STRENGTH, SUSTAINABILITY AND CONSTRUCTION SUITABILITY OF LIGHTWEIGHT CONCRETE BLOCKS MODIFIED WITH AIR-ENTRAINING AGENT AND CERAMIC POWDER

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DOI: https://doi.org/10.5281/zenodo.21254784

Keywords
Air entraining agent, AE192, Ceramic powder, Compressive strength, Concrete blocks, Fly ash, Lightweight masonry, Sustainability

Article History
Received: 25 April 2026
Accepted: 04 June 2026
Published: 21 June 2026

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Abstract
This study investigates the use of air -entraining agent (AE192), fly ash and ceramic powder in lightweight concrete blocks as sustainable alternatives to locally available first-class bricks. A 1:2:4 cement: sand: coarse aggregate mix was prepared with 20% fly ash replacement and ceramic powder as fine material replacement with AE192 dosages of 5%, 8%, and 10%. Specimens were tested for strength, weight loss and suitability for construction at 7, 14 and 28 days. The control mix attained the maximum compressive strength while the 5% AE192 mix showed the best balance by retaining approximately 90.7% of the control strength in Sample 1 at a reduced weight and achieving around 19.0% weight reduction in Sample 2. Higher AE192 dosages showed higher strength loss but better lightweight performance, thus being more suitable for non-load-bearing and insulation applications. The sustainability potential of the ceramic-powder modified blocks was improved and the 10% ceramic/AE192 mix performed better than the 8% ceramic/AE192 group retaining about 93.4% of the Sample 2 control strength. The strength of the first-class bricks was competitive, but the proposed blocks provide better circular-material benefits by using fly ash and ceramic waste. 5% AE192 is recommended for semi-structural lightweight blocks, while 8–10% AE192 mixes are suitable for non-load bearing sustainable masonry applications.

1. INTRODUCTION

Construction masonry units continue to be the backbone of residential, commercial and institutional buildings providing ease of production, modular placement and acceptable structural behavior. Although masonry construction has traditionally been dominated by locally available bricks, their production is energy intensive, and dependent on the extraction and firing of natural clay. In contrast, concrete blocks can be designed through mix design, curing control and use of supplementary cementitious materials to achieve specific combinations of strength, density, workability and environmental performance [1-5]. The demand for lighter and more sustainable masonry units has grown as reduced dead load can simplify handling, decrease the effort of transportation and increase construction productivity. Particular interest attaches to fly ash and ceramic powder. Fly ash pozzolanic reactions contribute to long term densification. Waste ceramic products can be used as a filler as well as reactive fine material and hence improve packing density and reduce the dependency on natural sand [6-10]. These materials also divert industrial and construction waste from disposal streams and enable circular-material construction.

Air entrainment using AE192 results in well-controlled microscopic voids in the cementitious matrix. These voids can improve workability, lower density, and possibly improve durability in environments where the internal pore pressure is of concern. However, air voids also disrupt the load-carrying skeleton of concrete and excess entrainment can reduce compressive strength. The technical problem is to find an AE192 content which reduces the mass without the block being weakened beyond its intended construction use [11]. The novelty of this research is in developing AE192-modified lightweight concrete blocks using locally available constituents and waste-derived supplementary materials and then evaluating them by an integrated strength-weight-sustainability comparison with conventional first-class bricks. Previous research has mainly focused on specific aspects of masonry performance. Muneron et al. studied the environmental performance of ceramic bricks and concrete blocks [3]. Hussein et al. manufactured sustainable lightweight concrete using waste clay bricks [4]. Wang et al. investigated the preparation and performance of concrete air-entraining agents [11]. Rahmat and Saleh evaluated the strength and environmental performance of bricks made from industrial wastes [12]. Vijayan et al. reviewed the thermal performance of building bricks and blocks [13]. In contrast, this study includes AE192 dosage optimization of 5%, 8% and 10%, fly-ash and ceramic-powder addition, age-wise compressive-strength development, variation of unit-weight and direct comparison with locally available bricks in a single experimental program. The combined approach provides a practical contribution by identifying the 5% AE192 mixture as a balanced lightweight masonry option, while higher AE192 contents are more suitable for non-structural applications where reduced density, workability and sustainability are prioritised over maximum compressive strength.

The study is important because it addresses two common problems in block construction; the need to reduce the unit weight for ease of construction and the need to incorporate waste derived materials without compromising the service performance. The work provides a practical basis for the selection of masonry materials for load bearing, semi-structural and non-load bearing applications by comparing lightweight concrete blocks with bricks available locally.

