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PERFORMANCE EVALUATION OF AIR-ENTRAINED CONCRETE BLOCKS INCORPORATING FLY ASH AND CERAMIC POWDER AS SUSTAINABLE ALTERNATIVES TO FIRST-CLASS BRICKS IN PAKISTAN

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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 [1-6]. 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 [7-10]. 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 AE192 content which reduces the mass without the block being weakened beyond its intended construction use [12]. 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 [12]. Rahmat and Saleh evaluated the strength and environmental performance of bricks made from industrial wastes [13]. Vijayan et al. reviewed the thermal performance of building bricks and blocks [14]. 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 prioritized 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 in this study was Bestway Ordinary Portland Cement (OPC) Grade 43. Lawrencepur sand was selected as the fine aggregate due to its availability and suitable gradation for producing dense concrete blocks. Crushed coarse aggregate with a nominal maximum size of 9.5 mm was used to ensure appropriate particle packing in the 150 mm cube/block specimens. Fly ash was incorporated as a 20% partial replacement of cement, while ceramic powder was used as a waste derived material to enhance sustainability and reduce reliance on conventional raw materials.

AE192 was used as the air-entraining admixture to achieve target air contents of 5%, 8%, and 10% in three separate mixtures. First-class bricks obtained from the local market served as reference masonry units. The compressive strength and mass characteristics of the developed lightweight concrete blocks were compared with those of the reference bricks to evaluate their relative performance and potential applications in masonry construction (Table 1).

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 prepared using a cement, sand and coarse aggregate ratio of 1:2:4. The air-entrained mixtures incorporated AE192 at target air contents of 5%, 8%, and 10%, while the control mixture contained no AE192. Fly ash and ceramic powder were also incorporated into selected mixtures to improve the sustainability of the concrete blocks while maintaining acceptable mechanical performance (Table 2).

The materials were proportioned by mass and mixed to obtain a uniform concrete matrix. The dry ingredients were mixed first, followed by the gradual addition of water and the admixture, where required. Fresh concrete was placed in layers into cube molds and compacted to minimize the formation of large voids. The specimens were demolded after approximately 24 hours and cured in water before being tested at 7, 14, and 28 days. This curing and testing procedure enabled the comparison of early age, intermediate age, and 28-day compressive strength development among the different mixtures.

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

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2.3 Testing methods

The experimental program included fresh-concrete workability tests, material density measurements, and compressive strength tests. The constituent materials were characterized by determining their specific gravity and bulk density, while fresh concrete workability was evaluated using the 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 for each sample to facilitate a comparison of the effects of curing age and AE192 dosage Since the same mixture proportions were evaluated using two separate sample sets, the analysis also considered variations in strength development, repeatability, and sensitivity to batch production conditions.

3. Results and discussion

3.1 Strength and weight development in Sample 1

Sample 1 demonstrated a clear increase in compressive strength with curing age (Table 3 and Figure 1). The control mixture increased from 1227.78 psi at 7 days to 2030.56 psi at 28 days, indicating the highest load-bearing capacity among the tested mixtures. The 5% AE192 mixture also showed substantial strength development, increasing from 633.33 psi at 7 days to 1841.67 psi at 28 days. At 28 days, this mixture retained approximately 90.7% of the control mixture's compressive strength while exhibiting a lower measured mass (Figure 2). These results suggest that 5% AE192 was the most suitable air-entraining admixture dosage for Sample 1, offering a favorable balance between compressive strength and weight reduction.

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 variation results for Sample 1

Mix	Compressive Strength			Weight Variation		
	7-day (psi)	14-day (psi)	28-day (psi)	7-day (lb)	14-day (lb)	28-day (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

