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Effect of volcanic tuff on the engineering properties of compressed earth block

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ABSTRACT

Purpose: of this paper is to investigate the durability and the mechanical properties, including compressive and flexural strengths, of the locally compressed earth blocks manufactured from soil in Irbid, Jordan. Moreover, effect of volcanic tuff as new stabilizer material on properties of compressed earth block (CEB). Compressed earth block is a technique that was created to solve environmental and economic problems in construction sector. It is widespread in many countries around the world but hasn't been used in Jordan yet.

Design/methodology/approach: 9 mixtures were carried out. One of this mixture is the control mix, beside other mixtures were performed by replacing soil with 40%, 10%, 10%, of sand, volcanic tuff, and lime respectively. In addition, polypropylene fibre was used. After 28 days of curing, the CEB were dried in oven at 105°C for 24 hours then tested.

Findings: Show that absorption and erosion were decreased when the lime used in the soil. On the other hand, the fibres presence significantly improved the durability and mechanical properties in all mixtures. Moreover, the higher compressive strength was obtained in the mixtures which contain lime only while the higher tensile strength was obtained in the mixtures which contain lime with sand replacement. The using of volcanic tuffs produced average compressive strength values. The reason is that in the presence of lime and pozzolana (volcanic tuff) reactions take place at low and slow rate at early ages.

Research limitations/implications: volcanic tuff can produce favourable compressive strengths at later ages and this is a point of interest in the future work.

Originality/value: Searching for a new material as stabilizer material that improves the properties of the compressed earth block (CEB).

Keywords: Compressed earth block, Volcanic tuff, Lime, Interlocking, Fibres

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PROPERTIES

1. Introduction

Historically, many techniques were used in earthen construction around the world in many areas such as Africa, India, Australia, America, and many other countries with large variation of its components [1-14]. One of the common techniques that has been used seven decades ago is compressed earth block (CEB). In this technique, wet soil is mixed with stabilizing materials and then pressed in a mould to make blocks that are suitable for modern construction methods. CEB could have flat or interlocking surface, big or small and its colour depends on the type of the used soil and the stabilizer.

The main technique used in CEB production is to press the soil strongly using manual or hydraulic machines to reduce the voids as much as possible (mechanical stabilization). Also, using binding materials that could hydrate and make a strong matrix between the soil particles (chemical stabilization). The ancient civilizations used many materials for binding, but the most common used materials were Cement and lime. Earlier studies have shown that cement is the best choice to use with the sandy soil as stabilizer, while lime is adopted for clayey soils [15-17]. Lime can reduce the degree, to which the clay absorbs water, and so can make the soil less sensitive to changes in moisture content and improve its workability [18]. Recent studies show that other materials could be used as stabilizers, such as bitumen materials, plastic resin and fly ash. All these materials have a large variance in the efficiencies, costs and the environmental effects between them [19].

Widely, the fibre used to improve some engineering properties such as the durability and the flexural strength at different percentages. The advantages of this technique are different materials can be used as soil fibre reinforcement; beside there are maximal and minimal requirement for additional mixing machinery. Alongside recycled, waste and by-product fibres can be utilized [20]. There are many different types of fibres that have been used with CEB through the history; it may be natural such as wheat and rice straws, animal's hair, palm fibres, banana fibres, sisal fibres, kenaf fibres or synthetic such as Polypropylene and steel from old tires [15, 21-25].

On the other side, the interlocking technique improve the total mechanical properties for the CEB walls and its seismic load resistance, it also makes the construction process easier and faster and need a little amount of mortar. This product is truly marvellous and it has found acceptance all over the world. It has been used and have codes in Nigeria, Angola, Uganda, Zambia, Mozambique, Ethiopia, Malawi, Mali, Madagascar, Ghana, Sierra Leone, Liberia, Mexico and USA, India, etc. In the Middle East there were a few individual attempts to prove this technique. This research helps people to know about this technique and how to use it. The objectives of this research are to investigate the durability and the mechanical properties including compressive and flexural strength of the interlocking compressed earth blocks which compacted manually and stabilized with lime, volcanic tuff and fibres with the locally soil of Irbid, Jordan.