Another contribution is a direct comparison of two experimental sample sets. The difference between Sample 1 and Sample 2 indicates the sensitivity of the production of lightweight concrete block to the consistency of mixing, compaction, curing and uniformity of materials. This variation is relevant for practical manufacturing, since an optimized mixture should not only perform well in isolated testing but also be reproducible in repeated production batches.

2. Materials and methods

2.1 Materials

The binder used was Bestway Ordinary Portland Cement (OPC) Grade 43. Lawrencepur sand was used as fine aggregate as it was available and gradation was suitable to produce dense concrete blocks. A crushed coarse aggregate with a nominal maximum size of 9.5 mm was selected to ensure proper packing of particles in 150 mm cube/block specimens. Fly ash was used as 20% partial replacement of cement and ceramic powder was used as waste derived fine material to increase sustainability and reduce the demand of natural aggregates.

The air-entraining admixture used was AE192. The admixture was added to obtain target air contents of 5%, 8% and 10% in three separate mixes. Test of reference masonry units was carried out with bricks of the first class from the local market. The strength and mass characteristics of the developed lightweight concrete blocks were compared with those of the bricks.

Table 1: Materials used in the experimental program and their functional role

Material	Source/level	Purpose in the study
Cement	Bestway OPC Grade 43	Primary binder and early strength contributor
Fine aggregate	Lawrencepur sand	Packing, workability, and matrix stability
Coarse aggregate	Crushed aggregate, 9.5 mm maximum size	Skeleton strength and shrinkage control
Fly ash	20% replacement of cement	Pozzolanic contribution and cement reduction
Ceramic powder	Waste ceramic powder used as fine substitute	Filler/pozzolanic contribution and waste utilization
AE192	5%, 8%, and 10% target air entrainment	Weight reduction, workability improvement, and void control
First-class bricks	Locally available bricks	Reference material for comparative evaluation

2.2 Mix design and specimen preparation

All concrete block mixtures were mixed at a 1:2:4 cement: sand: coarse aggregate ratio. Air-entrained mixes contained AE192 to achieve target air contents of 5%, 8%, and 10% while the control mix did not contain AE192. The thesis data reported the use of fly ash and ceramic powder to improve the sustainability profile of the blocks while maintaining acceptable mechanical performance.

The materials were mixed to produce a uniform concrete matrix in a proportion by mass. First the dry ingredients were mixed and then water was added slowly and admixture was added if required. Fresh concrete was poured in layers and compacted in the cube molds to minimize unwanted large voids. The specimens were de-molded at about 24 h, water cured and tested at 7, 14 and 28 days. The curing regime enabled the early-age, intermediate-age and mature strength behavior of the mixes to be compared.

Table 2: Experimental mixture groups used for block performance evaluation

Mix group	Target level	Main technical purpose
Control	0%	Baseline concrete block without AE192
AE192-5	5%	Balanced lightweight mix for strength and reduced mass
AE192-8	8%	Higher air content for lighter blocks and improved handling
AE192-10	10%	Maximum studied entrainment level for non-structural/lightweight use
Ceramic-8	8% ceramic/AE192 group	Sustainable ceramic-powder modified block
Ceramic-10	10% ceramic/AE192 group	Higher ceramic-powder modified block

2.3 Testing methods

Experiments included fresh workability tests, determination of the density of the materials and compressive strength tests. Material was characterized through specific gravity and bulk density measurements and workability was checked through slump test. The compressive strength was calculated as the load at failure divided by the load bearing area as shown in Eq. (1).

$$f_c = P / A \quad (1)$$

where fc is compressive strength, P is the maximum applied load, and A is the loaded area. Weight reduction was calculated relative to the control specimen at the same curing age, as expressed in Eq. (2).

$$\text{Reduction } (\%) = \frac{(W_{control} - W_{mix})}{W_{control}} \times 100 \quad (2)$$

The tabulated results were presented in figures sample-wise for comparison of influence of curing period and AE192 dosage. As the same mix family was tested on two different sets of samples, the analysis also takes into account repeatability and batch sensitivity.

3. Results and discussion

3.1 Strength and weight development in Sample 1

Sample 1 showed the most obvious trend of strength development. The control mixture increased from 1227.78 psi at 7 days to 2030.56 psi at 28 days. This verifies the maximum load-carrying capacity of non-air-entrained matrix. The 5% AE192 mixture also exhibited the ability to develop strength effectively, from 633.33 psi to 1841.67 psi in the same curing interval. The 5% mixture retained approximately 90.7% control strength at 28 days with a lower measured mass. This response indicates that the optimal dosage in Sample 1 is 5% AE192.

