

TOWARDS UNCONFINED COMPRESSIVE STRENGTH OF CEMENT STABILIZED MASONRY BLOCKS – EXPERIMENTAL STUDY

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Abstract

Cement stabilized masonry blocks (CSMB) prepared using brick powder (BP) and fine recycled concrete aggregate (FRCA) with 8% cement as stabilizer are considered as sustainable building material. Nevertheless, the geometry of the units has a significant effect on the compressive strength due to platen restraint. To arrive at unconfined compressive strength, an experimental study has been performed on both CSMB units (by varying the aspect ratio), as well as on masonry triplets. CSMB units of size 190X90X90mm and 290X90X90mm conforming to IS 1725:2013 were casted and tested in horizontal and vertical orientation. The compressive strength of 190X90X90mm is higher than that of 290X90X90mm in horizontal orientation even though the aspect ratio remains 1. The compressive strength decreases when it is tested in vertical orientation with increase in the aspect ratio. To reduce friction, 2mm thin rubber films were introduced, which reduced compressive strength by 39%. The compressive strength of the CSMB units was also assessed as per the RILEM recommendations 164. The compressive strength is similar to that of the CSMB units of size 190X90X90mm, when tested in vertical orientation. Further to affirm this, a masonry triplet of height 290mm were tested, and the results are found to be very close to those of the CSMB units of size 290X90X90mm, when tested in vertical orientation. The study concludes that, CSMB units capped with rubber film and the RILEM test procedure is more appropriate method to arrive at unconfined compressive strength.

Keywords: Cement stabilized masonry blocks (CSMB), Aspect ratio, unconfined compressive strength, RILEM recommendations 164.

1.Introduction

Construction and Demolition (C&D) waste is generated in the construction, maintenance and disposal phases of a building as well as razing down of buildings due to natural and manmade disasters. It is universally accepted that the sustainable preference of handling C& D waste should be based on golden 4R's rule – Reduce, Reuse, Recycle and Recover before final disposal. C& D waste is mainly consist of concrete and brick masonry waste. Concrete waste can be processed and recovered as coarse recycled aggregate and fine recycled aggregate and it is used in production of recycled aggregate concrete. Recycling of the brick masonry waste has drawn least importance in production of concrete. Few experimental studies were carried out in the literature highlighted the drawbacks of using brick masonry waste as aggregates in concrete [1–7]. C L Wong et al suggested using 20% of brick dust as partial replacement for cement in concrete and mortar [8]. Sadek explored the possibility of preparing of solid cement bricks of different grades using brick masonry waste [9]. Vinay Kumar et al conducted a detailed experimental studies of using brick masonry waste as a resource in the manufacturing of the cement stabilized masonry blocks (CSMB). These studies highlighted the possibility of using brick masonry waste in a granular form with cement as a stabilizer [10, 11]. The study also highlighted the effect of the geometric of the specimens on the compressive strength, due to confinement produced by the friction of the steel plates.. Hence in view of this; an experimental study is designed to arrive at unconfined compressive strength for the CSMB units.

2.Literature review

Many international standards such as British Standard, European Standard, Australia and New Zealand standards consider the effects of the geometry on the compressive strength of the bricks [12, 13, 14, and 15]. The geometric correction factors are applied to the compressive strength based on its aspect ratio. The RILEM Technical Committee 164 has proposed the test set-up to arrive at unconfined compressive strength of the blocks. The blocks were made into two equal halves and bonded using an earth mortar bed. The specimens are also capped with the neoprene layer to facilitate the uniform transfer of stress between platens and blocks. The Teflon sheet is also used between the specimen and platen to minimize friction [12]. It is inferred that, the RILEM procedure is considered as most suitable testing method to arrive at unconfined compressive strength of the earth blocks.

Several studies were also carried out in the literature to ascertain the effect of friction on the compressive strength of the masonry units. *P.Walker* reviewed the test procedures to assess the compressive strength of earth blocks. According to him, the compressive strength of the earth blocks is closely related to unit aspect ratios. The correction factors, which were established for fired clay and concrete masonry, seem to be applicable for cement stabilized pressed earth blocks [14]. *G. Bei & I. Papayianni* evaluated the compressive strength of the earth block masonry using specimens of different geometrical aspect ratio. The mode of failure in compression of the earth blocks is dependent on the test method and the geometric aspect ratio plays a significant role on compressive strength of the blocks [15]. *J C Morel et al.* outlined the current methodologies used to determine compressive strength of earth blocks. They suggested that, the further research work is required to conclude the effects of geometrics on compressive strength of the blocks [16]. A

