Mediterranean Journal of Basic and Applied Sciences (MJBAS)
Volume 7, Issue 4, Pages 101-113, October-December 2023

Investigation on the Strength of Cement Blocks Reinforced Using Old Tyre Wires Residues

Leopold Mbereyaho[1*], Clemence Uwimbabazi[2], Maurice Kubwimana[3] & Marius Basile Abayisenga[4]

[1-4]University of Rwanda, College of Science and Technology, P.O Box: 3900 Kigali, Rwanda.
Corresponding Author Email: lmbereyaho2015@gmail.com[*]

DOI: https://doi.org/10.46382/MJBAS.2023.7407

Article Received: 14 October 2023 *Article Accepted: 21 December 2023* *Article Published: 28 December 2023*

ABSTRACT

From many years, cement block has been used as one of the main building materials for wall construction. Based on current situation in construction sector in Rwanda, different and important building structures are being constructed and the majority of them with block walls. Therefore, the high performance of this material would mean the sustainability of the majority of respective constructions. On one side, the strength performance for these blocks is still low and this put limitations into their application. On the other side, the waste management of used tyres has been a major concern for many environmental bodies and agencies worldwide. The general objective of this study was to investigate on the applicability of tyres wires residues in hollow blocks in order to improve the block strength, while contributing in solving the problem of environment pollution. To achieve the above objective and solve this dual problem, a new cement block, reinforced with tyre wires was manufactured and its performance was checked. The mixing ratio used in making conventional cement block was 1:6 while for reinforced cement block the ratio of 1:8 was used with additional of 3kg tyre wires of 30mm to 40mm long. Among other results, the study established that the density for conventional and reinforced cement blocks was respectively 1840.5kg/m^3 and 1854.9kg/m^3; the water absorption of 6.2% and 5.1%; the compression strength, 3.5N/mm^2 and 4.2 N/mm^2 respectively, after 28 days. These results show the strength and durability performances improvement for the manufactured cement block with addition of tyre wires. A further study using different quantities and/or sizes of wires in replacement of cement would be welcome to establish the point of maximum performance of reinforced blocks.

Keywords: Aggregates; Cement block; Compressive strength; Reinforced cement block; Tyre wires; Water absorption.

1.0. Introduction

1.1. Worldwide experience

Conventional cement block is a construction material made from a mixture of Portland cement, aggregates and water, with or without mineral aggregates. The mortar from which cement block is made should have a low consistence not only for better workability, but also for easy removal from used moulds. Cement blocks have been used as building materials in the construction of walls since the last century. Rwanda Standards specifies solid and hollow cement masonry building blocks and bricks for interior and exterior use in construction of structural and non-structural masonry walling [1]. Buildings developed with cement blocks sometimes show cracks which are the sign of poor performance either due to construction techniques, or to construction materials. Mainly poor construction materials lead to the failure of structure under imposed load [2]. Cement block constituents determine the performance of final cement block. Requirements for acceptable construction materials, including cement blocks shall be satisfied if the use, method of mixing, preparation, application, or fixing comply with the provision of approved Standards [1]. Regarding cement blocks, sometimes other components are added in the mixture with purpose to increase its performance. This study aims at assessing the performance of cement block, reinforced with tyre steel wires, in comparison with the conventional block without reinforcement.

1.2. Status of cement block application in Rwanda

Traditional construction industry in Rwanda has been mainly using timber logs embedded in mud plaster in walling and was the cheapest mode of construction especially in remotes areas where trees have been available. However, dispute the sustainability of timber construction, with the need for environment protection, the adoption

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of other modes of construction rather than using trees was urgently needed. Adobe bricks are second cheaper construction materials and its respective construction is adequate for the areas with sufficient earth materials [3]. Ordinary burn clay bricks construction is also adopted method and covers a wide range of several population shelters; raw material for burnt bricks being clay from swampy areas. However, not only a good quantity of wood was needed for use in kiln during brick burning, but also the governmental rules and regulations enforce the protection of swamps [4]. As a consequence, burnt clay bricks production is limited. Therefore, in Rwanda construction industry, cement blocks have been the favorable construction materials both in rural and urban construction activities. Dispute that wider application, the limited strength of cement blocks has been one of drawbacks and its limitation. There has been therefore, a need for its improvement in order to ensure the sustainability of the majority of respective local constructions.