The 8% and 10% AE192 blends demonstrated more significant loss in strength. The 8% mixture attained 1236.11 psi at 28 days and 10% mixture attained 875.00 psi. This reduction is indicative of the increased disruption of the cementitious load path due to the entrained air voids. Lighter blocks are produced with higher AE192 contents, but the decrease in strength restricts the application of the blocks for non-load-bearing or low-demand masonry.

Table 3: Compressive strength and weight results for Sample 1

Mix	7-d strength (psi)	14-d strength (psi)	28-d strength (psi)	7-d weight (lb)	14-d weight (lb)	28-d weight (lb)
Control	1227.78	1536.11	2030.56	18.03	17.77	17.20
5% AE192	633.33	1433.33	1841.67	16.62	16.05	15.74
8% AE192	700	841.67	1236.11	15.90	15.87	15.87
10% AE192	802.78	869.44	875	16.23	15.79	15.17

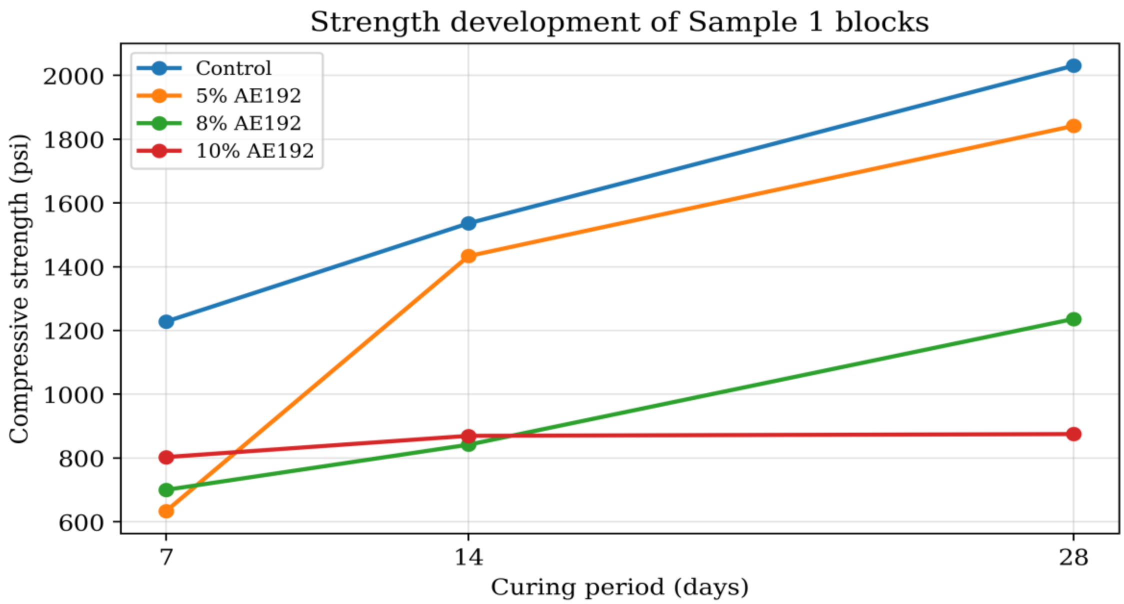

Figure 1: Strength development of Sample 1 blocks at different AE192 contents

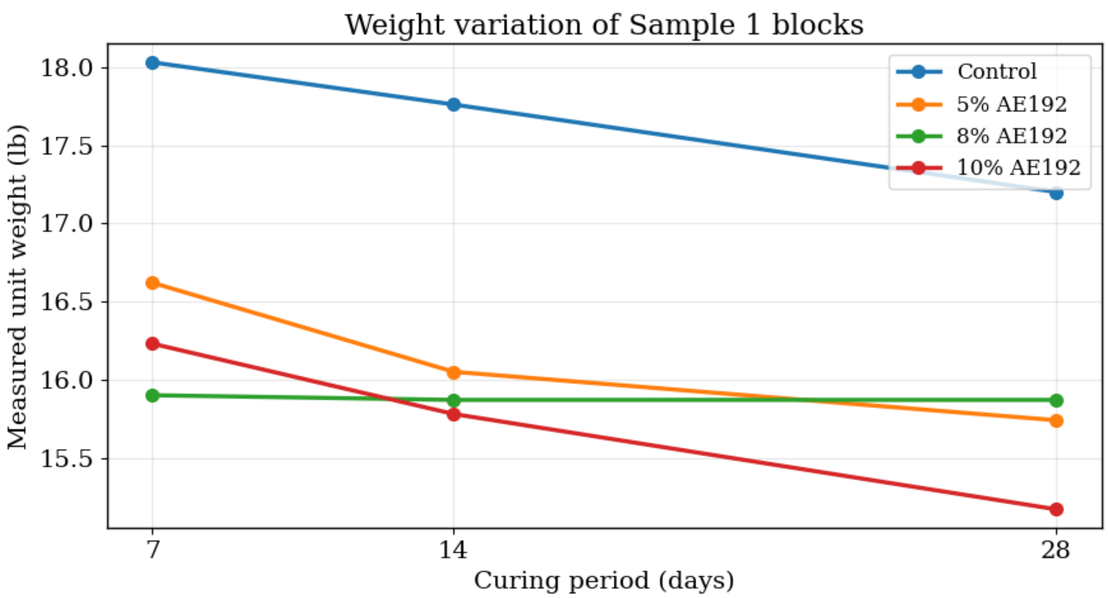

Figure 2: Weight variation of Sample 1 blocks at different AE192 contents

3.2 Strength and weight development in Sample 2