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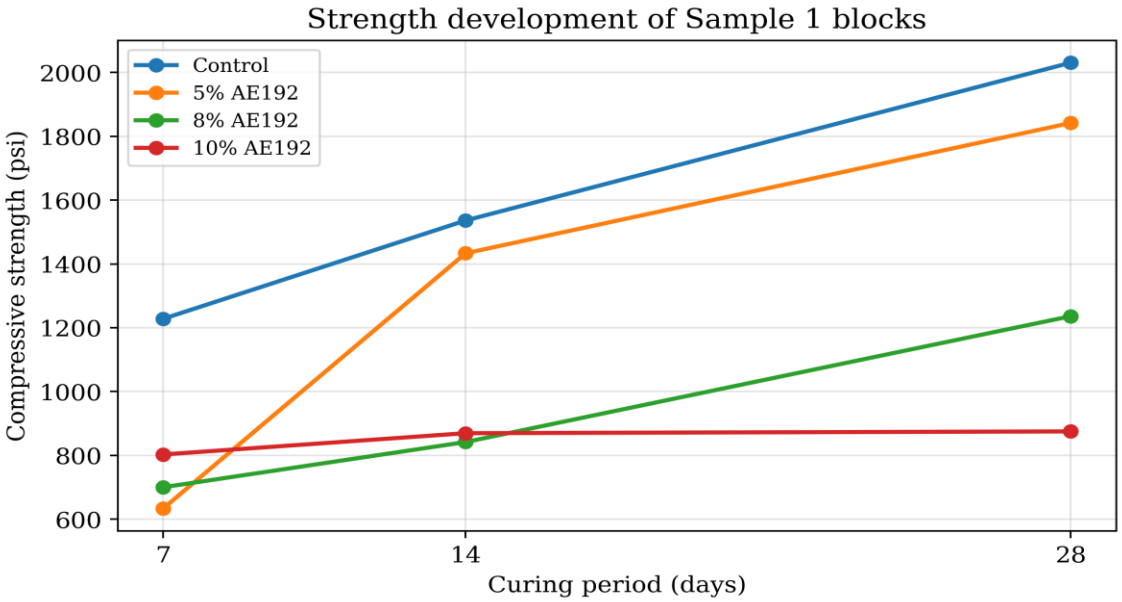