1.3. Quantity of Tyres Present in Rwanda

Worldwide, it is estimated that more than one billion used tyres arise annually [5]. The amount of tyres present in Rwanda is reflected by the number of imported vehicles in the country. According to national statistical data, the quantity of imported vehicles in the country was around 221,688. Consequently, the quantity of old used tyres disposed in the local environment was estimated at 216, 204 [6], [7]. This kind of waste has been jeopardizing the environment, especially due to the low recycling industry [8]. With the continued worldwide increase in production of automobiles and trucks, the generation rate of waste tires will keep increasing dramatically [9]. The use of steel wires from old tyres in hollow cement block as their reinforcement may be a solution to excellent quality structures at a minimum cost. The remaining part of rubber scraps should be reserved for recycling in manufacturing rubber materials industries, and this would provide a contribution to the environment protection.

1.4. Literature review

Cement blocks have been under use in construction all over the world from many years, and different studies regarding their performance and improvement have been conducted.

The study about concrete manufactured using modified waste tyre rubber chips as partial replacement of coarse aggregates established a significant increase in mechanical strengths compared with ordinary concrete [10]. Results from the study related to the use of waste wires in light weight concrete, showed improvement in the flexural, tensile and impact characteristics of concrete [11]. In the same line, it was established that the use of recycled steel fibers in concrete improved its properties and offered good environmental and economic benefits, among other merits [12], [13], [14]. Another investigation on mechanical properties of structural lightweight concrete reinforced with waste steel wires by [15] concluded that waste steel wires could be used as a suitable alternative to industrial steel fibres for structural lightweight concrete applications. Furthermore, on their side, [16], using steel fibres recovered from waste tyres as reinforcement in concrete established satisfactory results regarding the bond between recycled steel fibres and concrete, compressive and flexural strength of concrete. Finally, for the purpose of this study, during their investigation, [17] established that test results of soil–cement blocks reinforced by waste tire steel fibers in different percentages, were in good agreement with the minimum requirements of the different standards considered. The current study aims at investigating on the strength of cement blocks reinforced using tyre wires residues with various lengths and constant weight.

2.0. Materials and Methods

2.1. Introduction

This study consists of engineering investigation with purpose to check the influence of old tyre steel wires used as reinforcement for cement blocks. Initially, the conducted survey confirmed the availability of used old tyres in big quantity all over the country. In brief, the field observation, interviews and discussions, as well as required laboratory tests were used among other methods. During this study, in order to get adequate amount of steel wires from old tyres, the manual work has been adopted where tyres were cut by using knives. Outside lubber part was removed to attain the layer of wires which were pulled out from tyres with hand. Details about materials and used methods are presented in the next sections.

2.2. Materials and Methods

2.2.1. Tyre wires

Tyre residues were collected from two garages in the City of Kigali, Biryogo and Nyabugogo where they were temporarily damped. In fact, there exist large quantities of used old tyres that are no longer productive but were yet to be properly disposed. Figure 1 shows tyre waste disposed in the open site at Biryogo garage, and this was not contributing to the environment protection at all.

Figure 1. Tyre waste disposed at Biryogo garage

Above used tyres were collected from the temporary damping site, and wires were extruded manually by cutting the rubber part with a very sharp knife. For each sample, three tyres were enough to provide the required quantity of steel wires. Figure 2 shows the process of wires preparation. Used steel wires were between 30mm and 40mm length 3kg weight.

Figure 2. Wires extrusion from cut tyres

It was observed that some old tyres do not have wires. The minimum quantity extracted from the smallest tyre was 1.3kg.

2.2.2. Aggregates

Aggregates form the body of the concrete, reduce the shrinkage and effect economy. They occupy 70-80 per cent of the volume and have considerable influence on the properties of the concrete. It is therefore significantly important to obtain right type and quality of aggregates at site. They should be clean, hard, strong, and durable and graded in size to achieve utmost economy from the paste.

