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Evaluating the Mechanical Properties of Concrete Blocks Incorporating Industrial By-Products

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Abstract. This research investigates the mechanical properties of concrete blocks made with industrial by-product materials including construction waste, washed cement fines from ready-mix concrete plants, brick dust, and ladle furnace slag. The study examines factors influencing compressive strength, void content, absorption capacity, and boiling water absorption, with the aim of increasing the acceptance of eco-friendly construction materials. Additionally, the feasibility of using these by-products in concrete blocks as a sustainable alternative to conventional bricks is discussed. Concrete blocks measuring 240 mm in length, 70 mm in height, and 100 mm in width were produced by partially replacing primary aggregate materials with specific by-product components in defined proportions within a regular concrete mix. These blocks were then tested for various mechanical properties in accordance with ASTM standards, including compressive strength, permeable voids, absorption capacity, and boiling water absorption. The results indicate that concrete blocks incorporating by-products exhibit similar and, in some cases, superior performance compared to conventional concrete blocks, highlighting their potential for sustainable construction.

Keywords: Concrete Blocks, Industrial By-Products, Compressive Strength, Sustainable Construction, Brick Dust.

1 Introduction

The brick industry in Bangladesh has been a significant contributor to the country's economic development, providing employment opportunities and supporting various construction activities. However, the industry's rapid and largely unregulated growth has also led to a range of environmental and public health concerns [1]. As to the World Bank, brick kilns are identified as a major contributor to air pollution in the greater Dhaka region. Not to overlook the severe consequences: air pollution is causing a 6 to 8 years reduction in life expectancy among the population, and in 2019, over 175,000 Bangladeshis succumbed as a result of it [2]. An analysis revealed that the brick kilns in the Dhaka region of Bangladesh emitted a combined total of 15,500 tons of SO_2, 302,000 tons of CO, 23,300 tons of PM 2.5, 6,000 tons of Black Carbon (BC), and 1.8 million tons of CO_2 [3]. All the brick kilns operations are accompanied by dust generation, leaving the neighborhood and workplace dusty [4]. A survey undertaken in the

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vicinity of brick kilns revealed that those in close proximity to the kilns are more prone to experiencing health risks resulting from the pollution generated by the kilns in comparison to those who do not reside in the kiln areas [5]. In order to mitigate air pollution, the government has made the decision to gradually eliminate the use of bricks in all construction projects by 2025. This decision is based on the recognition that brick kilns are a major contributor to respiratory pollution in Bangladesh [6]. In light of these difficulties, the concrete block-manufacturing sector has been flourishing in Bangladesh, capturing the majority of the Tk9,000 crore brick market due to the non-toxic and far more cost-effective nature of the new-generation building blocks [7]. Diversifying the usage of blocks in residential buildings will significantly mitigate air pollution. In addition, the magnitude of agricultural land loss will be diminished, therefore preventing any deficit in the overall productivity of the country [8]. Nevertheless, its conventional practices have raised ecological red flags, resulting in environmental degradation and resource depletion [9].

Research indicates that advancements in concrete mix design and composition can improve durability and reduce material usage. This includes incorporating supplementary cementitious materials (SCMs) like fly ash, slag, and silica fume, which enhance the concrete's performance and reduce the carbon footprint of cement production [9]. A number of previous investigations have discovered by-products and waste materials, including rice husk ash, limestone quarry wastes, oil palm ash, and steelmaking slag. Each of these items has the potential to replace cement and sand in the creation of concrete materials, therefore enabling the attainment of environmental advantages, enhancement of certain characteristics, and reduction of manufacturing expenses [10-13]. So, our current research also explores and evaluates how concrete blocks containing diverse by-product materials (construction waste, washed cement fines of ready-mix concrete plant, brick dust, and ladle furnace slag) demonstrate their mechanical properties. This study also intends to assess the feasibility of upgrading these by-products as suitable partial substitutes for traditional concrete ingredients, aiming to save resources and promote more sustainable building practices.

2 Methodology

2.1 Material Used

Various materials were selected and evaluated for their suitability in this study. The primary materials included cement (C), water (W), coarse sand (CS), Sylhet sand (SS), medium sand (MS), and fine sand (FS). Additionally, four industrial by-products, such as washed cement fines (WCF) of ready mix concrete, ladle furnace slag (LFS), construction waste (CW) from construction sites, and brick dust (BD), were incorporated as partial replacements for aggregate materials to assess their potential contributions and impacts on concrete blocks.

