SMART GREEN MATERIALS

POPULAR SCIENTIST

RESEARCH ARTICLE

Effect of Different Admixtures on Mechanical Properties of Concrete Paving Block: A Comparative Study

Asif Hossain Abir[a,*], Md. Akhter Hossain Sarker[b]

[a]Senior Executive-Research & Development, Concord Ready-Mix & Concrete Products Ltd., Dhaka-1216, Bangladesh

[b]Principal Research Officer, Housing and Building Research Institute, Ministry of Housing and Public Works, Dhaka-1207, Bangladesh

***Corresponding Author:** Asif Hossain Abir (asifhossain49@iut-dhaka.edu)

Articles History: Received: 28 August 2024; **Revised:** 11 September 2024; **Accepted:** 30 September 2024; **Published:** 13 November 2024

ABSTRACT

Ever since their introduction nearly a century ago, concrete paving blocks have become increasingly common. They evolved into an alternative to burned clay brick and natural stone. Concrete paving blocks are used to lay down areas for vehicles and pedestrians as well. Durability is one of the most crucial elements in the production of high-quality concrete paving blocks. Maintaining the quality as well as cost effectiveness of the concrete paving block is a great challenge in the present days. The aim of this study is to optimize the mechanical properties of concrete paving block units by experimenting with different admixtures. Compressive strength, water absorption, oven dry density, and drying shrinkage are among the attributes that were evaluated. The cost of production was also contrasted with and without the use of an admixture to achieve a comparable compressive strength. The results showed that admixtures could be used to produce high early strength units, and this was considered to be an economical factor in the production of concrete paving block units. At all ages, the use of admixtures increased these units' compressive strength by 30–40%. Although they did slightly increase density, additives also decreased the absorption and drying shrinkage of concrete paving block units.

Keywords: Admixture, Compressive Strength, Concrete Paving Block, Oven Dry Density, Production Cost, Water Absorption

INTRODUCTION

One material that is frequently used in the construction sector is concrete. It is made by combining the necessary amounts of cement, water, fine and coarse aggregates, and occasionally admixtures [1]. The type of cement used, the makeup of the fine and coarse aggregates, the concentration of the aggregates, the water quality used, the admixture type, and the ambient conditions—mostly temperature—all have a significant impact on the engineering properties of concrete [2]. Particles with sizes ranging from 75 μm to 4.75 mm are typically found in fine aggregate, while those with sizes ranging from 4.75 to 50 mm are found in coarse aggregate. The ease and uniformity with which fresh concrete can be mixed, transported, and compacted—without experiencing undue bleeding or segregation—is typically used to assess the quality of the material. [3]. If the right amounts of fine and coarse aggregate are used, bleeding in newly mixed concrete can be minimized. Admixtures and a higher cement content can also aid.

Admixtures composed of chemicals include water reducers, super plasticizers, set retarders, set accelerators, air entrainers, and specialty admixtures [4]. Admixtures are a significant and increasingly common component of concrete mixes, even though they are not necessary like cement, aggregate, and water are [5], [6]. In fact, a mix without admixtures is now the exception in many countries. The ability of admixtures to provide concrete with significant physical and financial benefits is the cause of the significant increase in their use [7]. Using concrete in situations where there were previously significant, or even insurmountable, challenges is one of these advantages. They also enable a greater variety of ingredients to be used in the mixture [8]. The survival of the concrete industry is largely dependent on the adoption of clever technical solutions to address the growing concerns about environmental pollution caused by construction materials and activities and the scarcity of natural resources, such as water. Admixtures are required in order to produce concrete with the proper design strength at a low water cement ratio due to the availability of a variety of cements other than regular Portland cement [9].

Chemical admixtures are substances that are added to concrete in the form of powder or liquid to give it properties that aren’t possible with standard concrete mixes [10]. Chemical admixtures are very little additions to concrete that are primarily used for air entrainment, water or cement content reduction, plasticization of fresh concrete mixtures, and setting time control [11]. Admixtures, while not always inexpensive, don’t always mean spending more money because their application can save money on associated costs, such as labor costs for achieving compaction or increasing durability without the need for extra precautions [12]. Nevertheless, it was found that chemical admixtures lower construction costs, alter the characteristics of hardened concrete, guarantee concrete quality while mixing, transporting, placing, and curing, and resolve specific emergencies during concrete operations [13].