Fodi analyzed the various factors affecting the compressive strength of a clay brick. The study concluded that the specimen height has significant effect on the compressive strength [17]. *J. E. Aubert et al.* studied the compressive strength of four different brick specimens by varying several parameters. The results affirmed to transform the bricks as little as possible before the test and thus to test entire bricks[19]

3 Materials and Methods

3.1 Physical properties of materials

Brick powder (BP) and Fine recycled concrete aggregate (FRCA)

BP and FRCA along with cement as stabilizer are used throughout the experimental study. BP are procured from the dump yard and it is processed through Los angelas abrasion testing machine, whereas FRCA is procured by crushing tested concrete cubes in the laboratory. Both BP and FRCA are sieved through 2.36mm IS sieve. The tests of BP and FRCA are carried out as specified in IS 2386-1963 [20] and the results are given in Table

Table 1 BP and FRCA test results

Tests	BP	FRCA
Specific Gravity	2.35	2.45
Fineness Modulus	2.45	3.18

3.1.2 Cement

The cement of 53 grade is used in the study, and it is tested as per IS 4031 [21, 22, 23, 24]. The results are tabulated in Table 2.

Table 2 Test results of Cement

Tests	Results
Standard Consistency (%)	31
Specific gravity	3.13
Fineness (%)	2.9
Initial setting time(mins)	46
Final setting time(mins)	340
Strength at 28 days (MPa)	55.86

3.2 Mix Proportions

Basic mix constitutes BP and FRCA only. BP at 70% and FRCA at 30% by weight of the basic mix are used in the experimental study [9]. To this 8% of cement and 16% of water is added to achieve dry density and wet compressive strength in excess of 1750 kg/m³ and 3.5 MPa respectively. These are minimum requirements as per IS 1725:2013[25].

3.3 Casting and curing

3.3.1 CSMB units

Two sizes; 190X90X90 and 290X90X90 conforming IS 1725:2013[25] is selected for casting of CSMB units. In both the sizes the aspect ratio remains 1, but the length of CSMB units is different. The CSMB units of both the sizes are casted by applying the compacting pressure of 3 MPa using Universal testing machine (UTM) of 1000KN capacity. Totally 36 CSMB units of 190X90X90mm size and 12 CSMB units of 290X90X90mm size are casted These specimens are demoulded after 24 hours and it is spray cured for 28 days. The process of casting of specimens is shown in Fig 1.

3.3.2 CSMB units for RILEM test

Six CSMB specimens of 190X90X90mm are subjected to the curing for a period of 15 days. Later it is cut into two halves and bonded using a cement mortar joint corresponding to the strength of 9Mpa. The thickness of the joint is around 10mm. The total height of the specimen is approximately 190mm and it is subjected to curing for next 13 days so has to have a uniform curing period of 28 days.



Fig 1 Process of Casting of Cement stabilized masonry blocks

3.3.3 CSMB Triplets

CSMB triplets with 10 mm-thick mortar joint are manufactured. For this, eighteen CSMB units of 190X90X90mm are used to prepare six masonry triplets. Three CSMB units are placed one above the other and bonded by the two cement mortar bed joint corresponding to the strength of 9Mpa. .

The thickness of the joint is around 10mm. The entire assembly is subjected to curing for next 13 days.

3.4 Testing of Specimens

3.4.1 Influence of aspect ratio

The dry density of the CSMB units are assessed as per IS 1725:2013[25], whereas the compressive strength of all the specimens are tested according to IS 3495:1976 [26]. CSMB units of size 190X90X90 and 290X90X90mm are tested in two orientations: horizontal orientation and vertical orientation so as to study the influence of aspect ratio on the strength of CSMB units. Six specimens of 190X90X90 and 290X90X90 size are tested in both horizontal orientation and vertical orientation. In horizontal orientation the aspect ratio remains unity for both sizes of CSMB units. Nevertheless, when the orientation is changed to vertical, the CSMB units of size 190X90X90mm corresponds to aspect ratio of 2.11 and the aspect ratio of 290X90X90mm is about 3.22. The testing of CSMB unit of size 190X90X90mm in horizontal and vertical orientation is shown in Fig 2

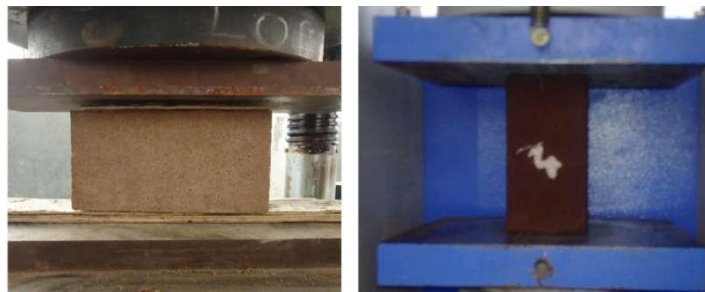


Fig 2 Testing of CSMB units of sizes 190X90X90

3.4.2 Effects of capping with rubber film

A thin rubber film (2mm) is introduced between the platens and specimen to reduce the friction between the platens and the specimen. Tests are performed on CSMB units of size 190X90X90 to study the influence of rubber film on the strength of CSMB specimens. Fig 3 represents the testing of CSMB units of size 190X90X90 by incorporating a thin rubber film at top and bottom of the specimen. Six specimens are subjected to testing, and the results are compared with the uncapped units of the same size.