For this study, sieve test has been conducted for aggregates that were to be utilized in cement block manufacturing. Sieve analysis helped to determine the particle size distribution of the coarse and fine aggregates. This allowed establishing the fineness modulus which is generally used to get an idea on either the aggregates are coarse or fine. Big fineness modulus value indicates that the aggregate is coarser and small value of fineness modulus indicates that the aggregate is finer. Apparatus used are the following:

✓ Weighting balance

✓ Set of sieves

✓ Shaker machine

Before the test took place, the sand firstly had to be dried. The mass of aggregate before placing into the set of sieves was recorded. For this study, the weight of used aggregate sample was 800g.

The used procedure is presented below:

1. Sieve the aggregate using the appropriate sieves (4.75 mm, 2.36 mm, 1.18 mm, 600 micron, 300 micron & 150 micron).

2. Record the weight of aggregate retained on each sieve.

3. Calculate the cumulative weight of aggregate retained on each sieve.

4. Calculate the cumulative percentage of aggregate retained.

5. Add the cumulative weight of aggregate retained and divide the sum by 100. This value is termed as fineness modulus.

Figure 3 below presents the apparatus used for sieve analysis test.

Figure 3. Sieve test apparatus

Aggregates were then mixed to consistency with steel wires cut into pieces of 30mm in cement mixture. There after clean water free from impurities and other oxidizing agents, was added. Sieve analysis tests results are presented in section 3.1.

2.2.3. Cement blocks

Cement blocks were manufactured at Gisozi site. Key attention was paid to proper mixing ratio and grading of used aggregates. The Figure 4 presents blocks manufacturing process at Gisozi site. The used mix ratios were of 1:6 and 1:8 respectively for conventional cement blocks and reinforced cement blocks.

In order to achieve research objectives, ten (10) specimens of cement hollow blocks were prepared: five conventional blocks and five blocks, reinforced by tyre wires. After being casted, cement blocks were brought to laboratory tests for compression and water absorption tests.

Figure 4. Cement blocks manufacturing at Gisozi site

2.2.4. Cement blocks production process

Cement blocks are precast construction materials. During production, the material constituents are adequately mixed to form cement blocks. Prepared aggregates, steel wires of lengths between 30mm and 40mm with cement

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were mixed together till they form homogeneous concrete with lower consistence. The mix ratio of 1:6 for conventional cement blocks and 1:8 for reinforced cement blocks were used. Figure 5 presents manufacturing process of both conventional and reinforced cement blocks.

Figure 5. Manufacturing cement blocks

The quantity of water is controlled to maintain lower consistence that thereafter favourable in moulding and demoulding. The key steps used during production of cement block reinforced by steel wires from used tyres are: ***Batching, Moulding and Curing*** [18].

2.2.5. Tests of cement blocks

A. Density of cement blocks

For determining the density of cement block, three blocks were taken randomly from all prepared samples. Cement blocks were of the same size of 40x20x20 cm and the sizes of the voids were 9x14x16 cm, and consequently the net volume was 9952 cm^3. Each block was weighed in kilograms and the density of each block was calculated as follows:

$$\text{Density}= \frac{\textit{mass of block in kg}}{\textit{volume of block in cm3}} \times 10^6 \text{ (in kg/m}^3\text{)} \quad (1)$$

Respective results are presented in section 3.4.

B. Water absorption test

This test is specifically needed to determine the amount of water that a given type of cement block can absorb. For that the block to be tested is dried, until the whole moisture is removed. Then the same is weighed, and this is weight is denoted as A. Next, the dried specimen is immersed into water during 24 hours, and then removed from water and weighed to get the weight denoted as B.

After both weights A and B are established, the block's water absorption is calculated using the following equation:

$$\text{Water absorption} = \frac{Weight\ B - Weight\ A}{Weight\ A} \times \mathbf{100} \quad \text{(in \%)} \quad (2)$$

Results from water absorption test are presented in section 3.3.