2. Materials and experimental program

2.1. Materials

The suitable soil that could be used in CEB production must have specific characteristics in terms of contents, Atterberg limits and its particle size distribution [1,11]. The required soil should be well graded and contains fractions of sand, silt and clay. The soil used in this investigation was taken from (Al Hi Al sharqi) the eastern area of Irbid – Jordan. It has been collected from an excavation work of a construction site, and has been sieved on sieve no. 4 (4.75 mm) to separate between small and large particles [27]. The soil description and characteristics are shown in Table.1.

The soil in Irbid area in general, is a clayey soil with a high expansion coefficient that may not be suitable for manufacturing the CEB. A 40% of the soil has been replaced with a well graded sand to make it suitable with the standards.

The soil sample is checked for suitability in the plasticity chart by using the Atterberg limits values. The value of plasticity index of and liquid limit as shown in the table indicates the non-suitability of the soil for compressed earth block production [26]. So, sand with particle size ranged from 0.1 to 2 mm mixed with gravel particles used to compensate for missing sizes in the soil. The clay content in the mix provides the cohesion and binding forces that be necessary to hold the particles together. The silt, sand and gravel particles combined with clay content and the stabilizer created a compacted earth block with the desired strength.

Table 1.
Soil description and characteristics

Common clay and silt	Sand	Gravel	Liquid limit	Plastic limit	Plasticity index
91.3%	8.6%	0.1%	74.1%	24.8%	49.3%

This investigation focused on studying and comparing the effect of the volcanic tuff and lime as stabilizers on the CEB characteristics. The volcanic tuff rock is a low-cost material and available nationwide in Jordan. It was collected and grinded in the laboratory using Los Angeles machine and sieved on sieve number 200 (75 µm) [27]. Table 2 summarizes the chemical compositions and physical properties of volcanic tuff used. The hydrated lime has a specific gravity of 2.34, absorption of 3% and Median Particle Size of 2 micron.

Polypropylene fibres with the following properties were used: fibre length (40 mm), specific gravity (0.92), modulus of elasticity (9501 MPa), and tensile strength (621 MPa). The fibre content was 0.9 kg/m^3 (this value recommended for the concrete mixes) according to manufacturer instructions, added by hand during mixing process.

2.2. Experimental program

Batch design and schedule

As mentioned above, two types of chemical stabilizers have been used in this study, lime and volcanic tuff to study their effect on the CEB characteristics, 10% by weight have been used from each stabilizer. A total of 9 batches were prepared with different combinations of constituents. The local soil was replaced with 40% by weight sand and 3% by weight gravel in 6 batches. The remaining 3 batches were completely of local soil only, in addition to the stabilizing material. fibres were used in 4 batches to study their effect on the mechanical properties of the block. The schedule is shown in Table 3.

Batch Code: Every batch has its own code which indicates all the information about its content. To explain that batch No. 7 will be used as example.

G40-LFZ
B: The base soil without any addition.
G: The gravel existence; in 0.03% by weight.
40: The sand existence; in 40% by weight.
F: The Fibre existence; in 0.9kg/m3.
L: The Lime existence; in 10% by weight.
Z: The Volcanic tuff existence; in 10% by weight.

Block manufacturing and curing

There is no standard shape or size specified for CEB in the literature. The shape and size mainly depend on many factors such as construction type, labour skills, available moulds, and the local tradition. A manually operated compaction machine [28] with mould size of 300×150×108 mm (Figs. 1 and 2) was fabricated and delivered to the laboratory. The compaction method used to press the block is manual compaction and the force required to do the compaction was specified by using the ratio method and cannot be given in MPa. The compaction ratio of this type of machines should not be less than 1.70. The compaction ratio = (H)/ (T), where H is the height of loosely filled mix in the machine mould and T is the block thickness [29]. In this machine H= 19cm and T= 10.8cm in average (because of the variation in the block thickness), and the compaction ratio was 1.75. The suitable water content determined by using the drop test method which is described in [30].

