ADOBE BLOCK STRENGTH TESTING TO INFORM STANDARDS IN RWANDA

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Abstract

This paper summarises the results and conclusions from adobe block strength testing that informed the RS 484 Adobe Block Specification and Technical Guidelines on Adobe Block Construction in Rwanda, both of which are to be published in 2022. The testing concluded that results from the NZS 4298 block drop test and compressive strength are strongly correlated. Due to the variability in block test results, the published documents included an amended block drop test that requires 20 blocks to be tested, rather than 2, and allows an 80% pass rate.

Introduction

In 2019 Rwanda released the latest version of the Rwanda Building Code (RBC) with a particular emphasis on promotion of use of local construction materials, including the use of adobe block.

Adobe block, locally known as Rukarakara, is a very common form of construction in Rwanda, with 67% of households living in adobe homes (National Institute of Statistics of Rwanda, 2020). Whilst adobe construction can be structurally stable and durable, many homes are poorly built and require significant maintenance. This is exacerbated by environmental issues – 23% of households were affected by floods, landslides, and heavy rains in 2020 (National Institute of Statistics of Rwanda, 2020).

To improve adobe block housing, the Rwanda Housing Authority (RHA) launched the Local Building Materials Think Tank to develop two documents: RS 484 Adobe Block Specification and Technical Guidelines on Adobe Block Construction in Rwanda.

The research behind these documents included 14 months of soil and block testing and analysis to answer several questions: Can field tests be used to determine soil classification? Can soil classification determine adobe block performance? Can field tests be used to determine adobe strength and durability? How do fibres and improved manufacturing methods affect block performance?

This was a significant body of research but this paper will focus on block strength.

Testing

Blocks were made from six commonly used but distinct block making soils from around Rwanda. Soil classification, particle size distribution and Atterberg limits can be seen in Table 1 for the six soils, named after where they are sourced: Gasabo, Rwamagana, Musanze, Nyarugenge, Kicukiro and Kamonyi. Musanze soil was not capable of making blocks and local masons will typically mix one part Musanze soil with two parts of a more granular soil, such as Kamonyi. This practice was followed for the block testing, so blocks referred to as being made from Musanze soil contain two parts Kamonyi soil.

Soil name and classification	Average Particle Size Distribution (%)				Average Atterberg Limits (%)		
	Clay	Silt	Sand	Gravel	LL	PL	PI
Kamonyi, Clayey Sand (SC)	15	20	62	4	29	17	12
Nyarugenge, Lean Clay (CL)	28	24	35	14	34	20	14
Gasabo, plastic Silt (ML)	17	42	21	20	46	31	15
Kicukiro, Lean Clay (CL)	24	35	41	0	27	15	12
Rwamagana, Lean Clay (CL)	34	17	49	0	29	18	11
Musanze, non-plastic Silt (ML)	12	75	12	0	n/a	n/a	n/a
LL: Liquid limit. PL: Plastic Limit. PI: Plasticity Index.							

Table 1: USCS soil classification, particle size distribution and atterberg limits

The purpose of the block testing was to understand the strength and durability of adobe blocks made from the six representative soils, how varying the fibre content and manufacturing method affected block performance, and whether field tests could reliably determine strength and durability.

The adobe blocks were subject to up to five tests depending on the hypothesis being explored. The compressive strength and drop tests are considered indicators of block strength. The visual test directly measures block cracking, which is expected to indicate strength and durability, and the water erosion and abrasion tests are considered indicators of durability, but these tests are not discussed in this paper.

Figure 1. Compressive strength testing of adobe blocks.

Block test phases

Testing was conducted in phases to allow observations from each phase to inform the subsequent phases. Phase 1 tested blocks that were made without fibres using a typical manufacturing method. Phase 2 tested blocks with different lengths, quantities and types of fibres. Phase 3 tested blocks with different manufacturing methods, such as, soaking in water for 24 hours prior to block making, curing techniques and varying the block size. Control blocks were made without fibres and manufactured using a typical method, agreed upon by a group of masons. Control blocks were made throughout the testing process to account for the effects of environmental conditions.