2.2 Material Properties

Specific gravity [14], fineness modulus [15], and water absorption capacity (%) [14] tests were conducted according to ASTM standards. The results are presented in Table 1, Table 2, and Table 3, respectively.

Table 1. Specific Gravity Test Results of Materials

Materials	Specific Gravity
Cement (C)	2.96
Coarse Sand (CS)	2.43
Sylhet Sand (SS)	2.43
Medium Sand (MS)	2.3
Fine Sand (FS)	2.2
Brick Dust (BD)	2.2
Washed Cement Fines - RMC Wastes (WCF)	2.31
Ladle Furnace Slag (LFS)	2.59
Construction Waste (CW)	2.2

Table 2. Fineness Modulus Test Results of Materials

Materials	Fineness Modulus
Coarse Sand (CS)	3.55
Sylhet Sand (SS)	2.65
Medium Sand (MS)	1.61
Fine Sand (FS)	2.14
Brick Dust (BD)	1.69
Washed Cement Fines - RMC Wastes (WCF)	2.28
Ladle Furnace Slag (LFS)	4.40
Construction Waste (CW)	2.21

Table 3. Water Absorption Capacity (%) Test Results of Materials

Materials	Water Absorption Capacity %
Coarse Sand (CS)	1.50
Sylhet Sand (SS)	1.40
Medium Sand (MS)	0.60
Fine Sand (FS)	11.4
Brick Dust (BD)	11.4
Washed Cement Fines – RMC Wastes (WCF)	16.7
Ladle Furnace Slag (LFS)	2.00

2.3 Details of Specimen

Concrete block specimens of size 100 mm width, 70 mm height, and 240 mm length were prepared in a local block manufacturing company's plant. A mix was prepared based on the mix design of concrete blocks. After placing the mix in a specimen-shaped mould, 16 MPa was applied to compact the specimen with intense vibration. After compression, the specimens were immediately demoulded and placed in humid conditions. During this period, the blocks undergo curing and progressively increase in strength as the cement hydration process continues. Once fully dried and solidified, they are ready for further testing of various mechanical properties. A photograph during the manufacturing process of concrete blocks is shown in Fig. 1.

Fig. 1. Concrete Blocks During Production: Freshly Moulded Units Prior to Curing

2.4 Case Investigated

A total of 14 cases of concrete blocks were examined, each with varied proportions of primary materials and industrial by-products. The water-to-cement ratios we considered were 0.25 and 0.3. All 14 cases, each with different compositions of aggregates and by-products, are detailed in Table 4.

Table 4. Detailed Descriptions of the 14 Cases

Cases	W/C	Percentage of Aggregates and By-Products (%)							
		CS	SS	MS	FS	BD	WCF	LFS	CW
C50S30M20	0.3	50	30	20	0	0	0	0	0
C50S30M20 – W/C.25	0.25	50	30	20	0	0	0	0	0
C50S30M20 – LC	0.3	50	30	20	0	0	0	0	0

C50S20M20F10	0.3	50	20	20	10	0	0	0	0
C40S20M20F20	0.3	40	20	20	20	0	0	0	0
C50S20M15F10B5	0.3	50	20	15	10	5	0	0	0
C50S20M10F10B5W5	0.3	50	20	10	10	5	5	0	0
C40S20M10F10B10W10	0.3	40	20	10	10	10	10	0	0
C30S20M20F20B10 – HC	0.3	30	20	20	20	10	0	0	0
C40S20M10B10CW20	0.3	40	20	10	0	10	0	0	20
C40S20M30L10	0.3	40	20	30	0	0	0	10	0
C50F45B5	0.3	50	0	0	45	5	0	0	0
C50F40B10	0.3	50	0	0	40	10	0	0	0
C50F35B15	0.3	50	0	0	35	15	0	0	0

C – coarse sand, S – Sylhet sand, M – medium sand, F – fine sand, B – brick dust, L – ladle furnace slag, CW – construction waste, W – washed cement fines, W/C.25 – water to cement ratio of 0.25, LC – low cement content, HC – high cement content. For example, in the case of C50S30M20 – W/C.25, the mix consists of 50% coarse sand, 30% Sylhet sand, and 20% medium sand, making up 100% of the total aggregate content, with a water-to-cement ratio of 0.25.

