

# Research Article

# Characteristics of Fibre-Reinforced Cement-Sand Blocks with Quarry Dust as Replacement for Sand

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The present investigation delved into the mechanical performance of fibre-reinforced cement-sand blocks with quarry dust as a replacement for sand. The introduction of fibres and quarry dust in the matrix is an attempt to achieve higher performance with available cement content and reduce the utilization of natural sand to improve the sustainability of the product. The experimental programme attempted to study the influence of quarry dust on the density, compressive strength, water absorption, sorptivity, and efflorescence characteristics of the blocks. The parameters considered include quarry dust (QD) content (replacement of sand from 0% to 100% in increments of 20%), a constant fibre content of 0.5%, and a constant water-cement ratio of 0.5. An attempt was also made to compare the strength performance of the blocks with various code requirements as well as results from similar previous investigations. The replacement of sand with QD resulted in a reduction in the density of the blocks from 2365 kg/m<sup>3</sup> to 2008 kg/m<sup>3</sup>. The results of the investigation revealed that 60% quarry dust replacement of natural sand developed the maximum strength of the blocks. After 28 days of curing, blocks with up to 60% QD replacement were able to produce strength more than 16 MPa. The water absorption increased only marginally from 5.52% to 5.83% for 60% QD replacement. Moreover, the blocks were able to meet the requirements of all the different types of blocks as stipulated by Bureau of Indian Standards including stabilized soil blocks, concrete solid blocks, concrete hollow blocks, lime-based blocks, and lime-flyash blocks of class up to 17.5.

# 1. Introduction

One of the oldest materials used in the construction industry is soil. The ease of availability, cost-effectiveness, and reasonable durability characteristics made it suitable for construction. The thickness of the wall is the major disadvantage while using this natural material, which is overcome by the use of stabilized blocks. The usage of stabilized blocks with sustainable material started in the early 20<sup>th</sup> century [1]. In the manufacture of stabilized blocks, lime is used if the soil possesses high expansive/plastic nature whereas cement is used for less expansive/low plastic clay soil. These blocks play a major role in housing and urban development of developing countries [2–4]. Earlier, manual process was used to make the soil blocks by altering the soil properties to the required configuration; i.e., if excessive clay is present in the soil medium, sand is added and vice-versa. With further development, developing countries along with the UN worked and developed semi and fully automatic block makers, still available in the market [5]. The types of the stabilized soil block (SSB) are grouped depending upon the geometry and types of additives used in the manufacturing process. The major limitations of SSBs blocks include low acceptability by the people and the need for technical knowledge and skilled labour [6, 7].

There have been a significant number of investigations in the development of SSBs. Both lime and cement have their own merits and demerits when used as stabilizers in SSBs. With lime as an additive, the compressive strength increases and reduces the cost of the brick by 41% compared to that of the conventional burnt brick [8]. With the addition of 7% lime (which is the initial consumption of lime for the chosen soil), the strength increases by four times because of the pozzolanic action [9]. The influence of applied forces on the compressive strength is reduced by 80% compared to that of cement as an additive. The SSBs stabilized with lime absorbs a better quantity of water for various forces under compaction [10]. The use of lime is preferable for clayey soil, thereby altering the particle size gradation. The use of lime in SSBs works well when it is used in lightweight structures [11].

The strength of the SSBs increases with an increase in the cement content, with an average range of 5 to 10% and reduction in clay percentage in soil; the ideal range of clay particles present in the soil is 15 to 30% for cement-stabilized blocks [12-15]. The major advantage of having cement as an additive is the increase in strength by threefold [8]. While considering the thermal conductivity of the SSBs, an increase in temperature, cement content, and density results in 12.5% increase in thermal conductivity [15]. This can be reduced by introducing natural fibres [9]. The water added should be more than the optimum moisture content obtained from the standard compaction test, as the mixture crumbles and the maximum density cannot be achieved. 4% of cement and proper curing increases the strength of the SSBs [16]. When a SSB is immersed in water for more than 48 hours, a reduction in strength is observed [17], as the sample is totally disintegrated. However, the use of cement in the development of such blocks is still a point in question from the point of view of sustainability as cement is a carbon footprint heavy material. Despite this argument, the emissions from cement-based SSBs are 2.4 and 7.9 times lower than conventional wire-cut bricks and country fired bricks, respectively [18]. Thus, cement-based SSBs provide the advantage of higher strength when compared to lime-based SSBs along with lower emissions when compared to conventional bricks.