Figure 1: Strength development of Sample 1 blocks at different AE192 contents

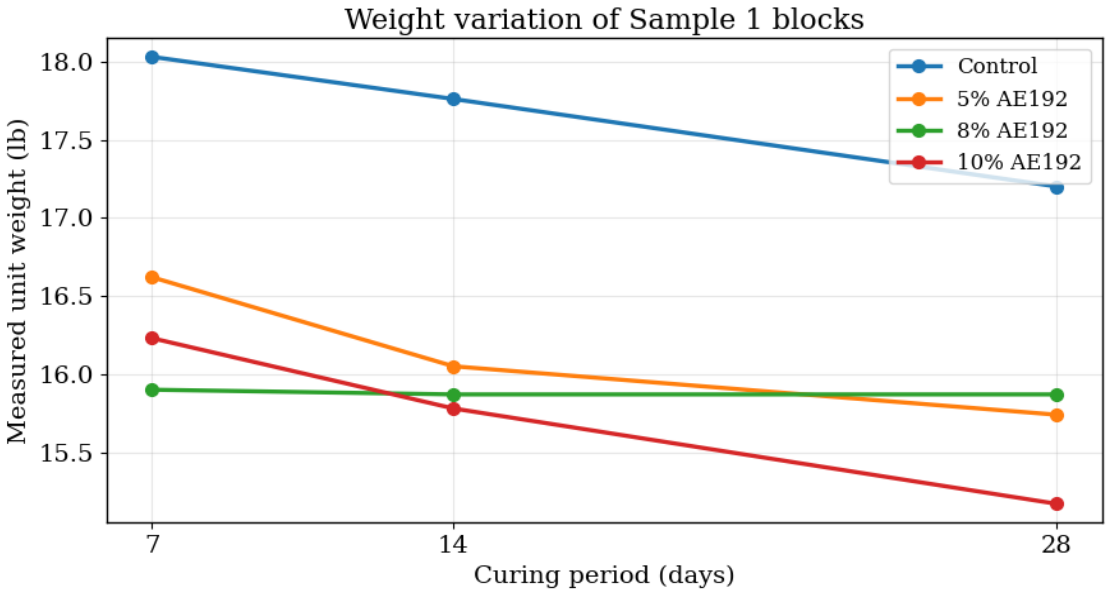


Figure 2: Weight variation of Sample 1 blocks at different AE192 contents

3.2 Strength and weight development in Sample 2

Sample 2 exhibited a similar trend in compressive strength, although the measured values were lower than those of Sample 1 (Table 4 and Figure 3). At 28 days, the control specimen achieved a compressive strength of 1269.44 psi, while the mixtures containing 5%, 8%, and 10% AE192 attained 733.33, 580.56, and 463.89 psi, respectively. These results demonstrate a progressive reduction in compressive strength with increasing AE192 content in both sample sets. The lower strength values recorded for Sample 2 also suggest variability in block production,

potentially associated with batching accuracy, mixing uniformity, compaction, and curing conditions. Consistent control of these factors is therefore essential to improve the reproducibility and mechanical performance of the developed concrete blocks.

Sample 2 demonstrated a clear reduction in block weight with the addition of AE192 (Figure 4). At 28 days, the average weights of the blocks containing 5%, 8%, and 10% AE192 were 14.84 lb, 14.82 lb, and 14.53 lb, respectively, compared with 18.32 lb for the control blocks. These values represent weight reductions of approximately 19.0%, 19.1%, and 20.7%, respectively. The lower weight can facilitate manual handling, transportation, and installation. However, these benefits must be evaluated alongside the reduction in compressive strength, particularly when considering structural masonry applications. Therefore, the suitability of these lightweight blocks should be determined according to their intended use and the applicable strength requirements. Figure 5 compares the 28-day strengths of both sample sets.

Table 4: Compressive strength and weight variation results for Sample 2

Mix	Compressive Strength			Weight Variation		
	7-day (psi)	14-day (psi)	28-day (psi)	7-day (lb)	14-day (lb)	28-day (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

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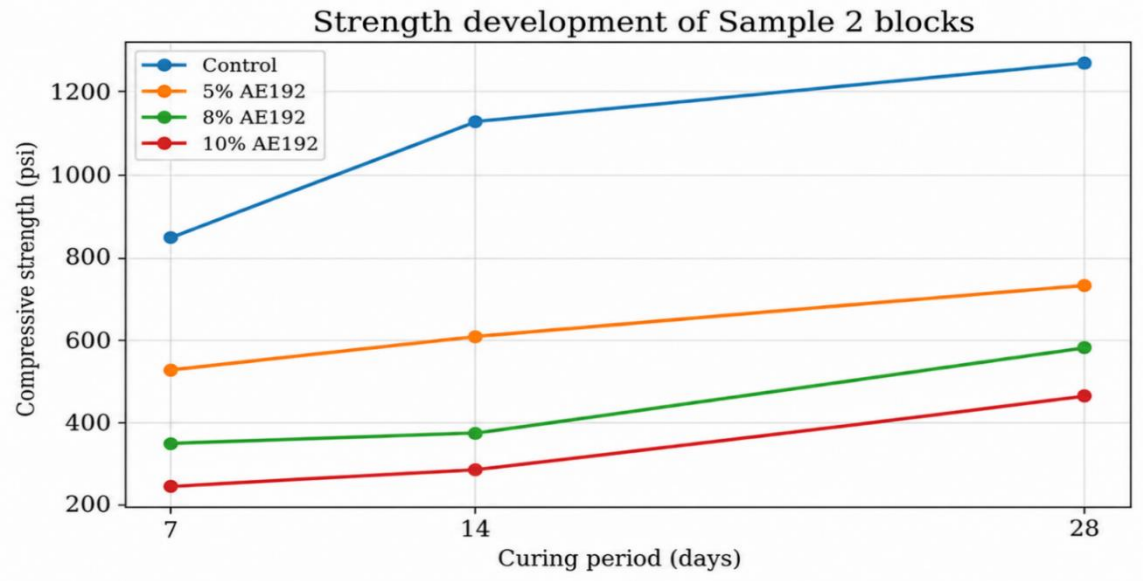