Sample 2 showed the same general pattern, but at a lower strength level. The control specimen reached 1269.44 psi at 28 days, while the 5%, 8%, and 10% AE192 mixes reached 733.33, 580.56, and 463.89 psi, respectively. This confirms that increasing the AE192 content reduced the compressive strength in both sample sets. Sample 2 was of lower magnitudes, indicating that the block production process is sensitive to batching accuracy, mixing uniformity, compaction and curing control.

Sample 2 was the most useful feature in losing weight. The average weight of the air-entrained blocks at 28 days was 14.84 lb, 14.82 lb and 14.53 lb for the 5%, 8% and 10% AE192 mixtures respectively while the weight of the control was

18.32 lb. The reduction of about 19.1-20.7% is beneficial to manual handling and transport. But the strength loss must be taken into account before using such blocks in structural masonry.

Table 4: Compressive strength and weight results for Sample 2

Mix	7-d strength (psi)	14-d strength (psi)	28-d strength (psi)	7-d weight (lb)	14-d weight (lb)	28-d weight (lb)
Control	850	1127.78	1269.44	18.34	18.25	18.32
5% AE192	527.78	608.33	733.33	14.37	15.08	14.84
8% AE192	347.22	372.22	580.56	14.11	14.33	14.82
10% AE192	244.44	286.11	463.89	14.02	13.71	14.53