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C. Slump test

Workability of concrete is determined by carrying out slump test. This test is carried out with a mould called slump cone whose top diameter is 10 cm, bottom diameter is 20 cm and height is 30 cm. Figure 6 presents apparatus used for this slump test.

Figure 6. Slump test apparatus

The test was conducted following the guidelines given under IS standards. Slump test results are presented in section 3.2.

D. Compressive strength test

This test aims to determine the block compression strength. The casted blocks were placed into the testing machine for them to be crushed. The machine applies pressure to the blocks until they are crushed, and then the results registered. Figure 7 presents the used universal testing machine.

Figure 7. Compressive strength testing machine and testing procedure

During this test conducted after 14 and 28 days of curing, five blocks were subjected to uniformly distributed Load (P). The following formula was applied to calculate the strength:

$$\text{Compressive strength}=\frac{\text{Maximum load}}{\text{Cross section Area}} \quad (3)$$

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Results are presented in section 3.5.

3.0. Results and Discussion

As it was stated earlier, reinforced cement blocks were produced and tested to check their performance. Firstly, the quality of the used aggregates has been checked, and used cement quality was confirmed as well. All results are presented in the following sections.

3.1. Sieve analysis

The sieve analysis test results are presented under respective graph shown in Figure 8.

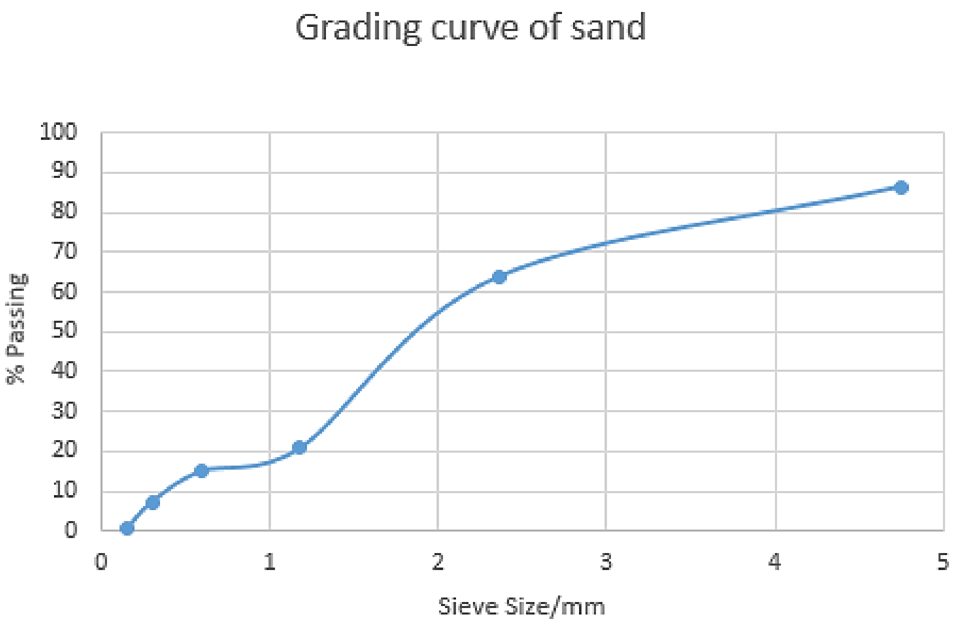

Figure 8. Gradation of aggregates used in cement block production

The fineness modulus **(F.M)** was determined taking the sum of the cumulative percentages retained on the sieves divided by 100 as given by the formula below:

$$\textbf{Fineness modulus (F.M)} = \frac{\textbf{Cumulative percentage retained}}{\textbf{100}} = \frac{\textbf{406.42}}{\textbf{100}} = \textbf{4.06.}$$

The fineness modulus (F.M.) varies between 2.0 and 4.0 for fine aggregate, between 5.5 and 8.0 for coarse aggregate, and from 3.5 to 6.5 for all-in aggregate (https://en.wikipedia.org/wiki/Fineness_modulus) Therefore, the obtained value indicates that the used aggregates are neither too finer nor coarser. If all the aggregates particles are of uniform size, the compacted mass will contain more voids whereas aggregate comprising of particles with various sizes will give a mass containing lesser voids. It is, therefore, essential that the coarse and fine aggregates be well graded to produce quality concrete. Therefore, these aggregates are suitable for this study regarding sand-cement blocks, because they contain appropriate percentage of fine and courser aggregates [19].