Chemicals known as additives are typically added to concrete to provide a variety of advantageous outcomes, including increased workability, enhanced strength and durability, acceleration, decreased void volume, improved plasticity, etc. [14]. In comparison to the weight of all components and the overall composition of concrete, the composition of additives varies from 0.02% to 0.5% [15]. Retarding admixtures, according to the European Federation of Concrete Admixture Associations (EFCA), work by influencing the hydration process, which lowers the rate at which water enters the cement particles and slows down the reaction rate (speed) between the cement and water [16]. On the other hand,

https://doi.org/10.70028/sgm.v1i2.13

certain admixtures have the ability to reduce water at a variety of dosages and, when used in large quantities, to speed up the concrete's compressive qualities. [17]. On the other hand, certain admixtures have the ability to reduce water at a variety of dosages and, when used in large quantities, to speed up the concrete's compressive properties [18]. Admixtures (retarders) for concrete setting time retardation can be inorganic (phosphates, borates, lead salts, etc.) or organic (lignosulphonates, hydroxycarboxylic acid, phosphonate, etc.). The quantity of water required to make the concrete more workable can be decreased by using a superplasticizer [19]. Long side chain polycarboxylic ether molecules improved fresh concrete performance, according to Sugamata et al.'s [20] investigation into the effect of the chemical structure of polycarboxylic ether-based superplasticizer on fresh concrete performance. When superplasticizers are used with hardened concrete, the concrete becomes denser and has a higher compressive strength due to improved compaction effectiveness [21].

Prior studies have demonstrated that the appropriate amount of admixtures can enhance the compressive strength of cement composite materials. According to Akpokodje and Uguru [22], sandcrete blocks made with cassava waste water (as an admixture) had a 39% higher compressive strength than blocks made with fresh water. According to Sanjeev et al. [23], concrete blocks' compressive and split tensile strengths increased when fly ash, ground granulated blast furnace slag (GGBS), and metakaolin were partially substituted for cement. According to Topçu and Ateşin [24], when fresh concrete made with a naphthalenesulfonate-based admixture was compared to fresh concrete made with a lignosulfonate-based admixture, the slump flow results were better (better flowability). After 28 curing days, the compressive strengths of concretes made with modified polycarboxylic ether polymer (admixture) were found to be higher than those of concretes made with modified sulfonated polymer and synthetic polymer, according to a different study by Papayianni et al. [25].

Numerous investigations into the mechanical characteristics of concrete paving block units have been conducted through the use of various admixtures. However, there is a lack of research on comparable mechanical properties of concrete paving block units that take production costs into account as well as the use of chemical admixtures. The aim of this study was to optimize the mechanical properties of concrete paving block units by experimenting with different admixtures taking production costs into account as well as. Compressive strength, water absorption, oven dry density, and drying shrinkage are among the attributes that were evaluated.

MATERIALS

CEMENT

In this study, Ordinary Portland cement (Seven Rings Cement: a local brand) was utilized. It was brought into the lab and kept out of the rain. The chemical and physical characteristics of the cement are displayed in Tables 1 and 2 according to test results, the adopted cement complied with ASTM C150 Type I [26].

https://doi.org/10.70028/sgm.v1i2.13

Table 1. Chemical composition and main compounds of cement

Oxide Composition	Abbreviation	Content Percent	Limits of ASTM C150 Type I
Lime	CaO	62.00	–
Silica	SiO_2	21.70	–
Alumina	Al_2O_3	6.57	–
Iron oxide	Fe_2O_3	2.11	–
Sulphate	SO_3	2.20	≤ 3.0%
Magnesia	MgO	2.90	≤ 6.0%
Potash	K_2O	0.21	–
Soda	Na_2O	0.15	–
Loss on ignition	LOI	1.11	≤ 3.0%
Insoluble residue	IR	0.85	≤ 0.75%
Lime saturation factor	LSF	0.90	–

Table 2. Physical properties of cement

Physical Properties	Test Results	Limits of ASTM C150 Type I
Specific surface area, Blaine method (m^2/kg)	274	280 (min)
Soundness (auto clave method)	0.31	0.8% (max)
Setting time (vicat's apparatus)		
Initial setting (minutes)	112	60 (min)
Final setting (minutes)	217	600 (max)
Compressive strength		
3 days (N/mm^2)	21	12 (min)
7 days (N/mm^2)	27	19 (min)

Table 3. Grading of fine aggregate

Sieve Size (mm)	Cumulative Passing	Limits of BS 882/1992
4.75	100.00	89-100
2.36	82.68	60-100
1.18	76.00	30-100
0.60	61.43	15-100
0.30	39.81	5-70
0.15	13.49	0-15
Fineness modulus = 2.27		

Fine Aggregate

Throughout this work, nature sand with grading limits BS EN 12620:2013 [27] and a maximum size of 4.75 mm was used. According to Table 3, the sieve analysis of the fine aggregate grading complied with BS EN 12620:2013 [27]. Table 4 shows the specific gravity, absorption, and sulphate content, all of which meet the same specifications.

https://doi.org/10.70028/sgm.v1i2.13

Table 4. Physical properties of fine aggregate

Physical Properties	Test Results	Limits of BS 882/1992
Specific gravity	2.52	-
Sulphate content	0.18%	0.5% (max)
Absorption	2.32%	-

Coarse Aggregate

The maximum size of the crushed aggregate that was used was 10 mm. The coarse aggregate grading in Table 5 is in accordance with BS EN 12620:2013 [27]. Table 6 shows the specific gravity, sulphate content, and absorption of coarse aggregate.

