blocks is only used to about 30%. Even if there is room for optimisation by choosing the right sand, having good compaction and using the right amount of water content these improvements will fall short of realising the full cement compressive strength potential. To realise the full potential a redesign of the solid sandcrete products is needed. One improvement which might double the current performance in MPa*tons is moving to hollow blocks. In the long run proper concrete
with precast elements might be the way to go for achieving better use of cement for more affordable housing and for a lower carbon footprint.

References