3.2. Slump Test

Three trials were conducted to ensure fair results were established (Table 1).

Table 1. Results of slump test

Trials	Slumps in cm
First trial	8
Second trial	11
Third trial	9
The average	9.3

From the results above, it can be seen that the average slump value was 9.3 cm. Such slump allows the stability after removing the mould from fresh cement block. Therefore, this mortar is suitable for cement blocks production [20].

3.3. Water absorption test of blocks

The block's absorption was calculated using equation (2), presented in section 2.3.3, and Results are presented in Table 2.

Table 2. Results of water Absorption test

Observations	Mass/g
Weight of Specimen (A)	18.35
weight of sample after immersing it into water (weight B)	19.45
Weight of Specimen contain wires (A”)	18.5
Weight of sample after immersing it into water (weight B”)	19.45
Water absorption of conventional cement block $\frac{\text{Weight B} - \text{Weight A}}{\text{Weight A}} * 100$	6%
Water absorption of reinforced cement blocks	5.1%

From Table 2, it can be seen that the water absorption values were 6 and 5.1%, respectively for conventional and reinforced cement blocks. According to available standards, the maximum water absorption for cement blocks should not exceed 10% [18]. Therefore, prepared cement blocks meet standards requirements. Also, these results show that reinforced cement blocks are more water resistant than conventional cement blocks.

3.4. Density of cement blocks

The testing procedure was presented in section 3.3.1. Table 3 presents the respective results for both conventional and reinforced cements blocks.

Table 3. Density of cement blocks

Specimen		Mass in kg	Volume in cm^3	Density kg/m^3	Average density kg/m^3
Conventional cement blocks	Specimen1	18.35	9952	1843.85	1840.5
	Specimen2	18.29	9952	1837.82	

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	Specimen3	18.31	9952	1839.83	
Reinforced cement blocks	Specimen1	18.5	9952	1858.92	1854.9
	Specimen2	18.45	9952	1853.89	
	Specimen3	18.43	9952	1851.88	

Results from Table 3 shows that the density of all cement blocks is above 1500kg/m^3. With reference to IS recommendation the manufactured cement blocks meet one requirement for Grade-A blocks [18]. The little difference in densities is due to the difference in material constituents; hence cement blocks reinforced with wires are denser than conventional blocks.

3.5. Compressive strength test results

Following the procedure presented in section 2.3.3, compression test results on cement blocks at 7 days as per IS recommendations are graphically shown in Figure 9.