Block strength test methodology

Compressive strength of masonry is an important material property for structural applications. It determines the resistance of the block to loading and is used to calculate the characteristic strength which is used in structural design. The blocks were tested in accordance with BS EN 772-1. Blocks were capped with mortar prior to testing to ensure an even load distribution (Figure 1).

The drop test in accordance with NZS 4298 was performed to compare against the compressive strength tests and as a measure of corner impact strength which could be more important than compressive or bending strength (Minke, 2006). During this test the blocks are dropped on their corner from 0.9m above a hard surface. If the block breaks into approximately equally sized pieces or shatters then it has failed. If the block does not fail in this way, the corner length was measured. NZS 4298 states that if the measurement is greater than 100mm then the block has failed but for purposes of this testing we just recorded the length. Figure 2 shows diagrams and photographs explaining the methodology, measuring procedure and failure criteria of the drop test.

Block test strength results

During Phase 1, for each soil type, 30 blocks were crushed to measure compressive strength and 30 blocks were used in the drop test. The results of which are presented in Figure 3 and Figure 4respec-tively. There is a higher level of variation from the drop test compared to the compressive strength test. The characteristic compressive strength, calculated using the methodology in NZS 4297, is

Figure 2. (top left) diagram showing drop test, (top right) dimension measured after drop test, (middle left) drop test in action, (middle right) block that passed drop test, (bottom left) block that failed drop test because it shattered, (bottom right) block that failed drop test because the measured dimension was too great.

compared to the average size of the corner piece broken off in the drop test in Figure 5. The smaller the size of the length of broken block, the stronger the block. The coefficient of determination, R^2, is 0.53, indicating a strong correlation.

Table 2 presents the Phase 1 drop test results and the characteristic compressive strength. All soils, except the Musanze-Kicukiro mix, produce blocks that have acceptable characteristic compressive strength, considering that NZS suggests the minimum design strength to be used is 0.5 N/mm^2 if no testing is performed, however some blocks still fail the drop test, suggesting that the NZS requirements need to allow for some failures. The NZS considers blocks acceptable if two blocks pass the drop tests, however the high level of variation shown in Figure 4 indicates that a larger number of blocks need to be tested with an allowance for some failures. The linear relationship in Figure 5 suggests a 150mm length of the broken off block would correspond to a compressive strength of 0.5 N/mm^2.

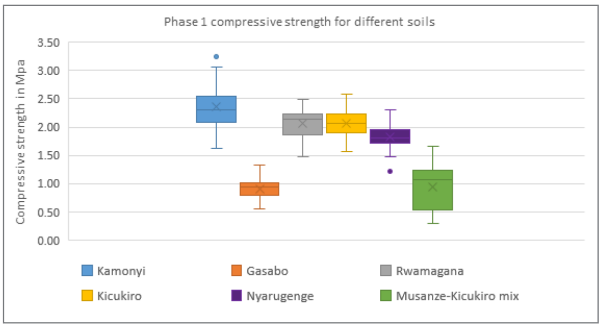

Figure 3. Phase 1 block compressive strength for different soils.

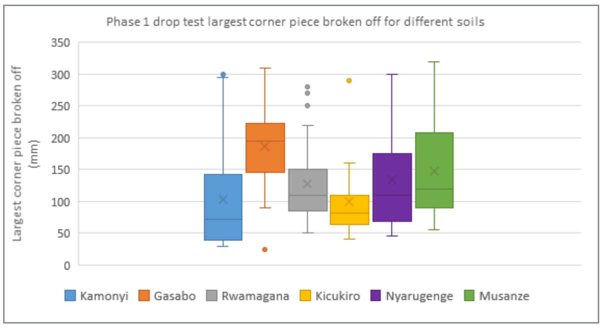

Figure 4. Phase 1 drop test largest corner break off for different soils. The smaller the length of the piece of broken block, the stronger the block.

Soil type	Average largest piece broken off (mm)	% passing drop test	Characteristic compressive strength (N/mm^2)
Kamonyi	50	100%	2.2
Kicukiro	91	90%	1.6
Rwamagana	115	80%	1.6
Nyarugenge	78	90%	1.5
Gasabo	160	40%	0.8
Musanze- Kicukiro mix	139	50%	0.3

Table 2. Phase 1 drop test results for different soils against characteristic compressive strength

Adjusting the manufacturing methods in Phase 3 did not significantly impact the strength of the blocks, however the addition of fibre in Phase 2 did significantly improve how the blocks behaved in the drop test, but did not affect compressive strength.