The development of SSBs evolved with the utilization of waste materials as fibres especially natural materials. With the addition of 0.25% bagasse fibre as a replacement with cement as an additive, the compressive strength of the block increased by 7% [19] and it could withstand 12 cycles of wetting and drying [20]. Sisal fibre shows higher strength performance in acting as reinforcement in SSBs in countries like Nigeria [21]. The addition of 1% pineapple leaf fibre by volume in mortars mixed with silica aerogel was capable of arresting the deterioration in compressive strength associated with the addition of silica aerogel [22]. Apart from the natural fibres, man-made fibres such as polypropylene fibres are used to increase the resistance of the block from the crack formation apart from the increase in strength [23, 24]. In addition to the primary additive, binary additives such as fly ash, quarry dust, and rice husk ash when added to cementand lime-based SSBs increase the compressive strength of the blocks [9, 25, 26].

Quarry dust (QD) is a waste that is generated during rock crushing process [27]. In recent times, multiple researchers have worked on the utilization of QD as a fine

aggregate, particularly as a replacement for natural fine aggregates like river sand. Along with SSBs, researchers have also worked on the development of cement bound sandcrete blocks as construction and masonry units. Kiptum et al. [28] attempted to study the strength performance of lightweight QD blocks with the help of expanded polystyrene wastes. Lee et al. [29] attempted to investigate the thermal performance of structural lightweight concrete composites with QD as one of its components. Chin et al. [30] attempted to develop sustainable green bricks using agro-industrial waste materials including QD. Kiptum et al. [31] attempted to study the mechanical characteristics of concrete reinforced with dried water hyacinth with QD as fine aggregates. Kadir et al. [32] attempted to characterize the mechanical properties of fired clay bricks incorporated with QD up to 30%. Mirasa et al. [33] delved into the performance of interlocking bricks with QD as replacements for sand. Prakash and Hanumantha Rao [34] studied the strength performance of concrete cubes with QD as a replacement for sand. Anya and Osadebe [35] investigated the partial replacement of sand with QD in sandcrete blocks. Irwan et al. [36] attempted to study the performance of cement-sand bricks with QD and different types of bacteria. Febin et al. [37] studied the strength and durability properties of concrete with QD. Kartini et al. [38] looked into the performance of lightweight sand-cement bricks with QD, rice husk, and kenaf powder. Sivagnanaprakash et al. [39] carried out a study on the structural applicability of QD flyash bricks. Azrizal et al. [40] investigated kenaf fibre-reinforced concrete blocks with QD as replacement for fine aggregates. A sift through the extensive literature available on the manufacture of lime-based and cement-based SSBs indicates an extensive array of binary waste additives as well as fibre reinforcement. The distinction between soil blocks and mortar/concrete blocks needs to be emphasized. The former has natural soil as its primary ingredient which fills the matrix of the block whereas the latter specifically has river sand as the filler material. Naturally, the latter tends to develop higher compressive strength than the former. In fact, BIS recommendations of minimum strength for soil blocks [41] are lower than those of concrete blocks [42]. Again, the distinction between mortar and concrete brings out a clear difference in the mechanical performance of concrete blocks when compared to mortar blocks with concrete being significantly stronger than mortar. The novelty of the investigation should be understood under this backdrop. In a significant number of investigations, QD has been adopted as a replacement for natural river sand, both in concrete as well as mortar. Even investigations on fibrereinforced concrete have been dealt with extensively. However, investigations on fibre-reinforced cement-sand bricks/blocks were very limited as fibre reinforcement was predominantly adopted in soil-based blocks/concrete rather than sandcrete blocks. Moreover, the combination of fibre-reinforced sandcrete blocks with QD as replacement was rare in literature. Thus, the present investigation attempted to study the hydromechanical performance of polypropylene fibre-reinforced cement-sand blocks with QD as a replacement for sand.

# 2. Materials Used

The materials used for the manufacture of the cement stabilized sand blocks with quarry dust (CSQ) were ordinary portland cement (OPC), sand, QD, and polypropylene fibres (PPFs). The OPC used was of 53 grade and purchased from a local supplier of construction materials. The cement was subjected to a specific gravity test, which came out to be 3.15. Clean river sand was procured from a local supplier and subjected to specific gravity and sieve analysis tests. QD used in the investigation was procured from a local stone crushing unit for the purpose of the investigation. The specific gravity of QD used in the investigation lies in the range of 2 to 2.7 suggested by Prakash and Hanumantha Rao [34]. The grain size distribution of the sand and QD used in the investigation is shown in Figure 1. Commercially available PPFs were used as fibre reinforcement for the CSQ blocks. The PPF had a length of 12 mm and diameter of 0.025 mm with an aspect ratio of 480. The specific gravity of the sand and QD came out to be 2.67 and 2.06, respectively. The bulk density of the sand was found as 17.03 kN/m<sup>3</sup>, and for QD, it was 17.61 kN/m<sup>3</sup>. Figure 2 shows the typical surface characteristics of waste QD [43].