Table 5. Grading of coarse aggregate

Sieve Size (mm)	Cumulative Passing	Limits of BS 882/1992
14.00	100	100
10.00	93	85-100
5.00	7	0-25
2.36	0	0-5

Table 6. Physical properties of coarse aggregate

Physical Properties	Test Results	Limits of BS 882/1992
Specific gravity	2.71	-
Sulphate content	0.07%	0.1% (max)
Absorption	0.86%	-

Admixture

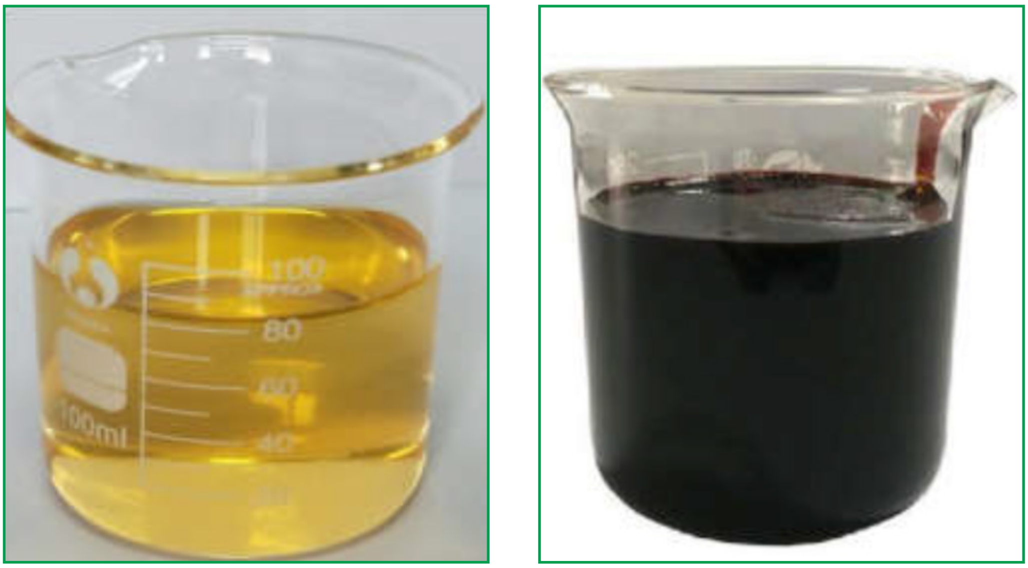
This investigation employed two different forms of admixtures: i) polycarboxylate ether (PCE) and ii) lignosulfonate-based admixture. According to ASTM C494 Type F [28], polycarboxylate ether (PCE) is a light brown liquid with a long lateral chain that is free of chloride. This super plasticizer has a specific gravity of 1.05 at 25 degrees Celsius. It improves the strength, density, and workability of concrete, according to the earlier study. Using this high-range water-reducing admixture used in research, an efficient mixture can be created. PCE lowers water consumption by 15% to 20%. The lignosulfonate-based admixture has a specific gravity of 1.17 at 25 degrees Celsius and is a dark brown liquid that complies with ASTM C494 type C [28]. Water demand is reduced by 5–10% when this admixture is used at a dosage of 0.3–0.6% (weight of cement). Figure 1 shows two different admixture used in this study.

Mix Design

Several slump tests were conducted in compliance with ASTM C143 [29] to determine the ideal admixture dosage that produces the greatest water reduction at the same workability and to adjust for the water content. According to these tests, the mix's maximum water reduction is 25%, which is equivalent to an

https://doi.org/10.70028/sgm.v1i2.13

admixture dosage of 1.5% by cement weight; water reduction stops at this dosage. Table 7 provides specifics about the mixes that were used in this investigation. In mix A, no dosage of admixture was used. The mix ratio of cement: fine aggregate: coarse aggregate was 1:1.6:3. In mix B and C, 1% Polycarboxylate ether based superplasticizer and 1% Lignosulfonate-based admixture was added by weight of cement respectively. The mix ratio of cement: fine aggregate: coarse aggregate was 1:1.7:3.2 for these two mixes. In mix D and mix E 1.5% Polycarboxylate ether based superplasticizer and 1.5% Lignosulfonate-based admixture was added by weight of cement respectively. The mix ratio of cement: fine aggregate: coarse aggregate was 1:1.8:3.4 for these two mixes. Cement content was same, 395 kg/ m^3, in all the mixes.