Figure 3: Strength development of Sample 2 blocks at different AE192 contents

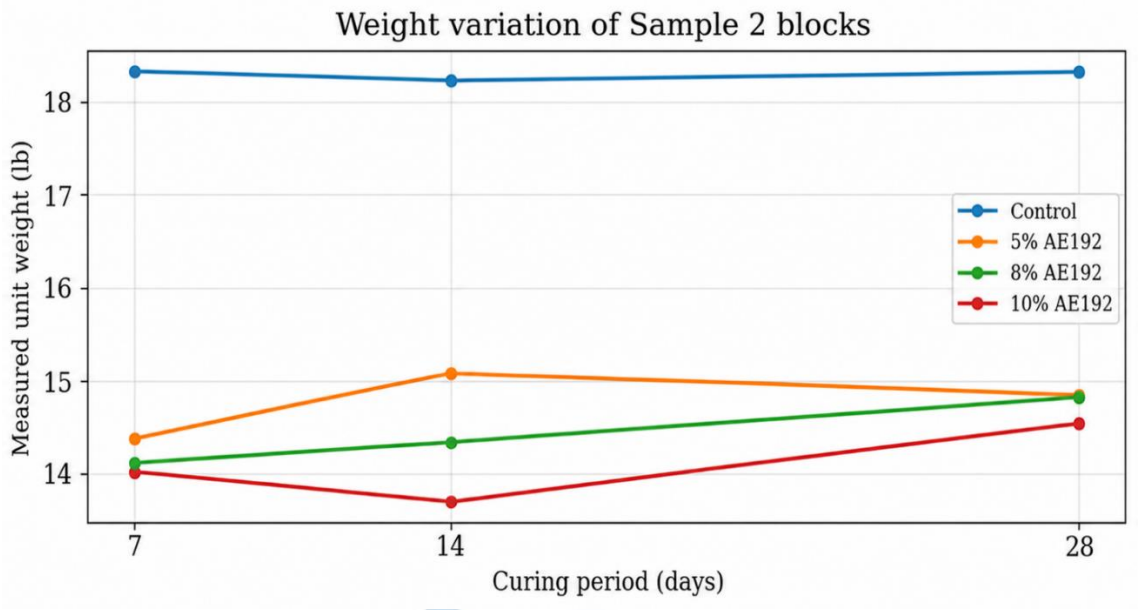


Figure 4: Weight variation of Sample 2 blocks at different AE192 contents

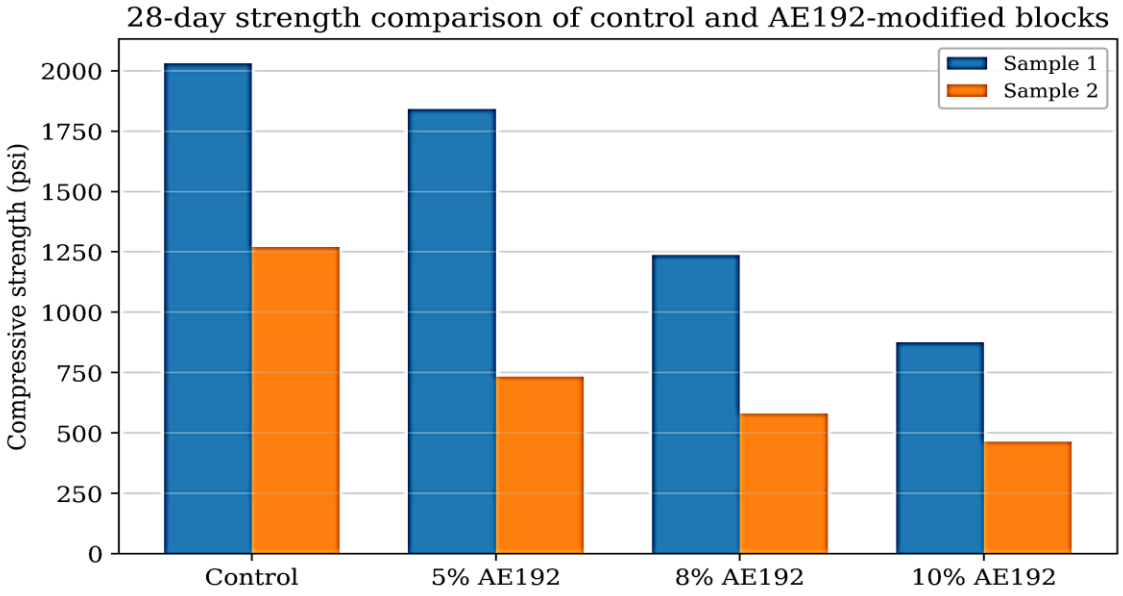


Figure 5: Comparative 28-day strength of Sample 1 and Sample 2 blocks

3.3 Effect of AE192 dosage on block performance

The effect of AE192 reflects a trade-off between the benefits of air void formation and the reduction in load transfer continuity within the concrete matrix. At a 5% dosage, the entrained air reduced block weight while preserving a relatively large proportion of the solid cementitious matrix. This may explain why the Sample 1 mixture retained approximately 90.7% of the control's 28-day compressive strength. In contrast, the 8% and 10% AE192 mixtures exhibited greater strength reductions, which may be attributed to increased

air void content, reduced density, and higher stress concentrations under compression. These findings indicate that increasing the AE192 dosage improves lightweight characteristics but can compromise compressive strength. The optimum dosage therefore depends on the required balance between weight reduction and mechanical performance.

The findings indicate that the selection of an appropriate air-entraining admixture dosage should not be based solely on workability improvement or weight reduction; compressive strength must also be considered. Among the air-entrained mixtures, 5% AE192 demonstrated the most favorable balance between weight reduction and strength retention, making it a potential option for semi-structural applications, subject to compliance with relevant strength requirements. In contrast, the 8% and 10% AE192 mixtures are more suitable for non-load-bearing applications, such as partition walls, internal walls, and façade units, where reduced density, improved thermal comfort, and sustainability are prioritized over maximum compressive strength.