Table 3 shows that both long and short fibres improved the drop test results for Kamonyi and Rwamagana soils. The same cannot be reported for Gasabo soil, however in the mason's experience, the addition of fibres meant blocks made from Gasabo soil were more likely to break into two halves rather than shatter, which meant the block held together better on impact. This is still recorded as a failure in the drop test and therefore the improvement in performance of blocks made from Gasabo soil is not represented by numerical data. The improvement can be shown visually in Figure 6 The difference between the drop test results in Table 2 and the control blocks in Table 3 is expected to be due to uncontrolled variables, primarily the weather.

	Gasabo			Kamonyi			Rwamagana		
	No fibres	Long fibres	Short fibres	No fibres	Long fibres	Short fibres	No fibres	Long fibres	Short fibres
Average largest piece broken off (mm)	208	180	224	160	74	69	170	90	101
% passing drop test	5%	5%	0%	35%	90%	80%	5%	85%	75%

Table 3. Phase 2 effect of adding fibres and their length on drop test results

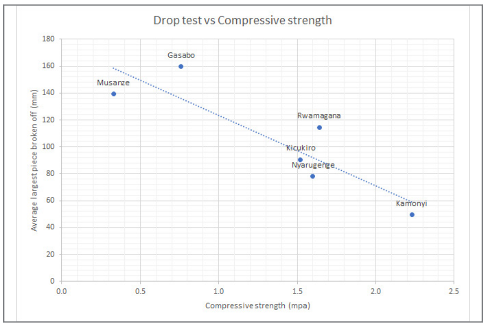

Figure 5. Phase 1 relationship between average length of the largest corner broken off during the drop test and characteristic compressive strength. R2 = 0.53.

Figure 6. Representational images of Phase 2 drop test results with blocks made with Gasabo soil. Right: control blocks without fibres. Left: blocks with 5kg/m3 of 5-7cm long Ishinge fibres.

Discussion

This section demonstrates how the results and analysis from the block testing have been used to inform the published documents.

The drop test has been modified from NZS 4298 to require a minimum of 20 blocks to be tested rather than two and a pass rate of 80% indicates good performance. These modifications account for the high level of variability observed in the drop test. The size of the corner piece that can break off in the test has been increased to 150mm from 100mm because it was found that the linear relationship between compressive strength and the drop test results demonstrated that a corner piece of 150mm breaking off still met the minimum compressive strength requirements.

A minimum compressive strength of 0.5 N/mm^2 is stated in the standard which is considered to be achieved if the drop test is successful, which is possible due to the strong correlation between compressive strength and drop test results (Figure 4).

Citations

British Standards. (2011). *Methods of test for masonry units. Determination of compressive strength (BS EN 772-1).* London: The British Standards Institution.

Government of Rwanda. (2019). *Rwanda Building Code Version 2.* Kigali: Republic of Rwanda.

Government of Rwanda. (2021). *Post Disaster Needs Assessment and Recovery Plan for Rubavu Seismic Disasters.* Kigali: Republic of Rwanda.

Minke, G. (2006). *Building with Earth, Design and Technology of a Sustainable Architecture.* Berlin: Birkhauser Publishers for Architecture.

National Institute of Statistics of Rwanda. (2014). *Fourth Population and Housing Census, Rwanda, 2012 Thematic Report Population Projections.* Kigali: Republic of Rwanda.

National Institute of Statistics of Rwanda. (2020). *Rwanda Household Survey 2019/2020 Report.*

Rwanda Standard. (2022). *Adobe blocks (Rukarakara) — Specification (RS 484).* Kigali: Rwanda Standards Board.

Standards New Zealand. (1998). *Engineering design of earth buildings (NZS 4297:1998).*

Standards New Zealand. (1998). *Materials and workmanship for earth buildings (NZS 4298:1998 A1).*

Standards New Zealand. (1999). *Earth buildings not requiring specific design (NZS 4299:1998 A1).*

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