Table 2.
Chemical composition and physical properties of volcanic tuffs

Parameters, %	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	SO_3
Volcanic tuffs	34.4	4.6	31.5	24.1	0.5	-	1.3	-

Table 3.
CEB batch schedule

Serial No.	Batch code	Gravel Content, %	Sand Content, %	Volcanic Tuff content, %	Lime Content, %	Fibre content, %
1	B	-	-	-	-	-
2	BL	-	-	-	10	
3	BLF	-	-	-	10	0.9kg/m^3
4	G40-L	3	40	-	10	-
5	G40-LF	3	40	-	10	0.9kg/m^3
6	G40-Z	3	40	10	-	-
7	G40-ZF	3	40	10	-	0.9kg/m^3
8	G40-ZL	3	40	10	10	-
9	G40-ZLF	3	40	10	10	0.9kg/m^3

Fig. 1. 300×150×108 mm block dimension

Fig. 2. Manual compression machine

Curing process for the fabricated blocks started the day after compaction and continued for next four weeks. The main objective of the curing process was to keep the blocks moist enough to maintain the stabilizer reaction continuity. So, the blocks were covered with plastic sheets after being sprayed with water. At the end of week four, the plastic sheets were removed and the blocks were exposed to the air.

2.3. Tests preparation

Before the testing campaign, the blocks have been produced by a manual press and stored in the ambient laboratory conditions for around one month with the relative humidity of 47% ± 10% and temperature 22ºC ± 5ºC. In order to eliminate moisture content effect on the mechanical properties, all specimens were placed in an oven at 105ºC for 24 hours, and left in the ambient laboratory for approximately 2 hours prior to tests according to the Australian Bulletin 5 [16].

Compressive Strength Test

The most important test performed on the compressed earth blocks was the compressive strength test. The compressive strength values usually give an indication of the quality of the blocks. This test was performed based on 30-day age after manufacturing [31]. The blocks were oven dried at 105ºC for 24 hours to equalize the moisture content for all mixes before testing. Oven drying is an important step before testing, because the variation in the moisture content produces a variation in the compressive strength readings.

The uneven block surface from both sides was a major problem when using compressions machine. Many standard test procedures in compressive test of CEB did not mention the problem of contact between the platens of the testing machine and the CEB specimen. One of the main materials used for solving this problem is plywood sheet according to the Bulletin 5 and Kenya standard, 3 mm thick layer of cement paste according to [32]. The capping material itself should have a compressive strength in decrease of that expected from the CEB specimens, for this reason, we avoid using cement paste for capping. In a previous research by the author [33], used three various capping methods (capping with rubber, plywood and without capping) and the result showed that for the whole block capped with rubber, the specimen shows more vertical cracks due to the less confinement compared with the ones capped with plywood or without capping. Moreover, for the block capped with plywood, the confinement is still high, thus, it presents similar crack pattern with the one without capping. The compressive strengths for the blocks capped with rubber are lower three times of the compressive strengths for the blocks capped with plywood and without capping. This is due to the enhanced lateral expansion, low friction coefficient between the steel plates and the block for the blocks capped with rubber. In such cases, it could be an appropriate way to obtain the compressive strength of the block by reducing the confinement effect. That is to say, the compressive strength measured from the whole block capped with rubber is the right design parameter as shown in (Fig. 3) [33].

Flexural strength test

Modulus of rupture or flexural strength test gives an indication of the ability of the blocks to resist bending forces. The flexural strength test was performed on block samples 30 days after moulds being removed [34-37]. The blocks were also oven dried at 105ºC for 24 hours before testing.