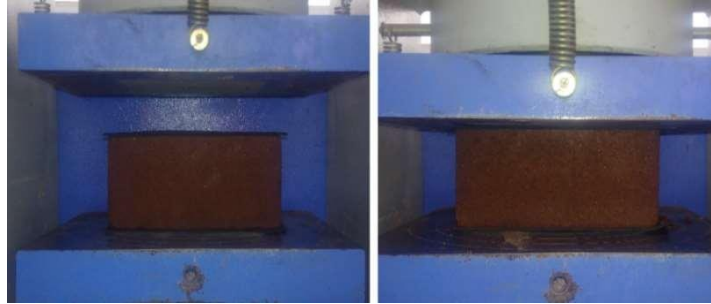


Fig 3 Testing of CSMB units by incorporating a thin rubber film

3.4.3 Compressive Strength as per RILEM test

Six CSMB specimens of 190X90X90mm are tested as per the recommendations of RILEM Technical committee 164 at 28 days of curing period.

3.4.4 Masonry Triplets

Six masonry triplets of height 290mm is tested in at 28 days. The specimens are directly placed between the platens and the load is applied to the triplets as shown in Fig 4



Fig 4 Testing of Masonry triplets

4 Results and Discussions

Table 3 shows the wet compressive strength of 190X90X90 and 290X90X90mm CSMB units, tested in horizontal orientation. The aspect ratio of both the size is 1. The strength of CSMB units of size 190X90X90mm varies from 4.63 to 6.18 MPa with average value corresponds to 5.3MPa. The strength of 290X90X90mm varied from 3.65 to 4.10 MPa with negligible standard deviation of 0.2. Comparing the test results of two sizes it can be inferred that the wet compressive

strength decreases as the length of the CSMB increased by 100mm even though the aspect ratio remains 1 in both the sizes. Further, the aspect ratio of the CSMB units is raised to 2.11 for 190X90X90mm and 3.22 for 290X90X90mm when the units are tested in vertical orientation. The test results are given in Table 4.

Table 3 wet compressive strength of CSMB units (Orientation: Horizontal)

Sl No.	190 X 90 X 90		290 X 90 X 90	
	Density (kg/m ³)	Wet Compressive Strength in MPa	Density (kg/m ³)	Wet Compressive Strength in MPa
1	1790	4.70	1963	3.72
2	1771	4.63	1950	3.77
3	1810	5.31	2039	3.65
4	1897	6.18	2005	4.10
5	1897	5.84	1920	3.96
6	1891	4.95	1958	4.05
Average	1843	5.3	1972	3.9
Standard deviation	58.9	0.6	42.6	0.2
Max	1897	6.18	2039	4.10
Mini	1771	4.63	1920	3.65

Table 4 Wet compressive strength of CSMB units (Orientation: Vertical)

Sl No.	190 X 90 X 90 (Aspect ratio=2.11)		290 X 90 X 90 (Aspect ratio=3.22)	
	Density (kg/m ³)	Wet Compressive Strength in MPa	Density (kg/m ³)	Wet Compressive Strength in MPa
1	1858	5.06	1831	2.49
2	1849	5.02	1988	2.64
3	1858	4.02	1967	2.7
4	1806	4.69	1928	2.6
5	1800	4.44	2009	2.73
6	1910	5.11	2005	2.79
Average	1847	4.72	1955	2.7
Standard deviation	40.4	0.4	67.7	0.1
Max	1910	5.11	2009	2.79
Mini	1800	4.02	1831	2.49

The average compressive strength of 190X90X90mm CSMB units with aspect ratio of 2.11 is about 4.72 Mpa with a standard deviation of 0.4. The aspect ratio of 290X90X90mm units is 3.22 and its corresponding strength is 2.7 Mpa with standard deviation of 0.1. From this, it is concluded that, increase in aspect ratio of the masonry units tends to decrease compressive strength.

4.2 Effects of capping with thin rubber film

Table 5 shows the wet compressive strength of CSMB units, when it is capped with rubber film (2 mm thick) and compared with the results of CSMB units when it is left uncapped. The test results of 190X90X90mm without capping are taken from Table 3. The effects of the capping (using 2 mm rubber film) are significant as the compressive strength reduced to 3.8MPa from 5.3 MPa. Nearly 30% of compressive strength is reduced as it when the rubber was introduced between the platens. This increases the compressive strength artificially, due to confinement effect.