3.4 Performance of ceramic powder modified blocks

The ceramic powder modified blocks demonstrated promising strength development, particularly at 28 days (Table 5 and Figure 6), with weight variation (Figure 7). The 8% ceramic/AE192 mixture increased in compressive strength from 588.89 psi at 7 days to 1080.56 psi at 28 days, while the 10% ceramic/AE192 mixture increased from 836.11 psi to 1186.11 psi over the same curing period. The 10% ceramic/AE192 mixture consistently achieved higher compressive strength than the 8% mixture. This improvement may be attributed to enhanced particle packing and a denser concrete matrix, which could partially compensate for the strength reduction associated with air entrainment. These results suggest that ceramic powder has potential as a waste derived material for improving the mechanical performance of air-entrained concrete blocks in moderate demand applications.

The 10% ceramic powder modified mixture is particularly significant because it combines moderate compressive strength with improved sustainability. Incorporating ceramic waste can reduce reliance on conventional raw materials and support circular economy principles in the construction industry. Although its 28-day compressive strength of 1186.11 psi was lower than those of the control and 5% AE192 mixtures in Sample 1, it was comparable to the Sample 2 control strength of 1269.44 psi. This indicates that ceramic powder modified blocks may be suitable for sustainable masonry applications with moderate strength requirements, provided they satisfy the relevant specifications for their intended use.

Table 5: Strength and weight variation of ceramic powder modified blocks

Mix	Compressive Strength			Weight Variation		
	7-day (psi)	14-day (psi)	28-day (psi)	7-day (lb)	14-day (lb)	28-day (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