Fig. 3. Compressive strength test preparation

The block dimensions were not on the standards of the testing machine. A modification on the machine was made according to [38]. An iron base was installed with a span length equals to 250 mm. The distance from the centre of the support to the block edge equals to 25 mm. A point load was applied to the block centre point, 125 mm from each support (Fig. 4).

Fig. 4. Flexural strength test preparation

<u>Absorption Test</u>

The water absorption test is another important test performed on the compressed earth block. It is described as the water content that could be absorbed by the block after soaking in water for 24 hours, this is done based on [7] by using three specimen for each sample.

<u>Durability Test</u>

Durability assessment for compressed earth blocks can be achieved by using Australian standard-Geelong drip test [39] which was originated to simulate rain droplets on adobe bricks. The test can be performed by allowing a 100 ml of water, released via a cloth wick within 20 to 60 minutes, to fall from 400 mm height onto a specimen 27° inclined from the horizontal. The degree of erosion is then measured by the depth of the whole resulted from the water drops (Fig. 5). A hole deeper than 15 mm leads to the rejection of the block [40]. The depth of pitting and the depth of moisture penetration have to be measured by caliber and tape measure in this test respectively.

Fig. 5. Geelong drip test

3. Results and discussion

One of the main reasons that prompted the authors to use volcanic tuff as stabilized material is the chemical composition of volcanic tuff. Since it consists, essentially, of SiO_2, Al_2O_3 and Fe_2O_3 which are the ingredients that mainly affect the activity of natural pozzolana. The overall ratio of those elements is 70.5% which complies with the ratio of 70% recommended by ASTM C618-12a (1994) [41].

The control mixture which consists of the soil without any modification was totally damaged in 24 hours after it dried and before any curing process. This due to the shrinkage cracks which appears immediately after the compaction process. Thus, the control mixture was not applicable for any of the tests mentioned, as a result of this we modified the soil by add gravel and sand to become the control mix for this study and labelled the G40 name so we use the modified soil (G40) as a reference mix and study the effect of lime, volcanic tuff and fibre on the modified soil. According to Ingles, 1987 a good rule of thumb in practice is to allow 1% by weight of lime for each 10% of clay in the soil [42]. The soil used in this research contains 93% of clay, so the optimum percentage is 10% percent of lime. Aside from, most standards set a percentage of 6 to 10 of cement or lime to stabilize of soil such as Bulletin 5 used 10% [43]. In addition, data produced by various researchers showed a strong, often linear, correlation between compressive strength and cement, lime content. Data showed the best compressive strength was obtained when the percentage of cement content was 10% [44]. In [45], the authors used 6, 8, and 10% of lime and from the results. Results showed that the 10% of lime had a significant influence in compressive strength. As a result, the percentage of 10% was chosen to be utilized in this research.

3.1. Compressive strength test

In the compressive strength test, three (300×150×108 mm) specimens were used for each mix. Table 4 shows all information and results of this test.

The BL mix consists of normal soil in addition to 10% lime. The presence of lime improved the mix properties and showed better results comparing with the base soil without any addition. Lime is indeed and excellent stabilizer but its positive effects depend on: particles grading especially clay, quantity in weight of the adding lime. There is a threshold for lime addition called 'fixation limit or quantity' [46-48]. Also, the addition of fibre to the mix improves the strength, as shown in BLF which is like the preceding sample in addition to fibre. The addition of fibre improves the strength up to 15% comparing with BL mix (Fig. 6).

The compressive strength values of G40-L mix were lower than the BL mixes by about 4%. The addition of fibres improves the compressive strength of G40-LF comparing to G40-L but in a small percent reaches 2% (Fig. 7).