2.5 Mix Design

Table 5 provides a detailed mix design for all 14 cases. A volumetric mix design approach was employed, in which primary aggregates were partially replaced with by-product materials across different cases. Additionally, two cases were included with low and high cement content to enable a more comprehensive analysis.

Table 5. Mix Design

Cases	C	W	Aggregate	CS	SS	MS	FS	BD	WCF	LFS	CW
					(kg/m^3)						
C50S30M20	205	61	1361	636	382	241	0	0	0	0	0
C50S30M20 – W/C.25	205	51	1433	670	402	254	0	0	0	0	0
C50S30M20 – LC	191	57	1423	665	399	252	0	0	0	0	0
C50S20M20F10	205	61	1361	636	254	241	115	0	0	0	0
C40S20M20F20	205	61	1361	509	254	241	230	0	0	0	0
C50S20M15F10B5	205	61	1361	636	254	181	115	58	0	0	0
C50S20M10F10B5W5	205	61	1361	636	254	120	115	58	60	0	0
C40S20M10F10B10W10	205	61	1361	509	254	120	115	115	121	0	0
C30S20M20F20B10 – HC	218	66	1299	364	243	230	220	110	0	0	0
C40S20M10B10CW20	205	61	1361	509	254	120	0	115	0	0	230
C40S20M30L10	205	61	1361	509	254	361	0	0	0	136	0

C50F45B5	205	61	1361	636	0	0	518	58	0	0	0
C50F40B10	205	61	1361	636	0	0	461	115	0	0	0
C50F35B15	205	61	1361	636	0	0	403	173	0	0	0

2.6 Test Performed

Compressive Strength. The compressive strength of the concrete blocks was measured in accordance with the standard test method for hydraulic cement mortars [16].

Permeable Void and Boiling Water Absorption. The permeable void and boiling water absorption tests were conducted in accordance with ASTM standards [17]

3 Results and Discussion

3.1 Compressive Strength of Concrete Blocks

The compressive strength of various concrete block mixtures is shown in Fig. 2. The mixture C50F40B10 has the highest strength (nearly 2200 psi), followed by C50F35B15 (nearly 2000 psi). Mixtures incorporating coarse sand, fine sand, and brick dust generally exhibited higher compressive strengths. Conversely, mixtures containing coarse sand, Sylhet sand, medium sand, and fine sand, such as C40S20M20F20, resulted in the lowest compressive strengths, around 1300 psi. Mixtures containing varying proportions of aggregates and by-products achieved medium to high compressive strengths, ranging from 1500 to 2000 psi. The minimum average compressive strength for non-load-bearing concrete blocks is 500 psi [18]. All cases presented in the figure exceed this standard value, indicating that the blocks meet the required strength criteria.