Table 5 Wet Compressive strength of CSMB units of size 190X90X90mm (With and without capping)

SL No.	Without Capping		With Capping	
	Density (kg/m ³)	Wet Compressive Strength in MPa	Density (kg/m ³)	Wet Compressive Strength in MPa
1	1790	4.70	1943	3.21
2	1771	4.63	1878	3.67
3	1810	5.31	1995	4.50
4	1897	6.18	1956	3.97
5	1897	5.84	1943	3.84
6	1891	4.95	1949	3.61
Average	1843	5.3	1944	3.8
Standard deviation	58.9	0.6	37.8	0.4
Max	1897	6.18	1995	4.50
Mini	1771	4.63	1878	3.21

4.3 Compressive strength as per RILEM test

The density and the compressive strength of the CSMB units are tested as per the RILEM recommendations 164 and the results are given in Table 6. The aspect ratio of the specimen is similar to that of the aspect ratio of 190X90X90mm, when it is tested in vertical orientation. The average compressive strength of CSMB units is found to be 3.5Mpa, which is 25% lower than the 190X90X90mm units with the same aspect ratio. This is due to presence of the mortar joint that modifies the behaviour of the masonry unit. The mortar joint is considered to be weaker and less stiff than the CSMB units [19].

4.4 Strength of the Masonry Triplets

The density and strength of the masonry triplets are given in Table 7. The compressive strength of the triplets corresponds to 2.92 Mpa with standard deviation of 0.16. The masonry efficiency (masonry strength/brick strength) of the CSMB units is found to be 0.55. The aspect ratio of the triplets is similar to that of 290 X 90 X90mm units, when it is tested in vertical orientation. It is observed that, a marginal increase in the compressive strength of masonry triplets as compared to the CSMB units of same aspect ratio. This attributes a strong relationship exists between the strength and geometric aspect ratio of the masonry units also.

Table 6 Test Results of CSMB units as per RILEM recommendations 164

SI NO.	90 X 90 X190 (Aspect ratio = 2.11)	
	Density (kg/m ³)	Wet Compressive Strength in Mpa
1	1841	3.42
2	1790	3.37
3	1810	3.55
4	1843	3.49
5	1910	3.65
6	1895	3.48
Average	1848.2	3.50
Standard deviation	46.8	0.1
Max	1910	3.65
Mini	1790	3.37

Table 7 Test Results of Masonry Triplets

SI No.	90 X 190 X290 (Aspect ratio=3.22)	
	Density (kg/m ³)	Wet Compressive Strength in MPa
1	1781.8	2.99
2	1798.2	2.85
3	1748.9	3.18
4	1798.2	2.88

5	1756.2	2.71
6	1809.2	2.91
Average	1782.1	2.92
Standard deviation	24.6	0.16
Max	1809.2	3.18
Mini	1748.9	2.71

4. Conclusions

The experimental study resulted in following conclusions:

- i. The wet compressive strength of CSMB units of size 190X90X90mm varies from 4.63 to 6.18 MPa with average value corresponds to 5.3MPa. The strength of 290X90X90mm varied from 3.65 to 4.10 MPa with negligible standard deviation of 0.2. Comparing the test results of two sizes it can be inferred that the wet compressive strength decreases as the length of the CSMB increased by 190 to 290mm even though the aspect ratio remains 1 in both the sizes. The increase in the area of the CSMB units has significant effect on the compressive strength.
- ii. The average compressive strength of 190X90X90mm CSMB units with aspect ratio of 2.11 is about 4.72 Mpa with a standard deviation of 0.4. The aspect ratio of 290X90X90mm units is 3.22 and its corresponding strength is 2.7 Mpa with standard deviation of 0.1. From this, it is concluded that, increase in aspect ratio of the masonry units tends to decrease compressive strength.
- iii. Incorporating 2mm rubber film between platen is significant as the compressive strength reduced to 3.8MPa from 5.3 MPa. Nearly 30% of compressive strength is reduced as it when the rubber was introduced between the platens. This increases the compressive strength artificially, due to confinement effect.
- iv. The RILEM test procedure recorded 25% lower compressive strength than the compressive strength of 190X90X90mm units with the same aspect ratio. This is due to presence of the mortar joint that modifies the behaviour of the masonry unit.
- v. The compressive strength of the triplets corresponds to 2.92 Mpa and the masonry efficiency of the CSMB units is found to be 0.55. A marginal increase in the strength of masonry triplets is observed as compared to the CSMB units of same aspect ratio.

5. Statements and Declaration

On behalf of all authors, the corresponding author declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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