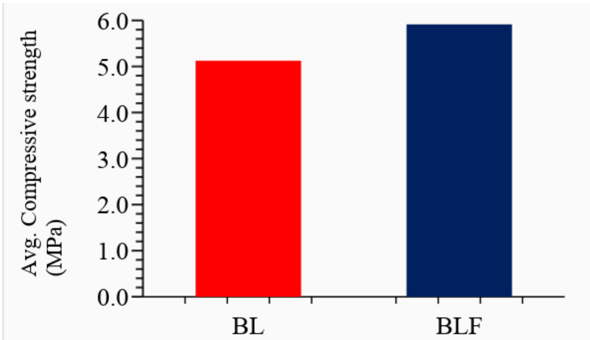

Fig. 6. Compressive strength results due to fibre addition

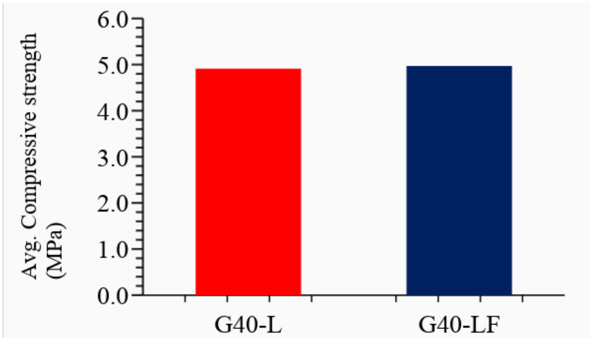

Fig. 7. Compressive strength results due to fibre addition

The average compressive strength of G40-Z was lower than G40-L for about 80%. The addition of fibre in this mix improves the compressive strength about 24%, up to 1.3 MPa (Fig. 8). G40-ZL mix showed better compressive strength results than volcanic tuff alone for about 230%.

Table 4.
Information and results for compressive strength test

Type of specimen \ Details of specimen	Specimen dimensions, mm	Number of specimens	Avg. dry weight, g	Avg. density, Kg/m^3	Avg. maximum load, KN	Avg. compressive strength, MPa	Standard deviation
BL	300×150×108	3	7123	1465	230.7	5.13	0.28
BLF		3	7310	1504	261.6	5.92	1.57
G40-L		3	7791	1603	221.1	4.91	0.44
G40-LF		3	8161	1679	223.7	5.00	0.31
G40-Z		3	7589	1561	45.6	1.01	0.03
G40-ZF		3	7674	1579	56.3	1.30	0.02
G40-ZL		3	7866	1618	150.5	3.35	0.11
G40-ZLF		3	8111	1668	163.9	3.64	0.35

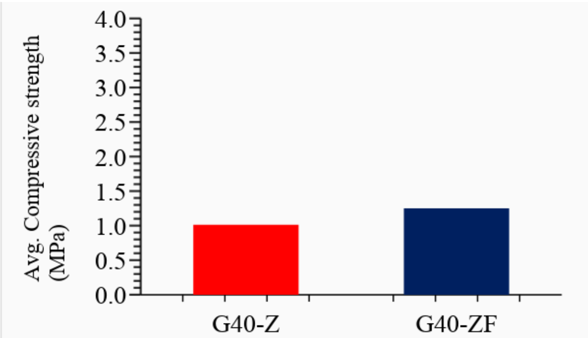

Fig. 8. Compressive strength results due to fibre addition

Also, the addition of fibre improved the compressive strength for about 9%, up to 3.6 MPa in G40-ZLF mix (Fig. 9).