(a) Polycarboxylate ether based superplasticizer

(b) Lignosulfonate-based admixture

Figure 1. Two different admixture used in this study

Table 7. Mix proportion of concrete paving block mixes

Mix Designation	Mix ratio (Cement : FA : CA)	Water Content	Cement Content (kg/m³)	Type and Dosage of Admixture by Weight of Cement
Mix A	1:1.6:3	.48	395	-
Mix B	1:1.7:3.2	.36	395	1% Polycarboxylate ether based superplasticizer
Mix C	1:1.7:3.2	.32	395	1% Lignosulfonate-based admixture
Mix D	1:1.8:3.4	.36	395	1.5% Polycarboxylate ether based superplasticizer
Mix E	1:1.8:3.4	.32	395	1.5 % Lignosulfonate-based admixture

https://doi.org/10.70028/sgm.v1i2.13

Mixing, Casting and Curing Procedure in Factory

In order to produce concrete paving block units, the experimental work was done in the Concord Ready-Mix and Concrete Products factory. Concrete's dry ingredients were added to the mixer to begin the material mixing process. To achieve a uniform mix, the materials were mixed for three minutes. After adding the necessary amount of water, the ingredients were thoroughly mixed for an additional three minutes. The admixture water content was deducted from the necessary amount of mixing water. Concrete was mechanically moved from the mixer to the block-making machine using metal pans. The blocks were placed inside the mold, which vibrated. The head and shoes were lifted out of the mold during the filling process to make room for the concrete. The head and shoes pressed against the top of the blocks when the mold was filled and vibrated. As seen in Figure 2, blocks were moved down to extrude from the mold at the conclusion of the vibration period. Following that, an excavator is used to move the concrete paving blocks to the storage area for curing, as depicted in Figure 3. Concrete paving block units were cured in the factory by being left in the storage area and, depending on the weather, being sprinkled with water. Figure 4 displays the final goods following the application of admixture.

Figure 2. After demolding from machine mold

Tests Results And Discussion Of Experimental Work

Compressive strength

The ASTM C140 was followed in the execution of this test [30]. Table 8 and Figure 6 display the compressive strength of concrete paving block units for mixes with and without admixtures at various ages. The compressive strength of all units, both with and without admixtures, increases steadily with age. The compressive strength of the units increased to 45%, 49%, 35%, 46%, and 34% higher after 28 days of moist curing (sprinkled with water) than it was after

https://doi.org/10.70028/sgm.v1i2.13

Figure 3. Carrying to the storage place for curing

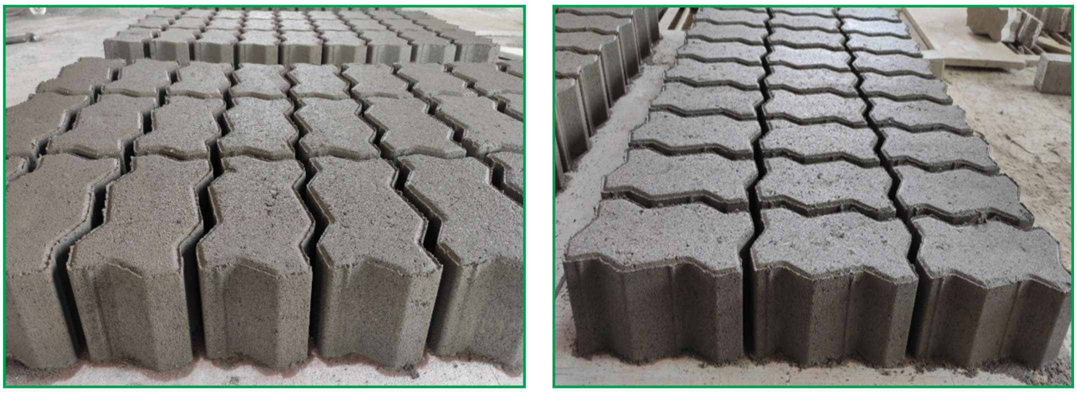


Figure 4. Finished products after the usage of admixture

three days for Mix A, Mix B, Mix C, Mix D, and Mix E, respectively. The units' compressive strength clearly increases as the amount of moist curing increases. When admixtures are used in the production of concrete paving block units, the factory curing time can be shortened because the finished units meet ASTM C90 [31], Grade-N1, requirements after just three days of moist curing. Mix A exhibits a lower compressive strength than mixes without admixtures, as demonstrated by the comparison with Mix B, Mix C, Mix D, and Mix E. This results from employing admixtures, which lowers the water content ratio. Even though pressed concrete is used to make concrete paving block units, the compressive strength of these units is increased by reducing the water content through the use of admixtures. Using these admixtures results in a roughly 30–40% increase in compressive strength for the produced concrete paving block units at all ages.