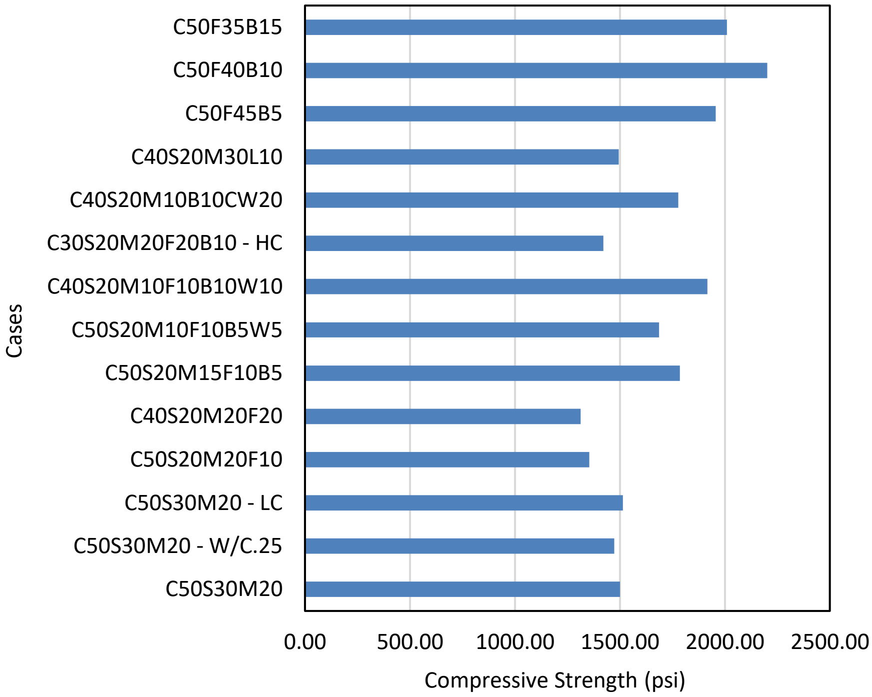

Fig. 2. Compressive Strength of Concrete Block

3.2 Void (%) of Concrete Blocks

The percentage of void (%) in different concrete block mixes is shown in Fig. 3. The highest void content, around 29% was found in the mixture C50S30M20-LC. In contrast, the mixture C40S20M10F10B10W10 exhibited the lowest void percentage, nearly 15%. Additionally, a lower water-to-cement ratio as, seen in C50S30M20-W/C.25, typically results in fewer voids due to a denser structure. The low void percentage of the C40S20M10F10B10W10 mixture suggests a well-graded blend of both aggregate and by-product materials, which effectively fills spaces between particles, resulting in concrete block with lower porosity. Conversely, the low cement content in the C50S30M20-LC mixture contributes to higher porosity due to insufficient filling of voids.

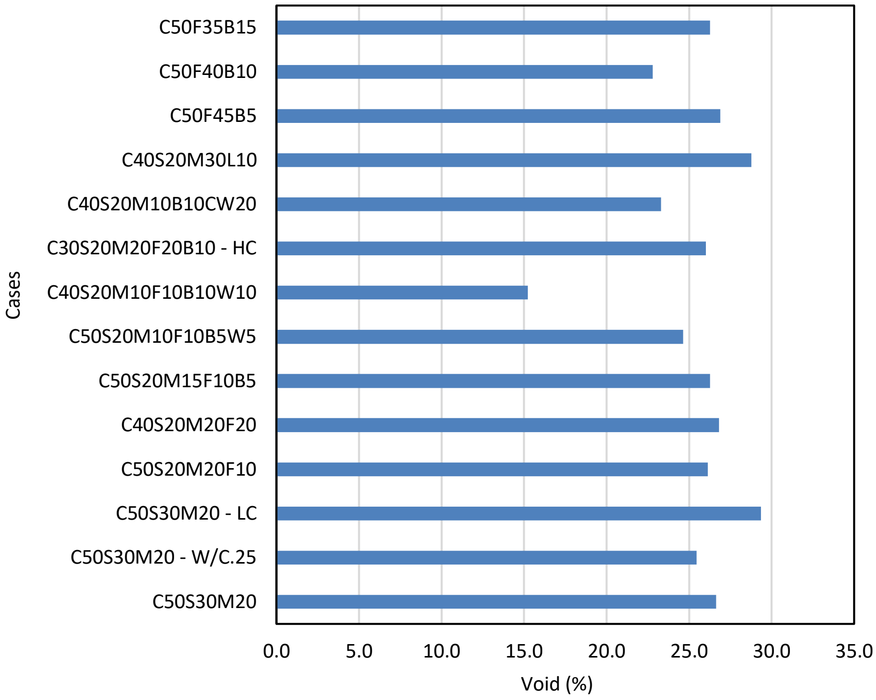

Fig. 3. Void (%) of Concrete Block

3.3 Absorption Capacity (%) of Concrete Blocks

The percentage of absorption capacity in various concrete block mixes is presented in Fig. 4. Among the mixtures, C50S30M20-LC exhibited the highest absorption capacity, approximately 13%. In contrast, the C40S20M10B10CW20 mixture demonstrated the lowest absorption capacity at around 6.5%. This variance in absorption capacity highlights the critical role of void percentage and material composition in influencing the absorption properties of concrete. Higher void percentages typically lead to increased absorption capacity, a trend evident in mixtures such as C50S30M20-LC, which exhibits both a high void percentage and high absorption capacity. Conversely, mixtures with lower void percentages tend to exhibit lower absorption capacities, as observed in the C40S20M10B10CW20 case, which also displayed relatively higher compressive strength compared to mixtures with higher absorption capacities. Additionally, mixtures with lower cement content displayed elevated absorption capacities, indicating greater porosity. Furthermore, a higher density of materials is associated with reduced absorption, similar to the effects of a lower water-to-cement ratio, which results in fewer voids.