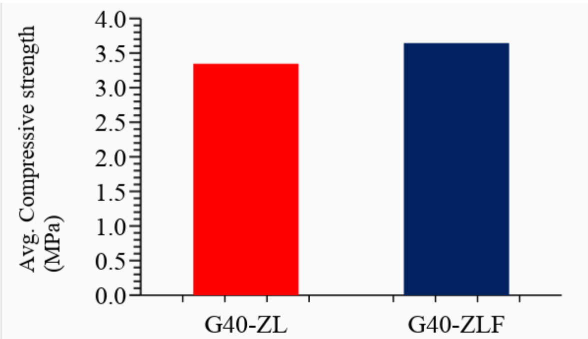

Fig. 9. Compressive strength results due to fibre addition

As a result, the best mixes according to the compressive strength test were BLF & G40-LF (Fig. 10). From the results, it can observed that the compressive strength of CEB obtained by adding lime to soil is higher than that obtained by adding volcanic tuff or by adding both lime and volcanic tuff together. This compressive strength is gained by the hydration, pozzolanic reaction between the lime and soil, and the increased potential of exchangeable cations calcium provided by lime [47,49].On the other hand, the inclusion of a partial lime replacement material such as nature pozzlana thus appears to be an effective mode of increasing the compressive strength of blocks [45], but this not happened in our research where the introducing of volcanic tuffs produced lower compressive strength values. The reason is that in the presence of lime and pozzolana (volcanic tuff) reactions take place at low and slow rate [49,50,51]. Consequently, volcanic tuff can produce favourable compressive strengths at later ages and this is a point of interest in the future work.

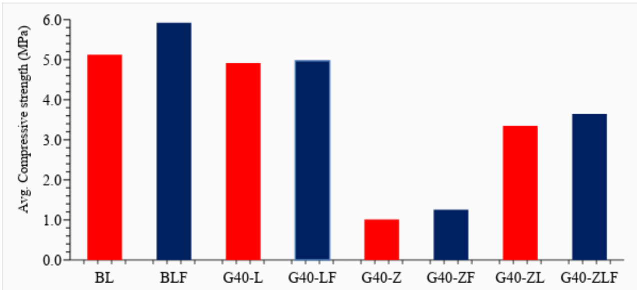

Fig. 10. Compressive strength results for all mixes

3.2. Flexural strength test

Similar to compressive strength test, three (300×150×108 mm) specimens for each mix were tested for the flexural strength. Table 5 shows all information and results of this test. The addition of fibre improves the flexural strength of BLF mix comparing to BL by about 78% with an average value of 0.2 MPa (Fig. 11). G40-L mix gives a flexural strength higher than BL mix by about 300%, while the addition of fibres increases it 0.04 MPa (Fig. 12).

Table 5.
Information and results for flexural strength test

Type of specimen \ Details of specimen	Specimen dimensions, mm	Number of specimens	Avg. dry weight, g	Avg. density, Kg/m^3	Avg. maximum load, KN	Avg. flexural strength, MPa	Standard deviation
BL	300×150×108	3	6918	1423	0.4	0.11	0.06
BLF		3	7135	1468	0.9	0.20	0.01
G40-L		3	8025	1651	1.6	0.37	0.08
G40-LF		3	7881	1621	1.9	0.42	0.06
G40-Z		3	7612	1566	-	Failed	-
G40-ZF		3	7677	1579	-	Failed	-
G40-ZL		3	7853	1615	0.97	0.21	0.02
G40-ZLF		3	8107	1668	1.1	0.24	0.04