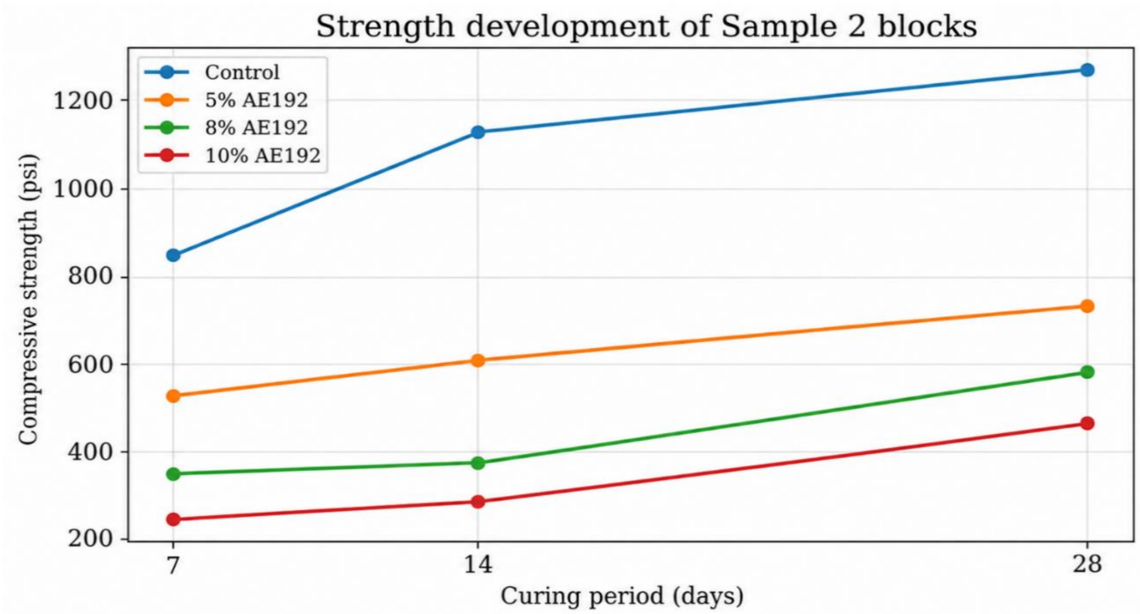

Figure 3: Strength development of Sample 2 blocks at different AE192 contents

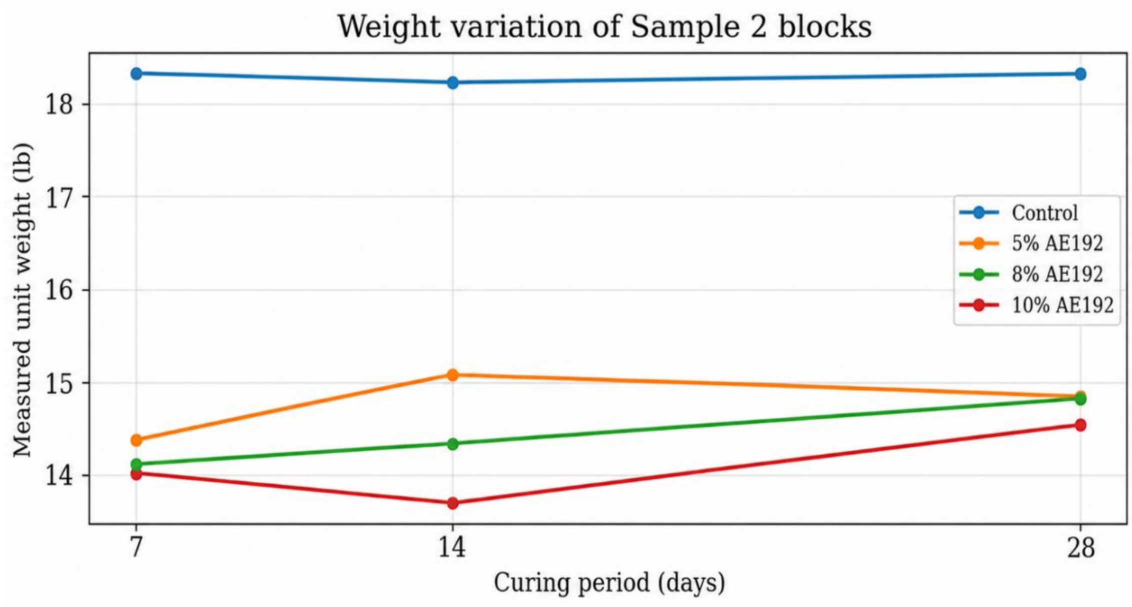

Figure 4: Weight variation of Sample 2 blocks at different AE192 contents

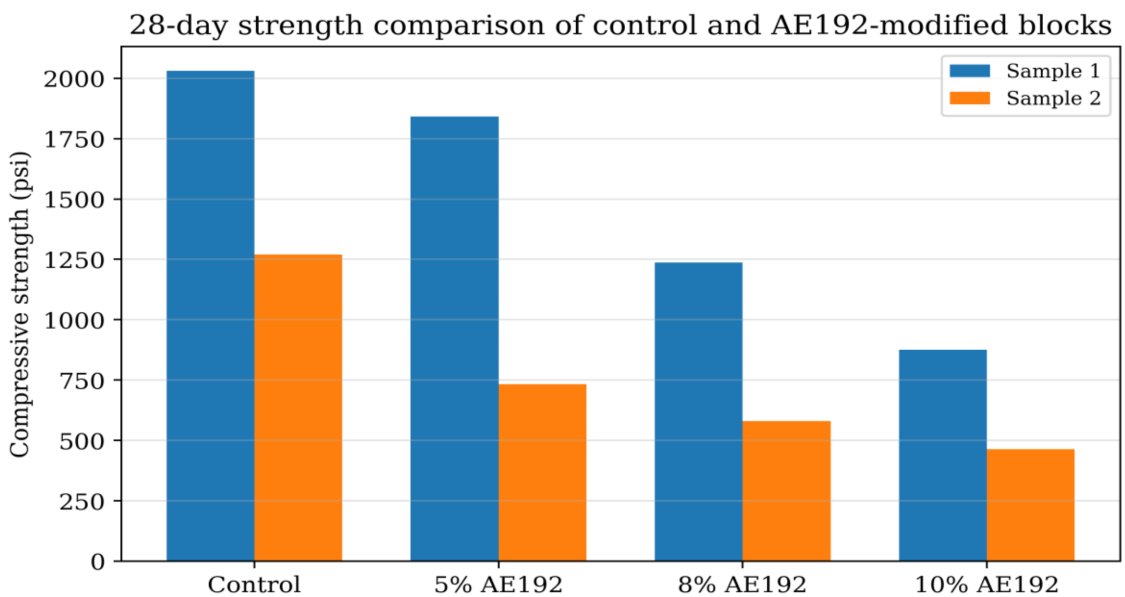

Figure 5: Comparative 28-day strength of Sample 1 and Sample 2 blocks

3.3 Effect of AE192 dosage on block performance

The effect of AE192 can be explained as a compromise between the beneficial void formation and loss of load transfer continuity. The 5% dosage of AE192 introduced sufficient air to reduce weight and improve handling, without excessively reducing the solid cementitious matrix. This is why the 5% mix in Sample 1 was close to the control strength at 28 days. However, the 8% and 10% AE192 contents resulted in higher air void content, lower density and higher stress concentrations under compression.

The findings also show that air entrainment should not be chosen on workability or weight reduction only. Among the air-entrained mixes, 5% AE192 is the best choice for structural and semi-structural applications. The 8% and 10%

mixes are suitable for non-load-bearing partitions, internal walls, facade units or uses where low density, thermal comfort and sustainability are more important than maximum compressive strength.

3.4 Performance of ceramic-powder modified blocks

Blocks modified with ceramic-powder showed a useful improvement in strength development, especially at 28 days. The 8% ceramic/AE192 group increased from 588.89 psi at 7 days to 1080.56 psi at 28 days and the 10% ceramic/AE192 group increased from 836.11 psi to 1186.11 psi. The higher ceramic group was consistently above the 8% group, which indicates that the ceramic powder was beneficial for packing matrix and it helped in the compensation of the strength loss due to air entrainment.

The 10% ceramic-powder modified mix is technically important because it combines moderate strength with improved sustainability. The reuse of ceramic waste reduces pressure on natural aggregates and supports circular construction practice. Although it did not achieve a strength greater than the best control or 5% AE192 in Sample 1, it did achieve a strength level similar to Sample 2 control block and therefore has good potential for sustainable masonry units in moderate demand applications.

Table 5: Strength and weight development of ceramic-powder modified blocks

Mix	7-d strength (psi)	14-d strength (psi)	28-d strength (psi)	7-d weight (lb)	14-d weight (lb)	28-d weight (lb)
8% ceramic/AE192	588.89	702.78	1080.56	15.63	16.36	16.09
10% ceramic/AE192	836.11	877.78	1186.11	15.67	16.14	15.87