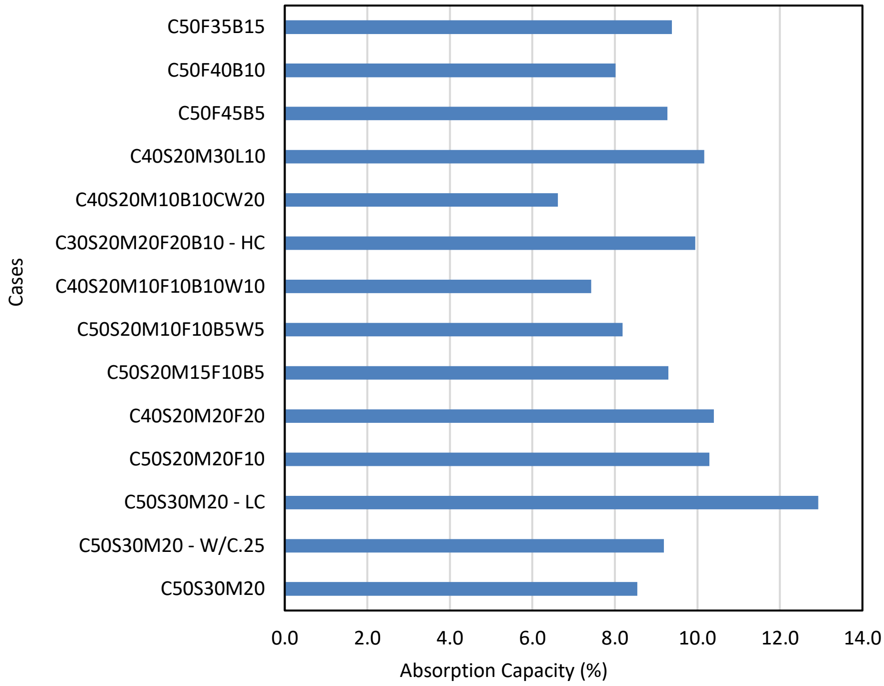

Fig. 4. Absorption Capacity (%) of Concrete Blocks

3.4 Boiling Water Absorption (%) of Concrete Blocks

The boiling water absorption percentage of the concrete block mixtures is shown in Fig. 5. Among the mixtures, C50S30M20-LC exhibits the highest boiling water absorption at approximately 16%, compared to C40S20M10F10B10W10, which has a significantly lower absorption rate of just under 8%. This substantial difference highlights the direct correlation among void percentage, absorption capacity, and boiling water absorption, as higher void percentages typically indicate increased porosity and, consequently, higher water absorption under boiling conditions. The C50S30M20-LC and C50S30M20-W/C.25 mixtures both demonstrate this characteristic, indicating that as void content increases, the capacity for water uptake under boiling conditions also rises. This correlation underscores the importance of porosity in influencing the physical properties of concrete blocks. In terms of structural integrity, it is crucial to minimize porosity and void content to enhance compressive strength. Mixtures such as C40S20M10F10B10W10, which exhibit lower void percentages, demonstrate not only reduced absorption rates but also improved compressive strength. This is because well-compacted and well-graded mixtures allow for better particle packing, leading to a denser structure that can withstand greater loads.