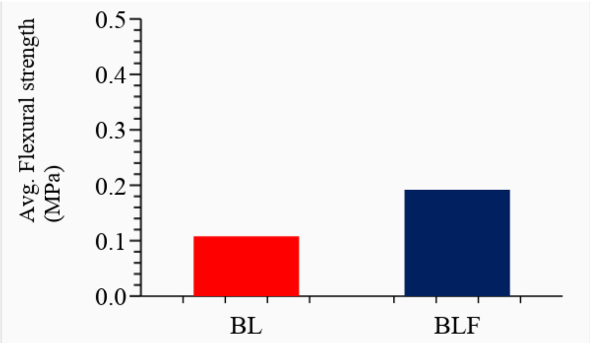

Fig. 11. Flexural strength results due to fibre addition

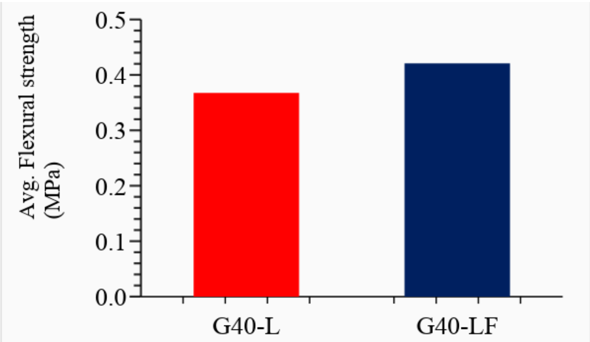

Fig. 12. Flexural strength results due to fibre addition

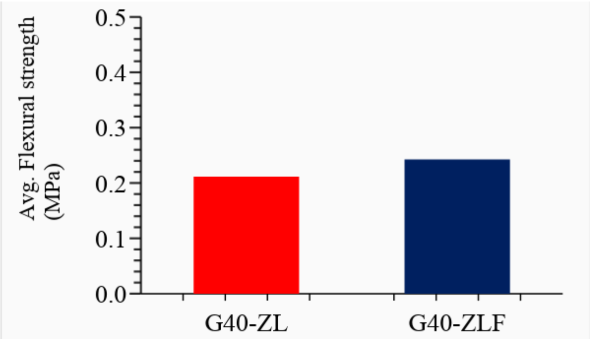

Fig. 13. Flexural strength results due to fibre addition

G40-Z mix samples have been totally failed in this test with no results were recorded for the three samples. This is an indication of the weakness of this mix sample to resist flexural forces. Also, the addition of fibre in this mix didn't work as expected. This mix was failed in the flexural strength test. The G40-ZL mix gives an average flexural strength around 0.212 MPa. And by using fibre, the flexural strength was improved by about 15%, up to 0.243 MPa (Fig. 13). As a result, the best mix according to the flexural strength test was the lime stabilized mix with sand addition and fibre G40-LF (Fig. 14).

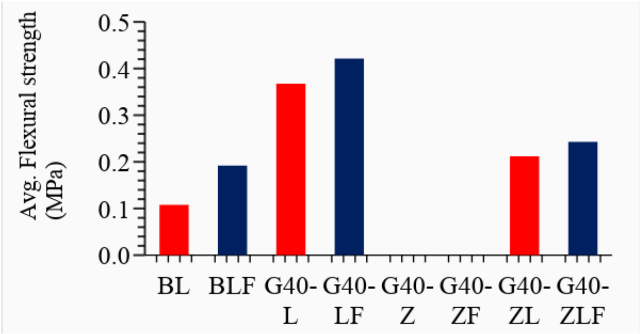

Fig. 14. Flexural strength results for all mixes

The addition of volcanic tuff as a stabilizing material has a little effect on the mechanical properties of CEB in spite of the reasons that pushed the authors to think that this stabilization method may be interesting according to the chemical composition of the volcanic tuff, the controlling percent was the silicon dioxide (SiO_2) referring to x-ray fluorescence test (XRF), with a 34.4% by weight [52]. Treatment of clayey soil with SiO_2 improves the bonds and interlocking forces between its particles. Also, this process produces a viscous gel fills the gap between clay particles and blocks the mitigation of water in the soil. As a result, the compressive strength of the clayey soil was increased by increasing the SiO_2 content [53].

3.3. Absorption test

Three (300×150×108 mm) specimen for each mix was tested; the results are presented in Table 6.

The BL mix specimen has failed in this test. The block was damaged immediately after being placed in the water (Fig. 15). The BLF mix has been successfully tested and gives a moisture content of 21.9% while G40-L mix gives a lower value for about 21.36%. The addition of fibre reduces the moisture content about 0.22%, up to 17% in G40-LF.