Additionally, the use of admixtures gave the concrete paving block units that were produced an early strength, which could shorten the curing period. Mix B and Mix D, which contain superplasticizer based on polycarboxylate ether, have a lower compressive strength than Mix C and Mix E, which contain lignosulfonate-based admixture. Figure 5 displays the compressive strength testing of concrete paving block units.

Table 8. Compressive strength of hollow block concrete units

Mix Type	Compressive strength (MPa), at age (days)			
	3	7	14	28
Mix A	18.80	22.03	24.09	27.32
Mix B	24.09	28.79	31.73	35.84
Mix C	27.17	30.84	33.19	36.72
Mix D	25.35	30.58	32.99	37.10
Mix E	28.08	31.76	34.19	37.66

(a) compressive strength test setup (b) typical rupture for a whole paving block

Figure 5. Compressive strength testing of concrete paving block units

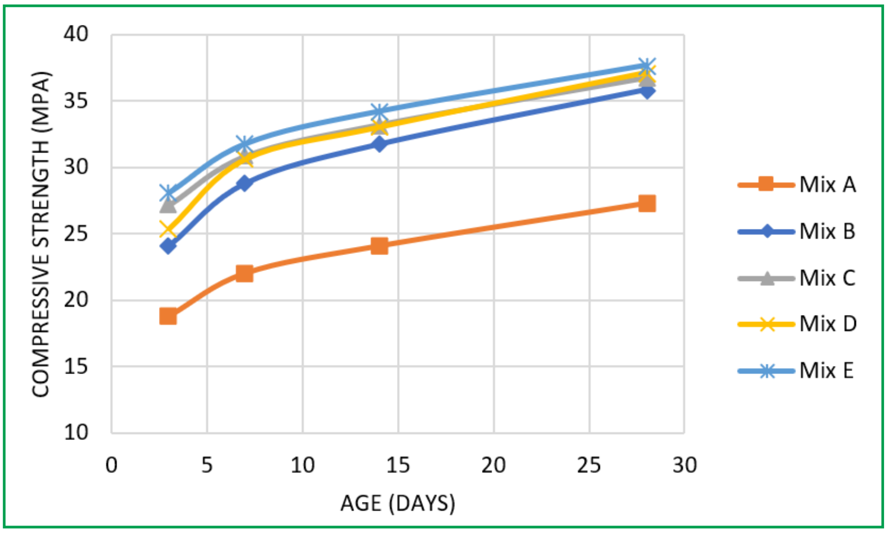


Figure 6. Development of compressive strength of different mixes of concrete paving block units with age

https://doi.org/10.70028/sgm.v1i2.13

Absorption and moisture content

Table 9 displays the absorption and moisture content of concrete paving block units after 28 days of moist curing. These findings demonstrate that the use of admixtures reduces the absorption of concrete paving block units by lowering capillary porosity, which is brought about by a significant reduction in the water content ratio. Figure 7 shows the relationship between the concrete paving block units' compressive strength and absorption. Evidently, a reduction in absorption results in a rise in compressive strength. The moisture content results for each unit meet ASTM C90's type 1 [31] moisture-controlled unit requirements. Compared to Mix B and Mix D, which contain superplasticizer based on polycarboxylate ether, Mix C and Mix E, which contain lignosulfonate-based admixture, produce less absorption and moisture content. As the water content decreases, we can also see a decrease in absorption and moisture content.

Table 9. Absorption and moisture content

Type of Mix	Absorption (%)	Absorption (kg/m^3)	Moisture Content (%)	ASTM C90
Mix A	5.70	126.92	36.10	Max. absorption 208 kg/m^3
Mix B	4.13	100.70	28.50	
Mix C	4.04	93.10	29.45	
Mix D	4.07	96.71	29.07	
Mix E	4.01	90.44	29.74	