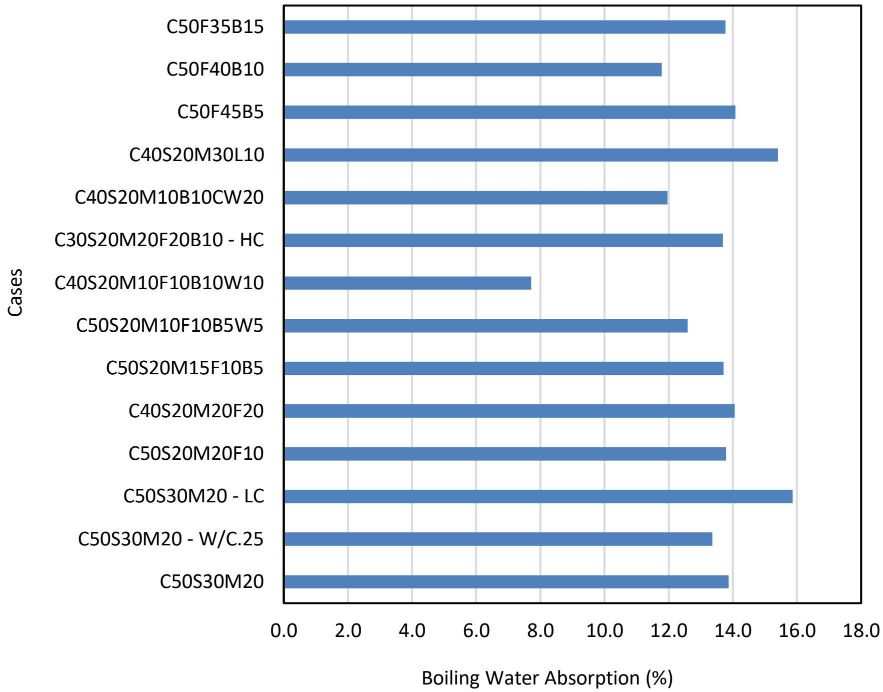

Fig. 5. Boiling Boiling Water Absorption (%) of Concrete Block

3.5 Compressive Strength and Void (%) Relationship

The relationship between compressive strength and void percentage in concrete blocks is illustrated in Fig. 6. Concrete block mixtures have a strong negative correlation between void percentage and compressive strength; the fewer voids in the concrete block mix, the more its compressive strength tends to increase. The relationship can be seen in the C40S20M10F10B10W10 mixture with its 15% (slightly lower) void percentage and compressive strength of about 1900 psi. This indicates that the well-graded materials and compaction actually managed to eliminate voids in this mixture, making a very solid concrete block. Also, mixtures like C50F35B15 and C50F40B10 have high compressive strength and lower void percentages, indicating a denser and stronger mix.

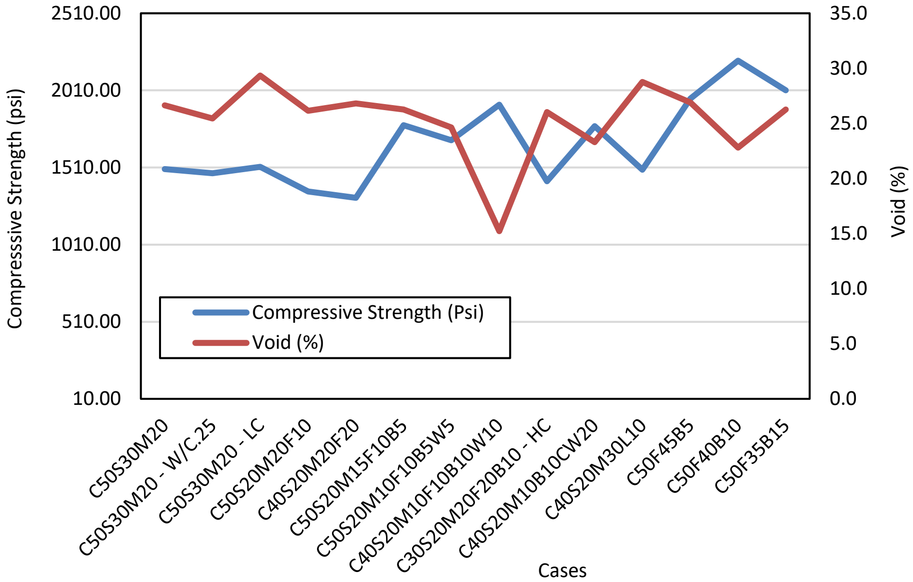

Fig. 6. Relationship between Compressive Strength and Void (%)

4 Conclusions

The results of this study demonstrate that industrial by-products can serve as effective partial replacements for aggregate materials in concrete block production. These by-products not only maintain but, in some cases, improve the mechanical properties of the blocks, offering a promising solution for sustainable construction. The key outcomes of this research are outlined below:

1. Brick dust and other industrial by-products can be used as partial replacements for aggregate materials.
2. Industrial by-product materials are effective in reducing void and water absorption capacity as required for concrete blocks.
3. All concrete blocks incorporating industrial by-product materials exceeded the standard strength criteria, achieving compressive strengths in the range of 1500 to 2000 psi.

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