Fig. 15. BL mix specimen after getting out of water

Table 6.
Information and results for water absorption test

Type of specimen \ Details of specimen	Specimen dimensions, mm	Number of specimens	Avg. moist weight, g	Avg. dry weight, g	Avg. moisture content, %	Standard deviation
BL	300×150×108	3	-	-	Failed	-
BLF		3	8707	7143	21.9	1.19
G40-L		3	9460	8070	17.2	0.96
G40-LF		3	9703	8293	17.0	0.92
G40-Z		3	-	-	Failed	-
G40-ZF		3	-	-	Failed	-
G40-ZL		3	9648	7748	24.5	1.26
G40-ZLF		3	9837	7970	23.4	1.22

Table 7.
Information and results for durability test

Type of specimen \ Details of specimen	Specimen dimensions, mm	Number of specimens	Pitting depth, mm	Erodibility index	Moisture depth, mm
BL	300×150×108	3	0	2	60
BLF		3	0	2	60
G40-L		3	0	2	60
G40-LF		3	0	2	60
G40-Z		3	16	5	60
G40-ZF		3	16	5	60
G40-ZL		3	0	2	100
G40-ZLF		3	0	2	100

G40-Z & G40-ZF was totally damaged and failed in the absorption test, because the specimens were crumbled after putting it in the water while G40-ZL mix gives a value of 24.52%. The addition of fibre reduces the moisture content for about 1%. As a result, the best sample in the absorption test, with the least absorption percent was the G40-LF by a 17% of moisture content (Fig. 16).

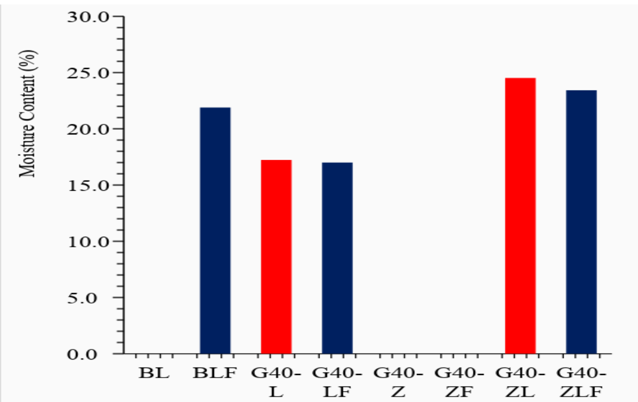

Fig. 16. Moisture content results for all mixes

3.4. Durability test

The results of this test on the compressed earth blocks with a dripping time fixed to 34 minutes are shown in Table 7.

The BL, BLF, G40-L & G40-LF mixes have the same pitting depth of 0 mm, and a moisture depth of 60 mm, which are considered as a very good samples that could be used in an external wall. The G40-Z & G40-ZF have the same results of 16 mm pitting depth, and 60 mm moisture depth which is considered as failed samples [40]. The last two mixes are G40-ZL & G40-ZLF, which gives the same results of 0 mm pitting depth, and 100 mm moisture depth. As a result, the mixes which contain lime show the lowest pitting and moisture depths.

4. Conclusions

The main objective of this research aimed to evaluate through experiments the durability and mechanical properties of compressed earth blocks CEB stabilized using lime, fibre and volcanic tuff. Based on the results of this experimental work, the following conclusions could be summarized:

- The local soil without any addition (B) indicates the non-suitability of the soil for compressed earth block production due to the extensive shrinkage cracks which appears immediately after the compaction process.
- The compressive strength of CEB stabilized using lime give better strength when compared to CEB stabilized by volcanic tuff or stabilized with lime and volcanic tuff together.
- The using of volcanic tuff with lime gives average values of mechanical properties, either using it with soil in the absence of lime gives weak mechanical properties and durability.
- Presence of lime – volcanic tuff reactions takes place at low and slow rate, which made early strength weak but the effect of volcanic tuff can appear in later ages.
- The addition of fibre to all mixes improves the compression strength and it also improves flexural strength greatly.
- The CEB stabilized by lime (G40-LF) and stabilized by lime and volcanic tuff (G40-ZLF) has been successfully tested in absorption Test.
- In erosion test, CEB stabilized by lime (G40-LF) have the pitting depth of 0 mm, and a moisture depth of 60 mm, which are considered as a very good samples and CEB stabilized by lime and volcanic tuff (G40-ZLF) gives the results of 0 mm pitting depth, and 100 mm moisture depth which are considered as a good samples.

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