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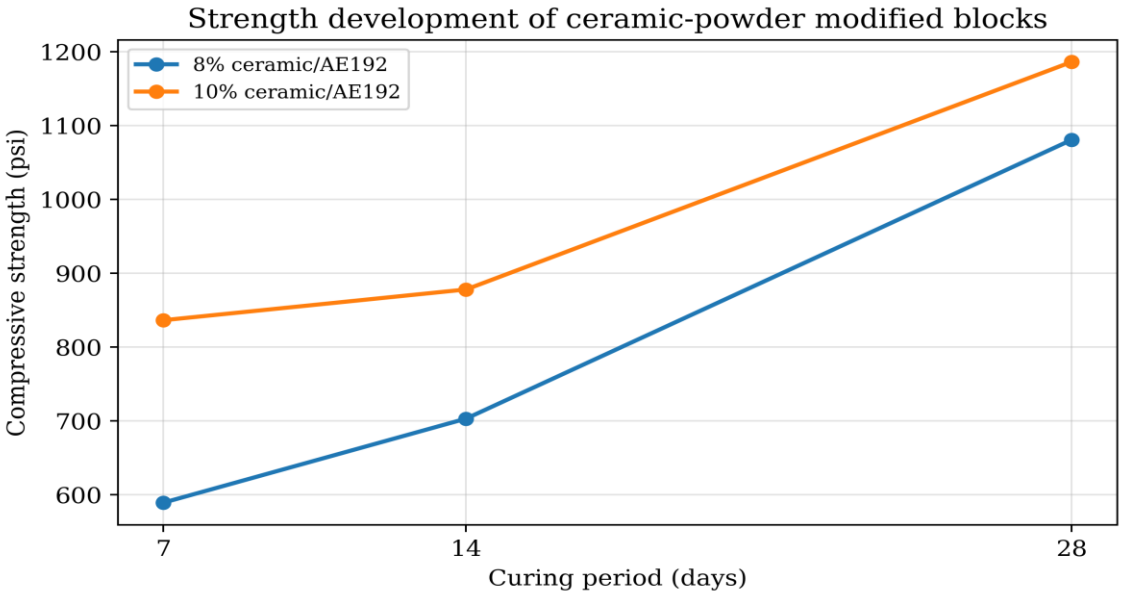


Figure 6: Strength development of ceramic powder modified block mixes

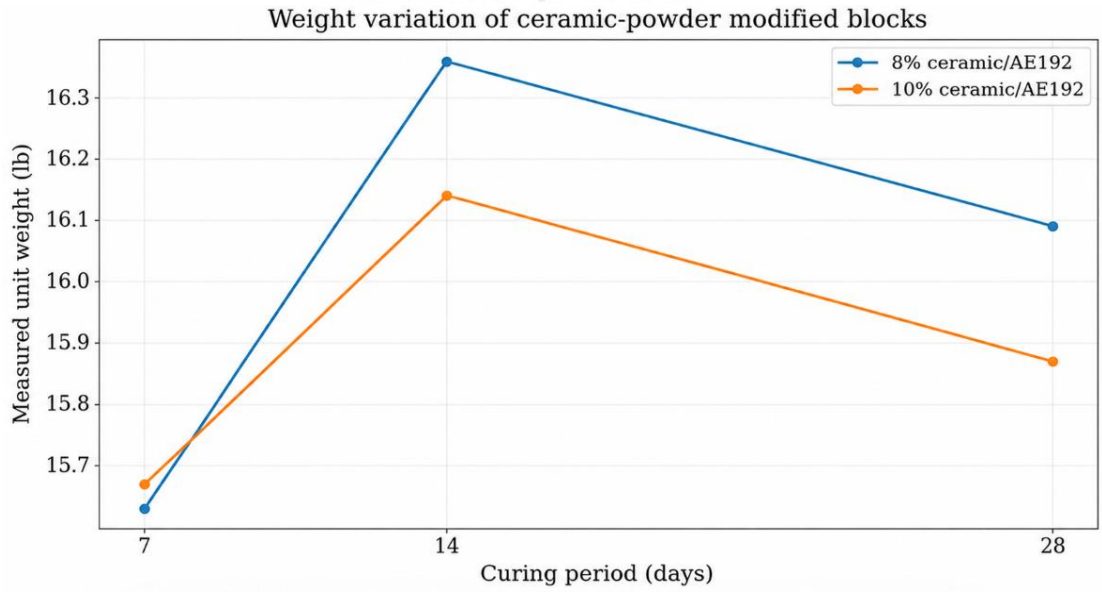


Figure 7: Weight variation of ceramic powder modified block mixes

3.5 Comparison with locally available bricks

The locally available first-class bricks exhibited compressive strengths of 1245, 1397, and 1593 psi for brick categories 313, 7, and 94, respectively (Table 6 and Figure 8). These results indicate that the brick specimens outperformed several of the lightweight concrete block mixtures. Brick 94, with a compressive strength of 1593 psi, was stronger than the Sample 2 control blocks and all Sample 2 air-entrained blocks However, the Sample 1 control and 5% AE192 blocks achieved compressive strengths of 2030.56 psi and 1841.67 psi, respectively, exceeding the strength range of the tested bricks.