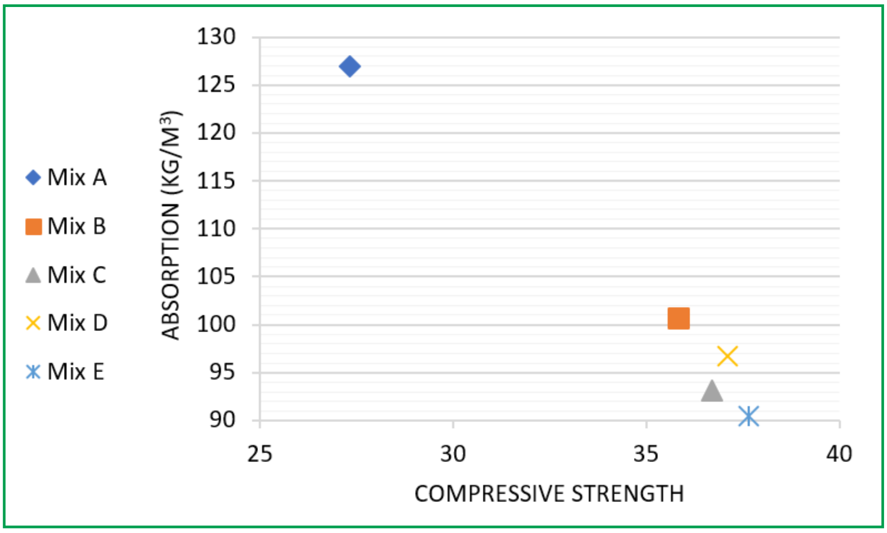


Figure 7. Relation between absorption and compressive strength for different mixes of concrete paving block units

Oven dry density

The ASTM C495 [32] was followed in determining the oven dry unit weight test. Table 10 lists the oven-dry density results at 28 days of age. Due to the admixture concrete's lower water content than the reference concrete, it is evident from the results that the units produced from Mix B, Mix C, Mix D, and

Mix E (mixes containing admixtures) have a higher oven-dry density than units produced from Mix A. Figure 8 demonstrates how an increase in oven-dry density clearly raises a unit's compressive strength. Mix B and Mix D, which contain superplasticizer based on polycarboxylate ether, yield a lower dry density than Mix C and Mix E, which contain lignosulfonate-based admixture. We can also observe that dry density increases due to decrease in water content.

Table 10. Oven-dry density

Type of Mix	Oven-dry Density (kg/m³)	Drying Shrinkage (%)	Percentage of Shrinkage Reduction (%)
Mix A	1543	0.028	-
Mix B	1565	0.016	43
Mix C	1579	0.012	57
Mix D	1569	0.015	47
Mix E	1585	0.011	60

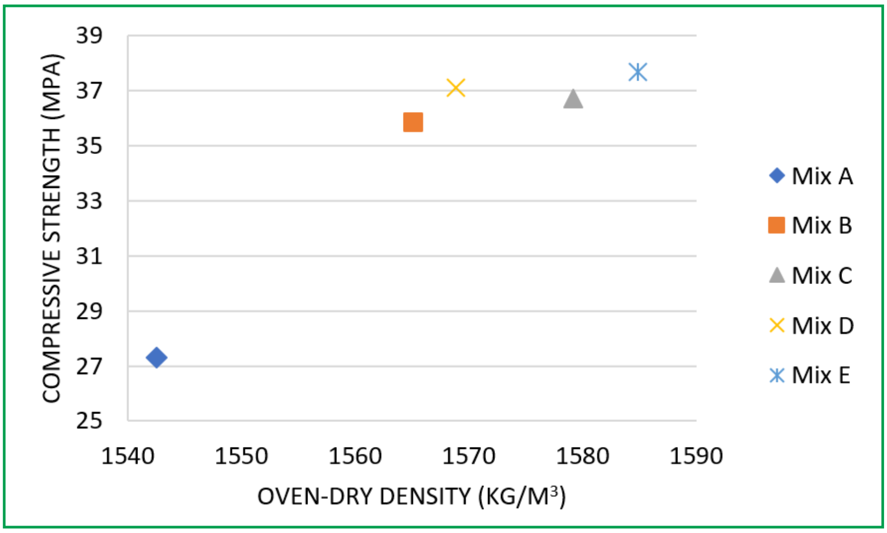


Figure 8. Relation between oven-dry density and compressive strength for different mixes of concrete paving block units

Drying shrinkage

In accordance with ASTM C426 [30], this test was performed to ascertain the shrinkage of concrete paving block units. The drying shrinkage results for the concrete paving block units made with and without admixtures are displayed in Table 10. The findings demonstrate that the admixtures reduce drying shrinkage. This results from employing these admixtures to lower the percentage of water in the concrete. Additionally, by using these admixtures, the aggregate volume percentage is increased. It is well known that concrete with a higher aggregate content shrinks less. Mix B and Mix D, which contain superplasticizer based on polycarboxylate ether, exhibit greater drying shrinkage than Mix C and Mix E, which contain lignosulfonate-based admixture. We can also observe that drying shrinkage decreases due to decrease in water content.

https://doi.org/10.70028/sgm.v1i2.13

Production cost

Production cost of concrete paving block units decreased due to the usage of admixtures. By adding admixture high strength concrete can be produced. From this study it can be observed that, by adding admixture high strength concrete block was produced in spite of increasing aggregate ratio, which decreased the usage of cement and reduced the overall production cost of concrete paving block units. Table 11 shows the production cost of concrete paving block units for different mixes.