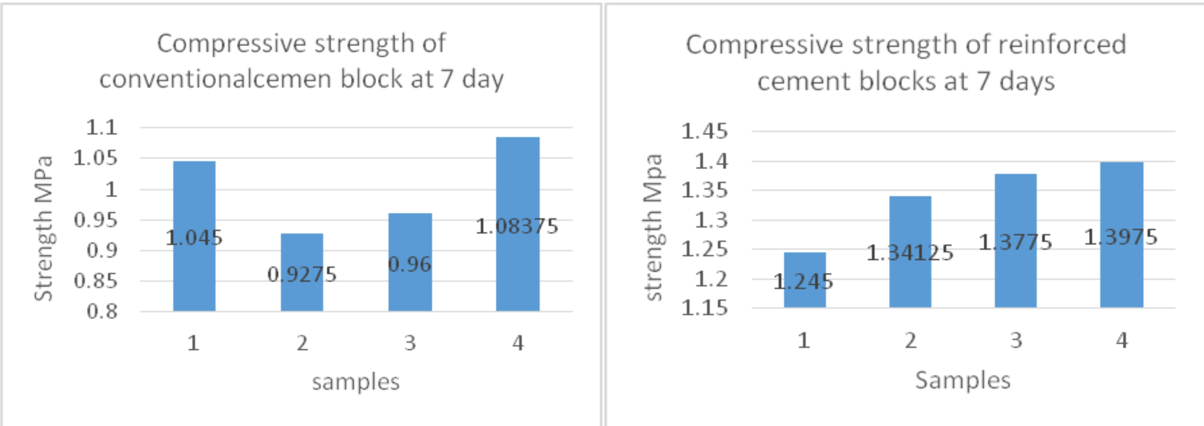

Figure 9. Compressive strength of cement blocks at 7 days

Obtained results of compressive strength of cement blocks after 28 days are plotted under chart in Figure 10.

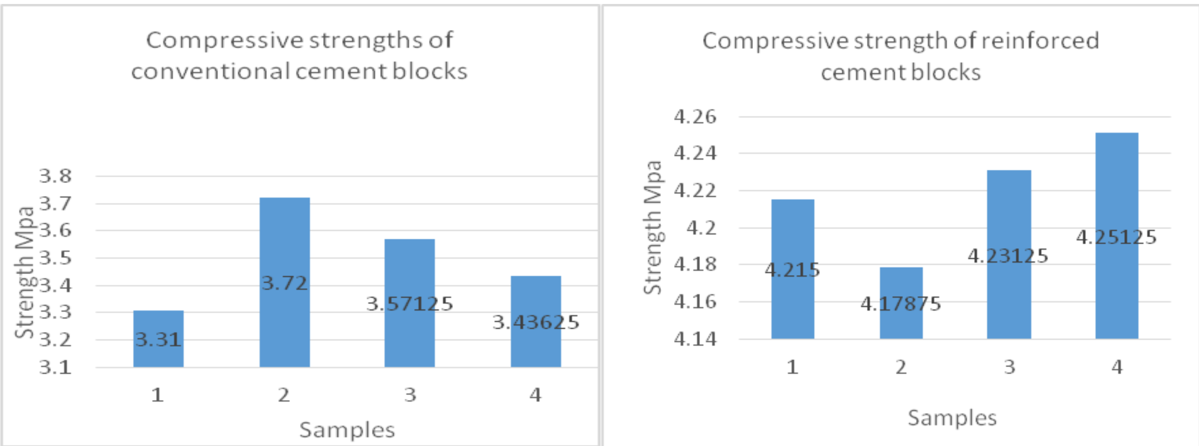

Figure 10. Graphical presentation of compressive strength of cement blocks at 28 days

Referring to IS Code, the compressive strength of all manufactured cement blocks comply with the 2nd requirement for grade-A blocks, and therefore they can be used for load bearing elements.

The comparison of above results shows that the strength of cement blocks reinforced by wires (4.219N/mm^2) is higher than the one for conventional blocks (3.509N/mm^2). Hence the advantage of reinforcement of cement blocks.

4.0. Conclusion

The objective of the study was to investigate on the strength of cement blocks reinforced using tyre wires residues, while solving the problem of environment pollution due to poor management of old tyres. The application of cement blocks was still limited due to the fair compression strength. Besides, the waste management of used tyres was still a major concern for many environmental bodies and agencies worldwide. To achieve the above objective and solve the identified dual problem, a two cement blocks were manufactured and their performance was checked: a conventional cement block and a new cement block, reinforced with tyre wires. For the reinforcement, steel wires of between 30mm and 40mm length and 3kg weight were used in each sample. The experimental study results showed that the conventional and new cement blocks had density of 1840.5kg/m^3 and1854.9kg/m^3, water absorption of 6.2% and 5.1%, and average compressive strength of 3.5 N/mm^2, and 4.2 N/mm^2. Therefore results show the strength and durability improvement of the manufactured cement block, reinforced by tyre wires. This new cement block would be also cost effective. A further study using different quantities and/or sizes of wires in replacement of cement would be welcome to establish the point of maximum performance of reinforced blocks.

Declarations

Source of Funding

The study has not received any funds from any organization.

Competing Interests Statement

The authors have declared no competing interests.

Consent for Publication

The authors declare that they consented to the publication of this study.

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