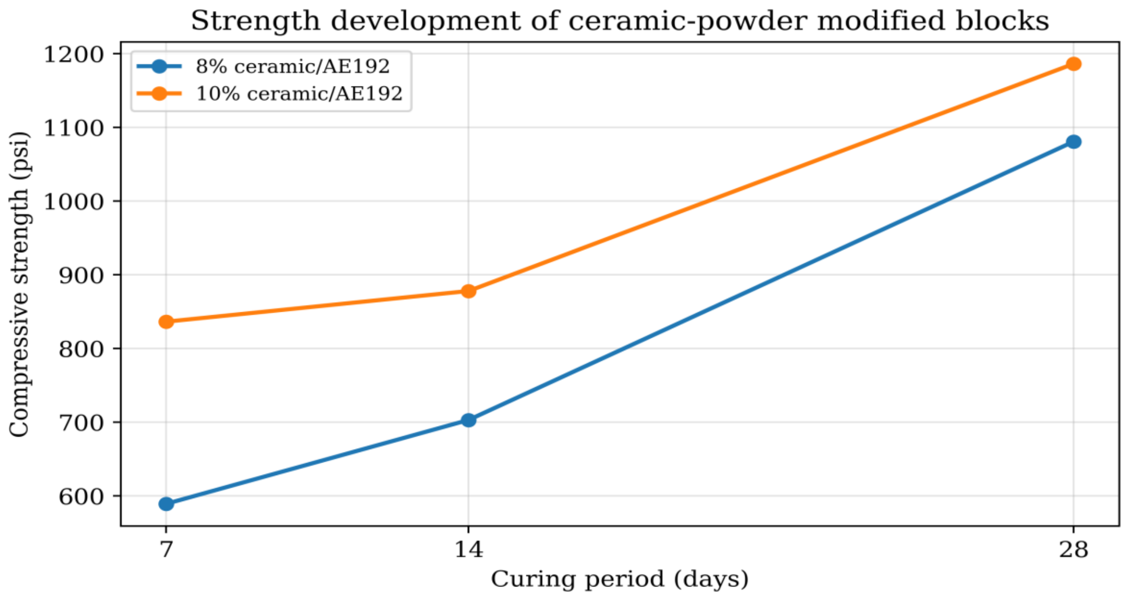

Figure 6: Strength development of ceramic-powder modified block mixes

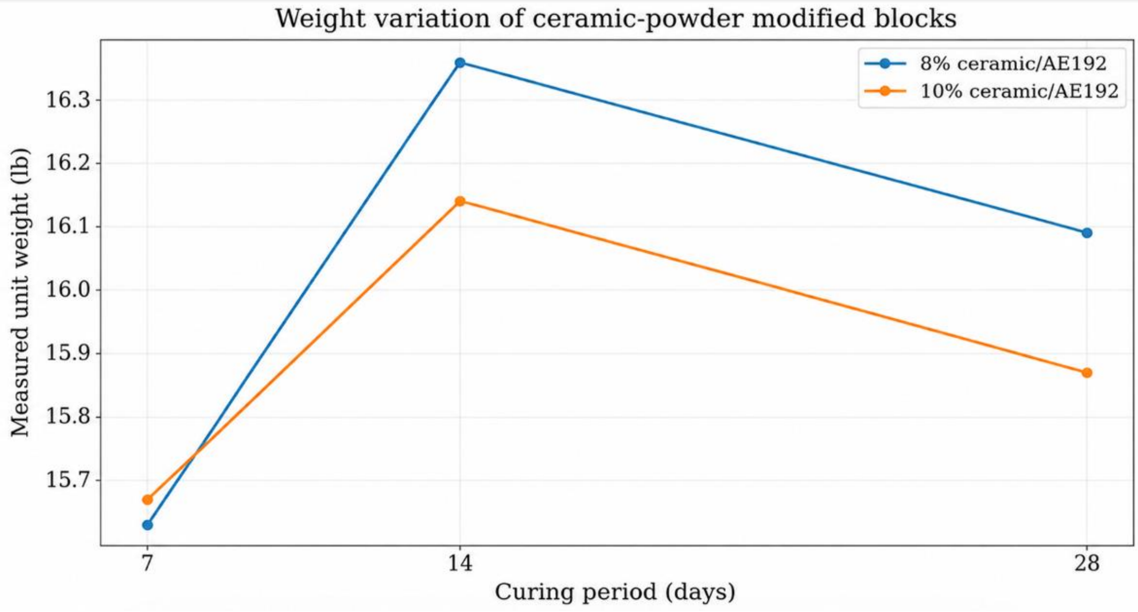

Figure 7: Weight variation of ceramic-powder modified block mixes

3.5 Comparison with locally available bricks

Locally available first-class bricks have compressive strength of 1245, 1397 and 1593 psi for brick categories 313, 7 and 94 respectively. The values obtained indicate that the performance of the brick specimens was superior to several of the lightweight block mixtures. Brick 94 was stronger than all of the Sample 2 control blocks and all of the Sample 2 air-entrained blocks, while the Sample 1 control and 5% AE192 blocks were stronger than the brick range.

The mass comparison should be done carefully, as the tested bricks and blocks have different geometries. The dry weights of bricks were lower (6.42-7.41 lb) than the concrete blocks due to the larger tested unit size of the concrete blocks. But the concrete blocks have one advantage over conventional bricks: they can include fly ash and ceramic powder. Therefore, bricks are still suitable for high-strength, traditional masonry, whereas AE192-modified blocks offer a more adaptable and sustainability-focused option for contemporary construction.

Table 6: Compressive strength and moisture results of locally available first-class bricks

Brick category	Load (lb)	Area (in²)	Strength (psi)	Wet weight (lb)	Dry weight (lb)	Moisture (%)
313	47300	9.1 x 4.2	1245	7.39	6.50	15.3
7	55300	9.0 x 4.4	1397	8.69	7.41	17.3
94	55500	8.5 x 4.1	1593	7.39	6.42	13.6