Table 11. Production cost of concrete paving block units for different mixes

Mix Type	Per Unit Price
Mix A	BDT 25.00
Mix B	BDT 23.50
Mix C	BDT 23.20
Mix D	BDT 22.50
Mix E	BDT 22.25

Conclusions

The following deductions are made in light of the investigation's findings:

1. By increasing the concrete paving block units' early age compressive strength, admixtures used in their manufacturing process enable a shorter curing time.
2. Using admixtures results in a 30–40% increase in compressive strengths for the produced concrete paving block units at all ages.
3. The use of admixtures lessens the absorption of concrete paving block units.
4. The oven-dry density of concrete paving block units is slightly increased by the use of admixtures.
5. The drying shrinkage of the produced concrete paving block units is decreased by approximately 40–60% when admixtures are used.
6. High strength concrete blocks were produced even with an increased aggregate ratio by adding admixture, which reduced the amount of cement needed and the overall cost of producing concrete paving block units.
7. Mix E with 1.5 % Lignosulfonate-based admixture provided highest compresive strength and also was most economical.

Acknowledgement

The authors would like to thank the technical staff in the concrete lab at the Housing and Building Research Institute for their support in conducting specimen testing and the technical staff of the factory of Concord Ready-Mix & Concrete Products Ltd. for precast unit production.

Conflicts of Interest

The authors declare no conflicts of interest.

Author Contributions

Asif Hossain Abir: conceptualization, methodology, software, data curation, writing-original draft preparation, visualization, investigation. **Md. Akhter Hossain Sarker:** supervision, validation, writing-reviewing and editing.

Data Availability Statement

The data used to support the findings of this study are included within the article.

References

[1] V. K. Sudha and V. Bhikshma, "Experimental Investigation on Field and Laboratory Curing of Natural and Recycled Aggregate Concrete," International Journal For Multidisciplinary Research, vol. 6, no. 3, 2024. doi: http://dx.doi.org/10.36948/ijfmr.2024.v06i03.16126

[2] A. Özbayrak, "Experimental Investigation of the Relationship between Dynamic Characteristics and Mechanical Properties of Fly Ash-Based Geopolymer Reinforced Concrete Beams," Journal of Materials in Civil Engineering, vol. 36, no. 8, 2024. doi: http://dx.doi.org/10.1061/JMCEE7.MTENG-17469

[3] A. Neville, Properties-of-Concrete-AM 149. 4th Edition, Essex: Addison Wesley Longman Ltd., 1995.

[4] B. R. T. Vilane, S. R. Mbingo and S. M. Innocent, "The Effect of Calcium Chloride Admixture on the Compressive Strength of Concrete Blocks," Journal of Agricultural Science and Engineering, vol. 7, no. 2, pp. 30-35, 2021.

[5] B. Hu, X. Wang , Y. Zhou , X. Huang and Z. Zhu , "Seismic performance of shear-critical RC columns strengthened by multiple composites considering shifted failure zone," Case Studies in Construction Materials, vol. 20, pp. 1-21, 2024. doi: http://dx.doi.org/10.1016/j.cscm.2024.e02971

[6] H. Lo, E. Sutandar and G. S. Budi, "Study of the Effect of Mineral Admixture Addition on Paving Blocks' Physical and Mechanical Properties," Jurnal Teknik Sipil, vol. 24, no. 2, p. 914, 2024. doi: http://dx.doi.org/10.26418/jts.v24i2.76545

[7] S. O. Odeyemi, M. A. Anifowose, M. O. Oyeleke, A. O. Adeyemi and S. B. Bakare, "Effect of Calcium Chloride on the Compressive Strength of Concrete Produced from Three Brands of Nigerian Cement," American Journal of Civil Engineering, vol. 3, pp. 1-5, 2015. doi: http://dx.doi.org/10.11648/j.ajce.s.2015030203.11

[8] W. Chen, M. Wu and Y. Liang, "Effect of SF and GGBS on Pore Structure and Transport Properties of Concrete," Materials, vol. 17, no. 7, p. Liang, 2024. doi: http://dx.doi.org/10.3390/ma17061365

[9] A. Gandage, "Admixtures in Concrete -A Review," International Conference on Construction Real Estate Infrastructure and Projects , Pune, 2018.

[10] C. K. Williams, E. M. A. M. A. Al Hatali and N. S. Al Ajmi, "A Study on the Mechanical Properties of Concrete by Partial Replacement of Cement with Calcium Chloride," International Research Journal of Engineering and Technology (IRJET), vol. 7, no. 8, pp. 160-164, 2020.