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 (in^2)	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

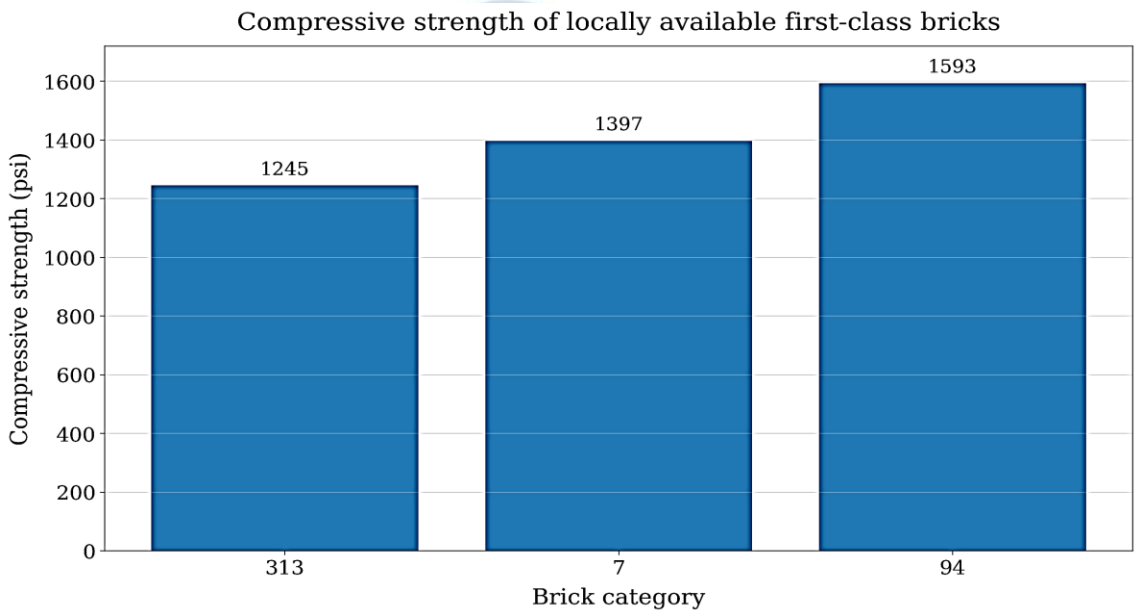


Figure 8: Compressive strength comparison of locally available brick specimens

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 optimization 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 achieved the highest 28-day compressive strengths of 2030.56 psi in Sample 1 and 1269.44 psi in Sample 2. Among the air-entrained mixtures, the 5% AE192 mixture demonstrated the most balanced performance, retaining approximately 90.7% of the control strength in Sample 1 while offering a reduction in block weight. In contrast, higher AE192 contents of 8% and 10% resulted in more significant strength reductions, making these mixtures more suitable for non-load bearing, lightweight, and insulation-oriented masonry applications.

The ceramic powder modified blocks also demonstrated promising potential for sustainable construction. The 10% ceramic/AE192 mixture achieved a 28-day compressive strength of 1186.11 psi, indicating that ceramic waste may contribute to improved particle packing and partially compensate for strength losses associated with air entrainment. The locally available first-class bricks exhibited competitive compressive strengths ranging from 1245 to 1593 psi. However, the proposed concrete blocks offer additional environmental benefits through the incorporation of industrial and construction related waste materials, particularly fly ash and ceramic powder. Overall, the 5% AE192 mixture is recommended for lightweight blocks intended for semi-structural applications, while the 10% ceramic/AE192 mixture shows potential for sustainable masonry units requiring moderate strength. Mixtures containing higher AE192 contents are more appropriate for non-load bearing applications. Nevertheless, careful control of batching, mixing, compaction, and curing is essential to achieve consistent quality and mechanical performance

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