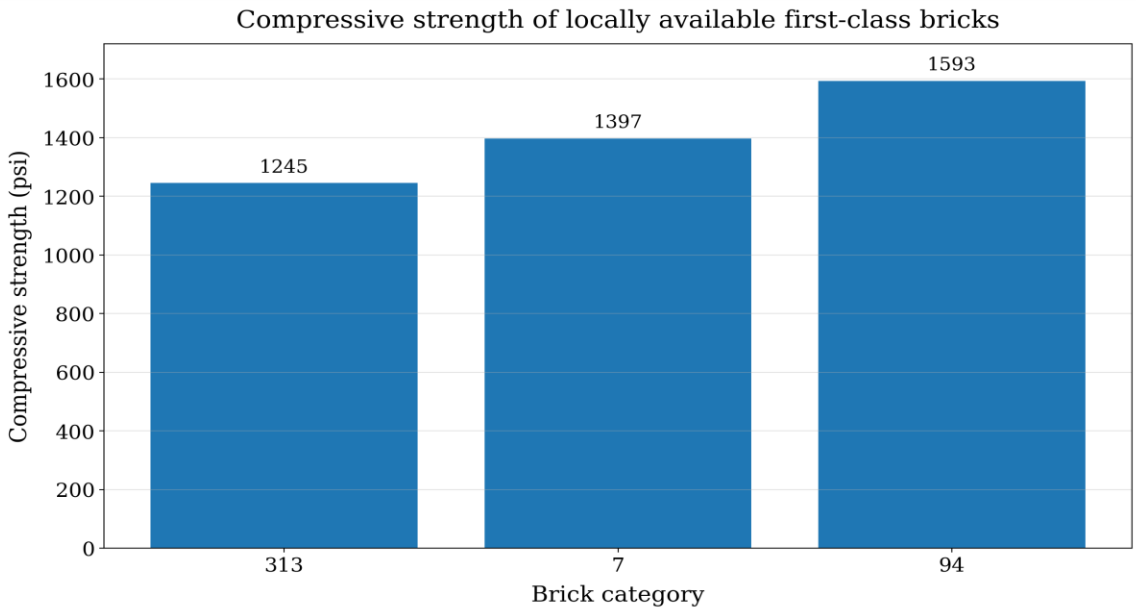

Figure 8: Compressive strength comparison of locally available brick specimens

3.6 Construction applications and technical interpretation

For compressive strength to be the major consideration, the control mixture is most appropriate, especially for those applications where higher block strength and only slight density reduction is desired. However, this combination gives limited lightweight benefit and does not fully utilize the air entrainment potential.

The 5% AE192 mix is the most well-balanced among the air-entrained mixes. It achieved 1841.67 psi at 28 days for Sample 1 and was close to the control strength, reducing the block mass. This mix is suitable for semi-structural walls, partitions, infill panels and external cladding where moderate strength, reduced handling effort and improved workability are required.

The 8% and 10% AE192 mixes are more appropriate for non-load bearing blocks. Their lesser density may allow for easier placement and could also contribute to insulation-related benefits but their lesser compressive strength rules out their recommendation as primary load-bearing masonry without additional optimisation and code-specific validation.

The modified blocks with ceramic powder are suggested for construction with sustainability perspective. The 10% ceramic/AE192 group attained 1186.11 psi at 28 days, showing that waste ceramic powder can enhance the performance of lightweight blocks. These mixes are applicable for projects with an emphasis on reduction of natural materials, reuse of waste materials and moderate strength in masonry.

The experimental results indicate that the choice between blocks and bricks is application dependent. Bricks are strong and easy to use locally, and AE192-modified concrete blocks give engineering control over density, inclusion of waste and workability. The optimized lightweight block concept provides a viable route for sustainable construction, provided that the quality of the production is strictly controlled.

4. Conclusions

The control concrete blocks showed the highest 28-day compressive strength of 2030.56 psi in Sample 1 and 1269.44 psi in Sample 2. The 5% AE192 mixture gave the most balanced performance, maintaining about 90.7% of the control strength with the reduced weight. The higher AE192 contents of 8% and 10% resulted in more strength reduction and better suited for non-load bearing, lightweight, insulation-oriented masonry applications. Ceramic-powder modified blocks showed promising potential for sustainability, with 10% ceramic/AE192 mix gained 1186.11 psi at 28 days, suggesting that ceramic waste could enhance particle packing and partially offset strength reduction associated with air-entrainment. The first-class bricks showed a competitive strength of 1245–1593 psi. The proposed concrete blocks have a better waste-utilization potential due to inclusion of fly ash and ceramic powder. In general, 5% AE192 is recommended for semi-structural lightweight blocks. 10% ceramic/AE192 for sustainable moderate strength blocks and higher AE192 mixes for non-load-bearing applications. Batching, mixing, compaction and curing must be carefully controlled.

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