[11] S. J. S. Allah, M. M. Kassim and G. A. Salman, "The Durability of Concrete Mortars with Different Mineral Additives Exposed to Sulfate Attack," Salud Ciencia y Tecnología - Serie de Conferencias, vol. 3, p. 885, 2024. doi: http://dx.doi.org/10.56294/sctconf2024851

[12] A. Hussain, R. L. Wankhade and H. Singh, "Enhancing the Properties of Self-Compacting Concrete by Using Steel and Polypropylene Fibers," Practice Periodical on Structural Design and Construction, vol. 29, no. 3, 2024. doi: http://dx.doi.org/10.1061/PPSCFX.SCENG-1460

[13] Z. B. Ozturk and M. Engur, "Exploring the Potential of Slag Waste Generated after Zinc Metal Recovery in Geopolymer Mortar Production," Eskişehir Technical University Journal of Science and Technology A - Applied Sciences and Engineering, 2024. doi: http://dx.doi.org/10.18038/estubtda.1482349

[14] V. Ramachandran, R. M. Paroli, J. . J. Beaudoin and A. H. Delgado, Handbook of thermal analysis of construction materials (Chapter 4), New York: Noyes Publications, 2002.

[15] J. Newman, B. John and B. S. Choo, Advanced concrete technology: Constituent Materials, Oxford : Butterworth-Heinemann, 2003.

[16] EFCA, "About Admixtures: Set Retarding," European Federation of Concrete Admixture Associations, 2006. [Online]. Available: https://www.efca.info/admixtures/set-retarding/. [Accessed 18 7 2024].

[17] ACI, "Committee Report ACI 212.3R-04, Chemical Admixtures for Concrete," American Concrete Institute (ACI) , Michigan, 2004.

[18] SINTEF, "Retarding admixtures for concrete State of the art," SINTEF Building and Infrastructure, Trondheim, 2007.

[19] I. B. Muhit , "Dosage Limit Determination of Superplasticizing Admixture and Effect Evaluation on Properties of Concrete," International Journal of Scientific & Engineering Research, vol. 4, no. 3, pp. 1-4, 2013.

[20] T. Sugamata, T. Sugiyama and A. Ohta, "The Effects of a New High-Range Water-Reducing Agent on the Improvement of Rheological Properties," in Seventh CANMET/ACI International Conference on Superplasticizers and Other Chemical Admixtures in Concrete, Berlin, 2003. doi: http://dx.doi.org/10.14359/12924

[21] S. Alsadey, "Effect of Superplasticizer on Fresh and Hardened Properties of Concrete," Journal of Agricultural Science and Engineering, vol. 1, no. 2, pp. 70-74, 2015.

[22] O. Akpokodje and H. Uguru, "Effect of Fermented Cassava Waste Water as Admixture on Some Physic-Mechanical Properties of Solid Sandcrete Blocks," International Journal of Engineering Trends and Technology (IJETT), vol. 67, no. 10, pp. 216-222, 2019.

[23] N. Sanjeev, K. H. Kumar and K. P. R. Kumar, "Strength and Durability Characteristics of Steel Fibre Reinforced Concrete with Mineral Admixtures," International Journal of Engineering and Advanced Technology (IJEAT), vol. 9, no. 1, pp. 3893-3897, 2019. doi: http://dx.doi.org/10.35940/ijeat.A1223.109119

[24] İ. B. Topçu and Ö. Ateşin, "Effect of High Dosage Lignosulphonate and Naphthalene Sulphonate Based Plasticizer Usage on Micro Concrete Properties," Construction and Building Materials, vol. 120, pp. 189-197, 2016. doi: http://dx.doi.org/10.1016/j.conbuildmat.2016.05.112

[25] I. Papayianni, N. Oikonomou, G. Tsohos and P. Mavria, "Influence of superplasticizer type and mix design parameters on the performance of them in concrete mixtures," Cement and Concrete Composites, vol. 27, no. 2, pp. 217-222, 2005. doi: http://dx.doi.org/10.1016/j.cemconcomp.2004.02.010

[26] ASTM International, "ASTM C150 1989 Standards Specification for Portland Cement," Annual book of ASTM Standards, vol. 4, no. 2, 1989b.

[27] British Standards Institute (BSI), "BS EN 12620:2013 Aggregates for concrete," British Standards Institution, London, 2013.

[28] ASTM International , "Standard Specification for Chemical Admixtures for Concrete," ASTM International , West Conshohocken, 2006 .

[29] ASTM International, "ASTM C143 1989 Standards test methods for slump of hydraulic cement concrete," Annual book of ASTM Standards, vol. 2, no. 2, pp. 85-86, 1989a.

[30] ASTM International, "ASTM C426 2000 Standard method for drying shrinkage of concrete block," Annual book of ASTM Standards, vol. 4, no. 2, 2002.

[31] ASTM International, "ASTM C90 1999 Hollow load-bearing concrete masonry units," Annual book of ASTM Standards, vol. 4, no. 2, 1999.

[32] ASTM International, "ASTM C495 1985 Standard method for oven dry density of concrete," Annual book of ASTM Standards, vol. 4, no. 2, 1985.