# 3. Investigation Procedure

The investigation procedure began with the characterization of the materials, followed by the selection of mix proportions, preparation of the mix, casting, curing, and testing. The methodology developed was based on an earlier work done by Vijayaraghavan et al. [44] which was also adopted by Saraswathy et al. [45].

3.1. Characterization of Materials. The different materials used in the investigation were characterized for their properties based on various codes of the Bureau of Indian Standards (BIS). OPC was subjected to various tests including normal consistency [46], initial and final setting times [47], fineness [48], specific gravity [49], and soundness tests [50]. Sand and QD were subjected to a specific gravity test [49] and tested for their grain size distribution [51]. All tests followed standard procedures stipulated in relevant codes of BIS, and hence individual test procedures have not been described in detail here. No specific tests were performed on the PPFs. Tables 1 and 2 give the various properties of cement and its chemical composition, respectively.

3.2. Mix Proportions. The CSQ blocks were prepared using a mortar mix of OPC with sand in the ratio of 1:4 with a water to cement (w/c) ratio of 0.5. PPFs were introduced in the blocks for the purpose of reducing the shrinkage cracks. Several investigations using PPFs in fibre-reinforced concrete utilized fibre content in the range of 0 to 2% with most of the investigations adopting fibre content less than or close to 0.5% [23]. Based on this, the quantity of the PPF was nominally fixed at 0.5% by weight of the total mix. To reduce the quantity of river sand in the mix to achieve sustainability, it was replaced in multiple stages using QD in increments of



FIGURE 1: Grain size distribution of sand and QD.



FIGURE 2: Microstructure of QD [43].

20% by weight of sand. The various mixes used in the investigation are shown in Table 3 considering the weight of the total dry mix as 100%.

3.3. Preparation of the Mix. All the ingredients of the mix were weighed to satisfy the mix proportions and were manually mixed thoroughly to obtain a uniform dry mix. After the completion of dry mixing, the requisite quantity of water to satisfy a water to cement ratio of 0.5 was weighed out and added to the dry mix in stages to obtain a uniform wet mix.

3.4. Moulding of the Blocks. Hand moulding technique of block manufacture was adopted in this study. Immediately after obtaining the wet mix, it was packed in moulds of dimensions  $190 \text{ mm} \times 90 \text{ mm} \times 90 \text{ mm}$  [41] in three layers. Gentle tamping using a tamping rod was done to ensure that no large voids were formed within the mix matrix. The excess mix was struck off from the top of the mould and levelled to achieve a clean and plain surface. No hydraulic pressure was applied to form the blocks. Figure 3 shows the demoulded blocks before moving to curing under wet gunny bags.

*3.5. Curing and Testing.* The blocks were demoulded after 1 day and cured by placing the blocks under wet gunny bags for periods of 7, 14, and 28 days. Care was taken to ensure that the gunny bags were maintained in wet conditions

Property	Value
Normal consistency (%)	29.5
Initial setting time (min)	69
Final setting time (min)	195
Fineness (% retained)	5
Specific gravity	3.15
Soundness (mm)	2.00

TABLE 2: Chemical composition of cement.

Oxide	Composition (%)
SiO <sub>2</sub>	19.71
Al <sub>2</sub> O <sub>3</sub>	5.20
Fe <sub>2</sub> O <sub>3</sub>	3.73
CaO	62.91
MgO	2.54
$Na_2O + K_2O$	1.15

TABLE 3: Mix proportions.

OPC (%)	Sand (%)	QD (%)	PPF (%)	w/c ratio	Notation
19.900	79.602	0.000	0.498	0.5	CS
19.900	63.682	15.920	0.498	0.5	CSQ20
19.900	47.761	31.841	0.498	0.5	CSQ40
19.900	31.841	47.761	0.498	0.5	CSQ60
19.900	15.920	63.682	0.498	0.5	CSQ80
19.900	0.000	79.602	0.498	0.5	CQ



FIGURE 3: Fibre-reinforced cement-sand blocks.

throughout the duration of the curing. At the end of the curing periods, the blocks were tested for their compressive strength, water absorption, and efflorescence based on the relevant BIS code [52]. Figure 4 shows the testing of the brick in a compression testing machine and immersion in water for determination of water absorption.

#### 4. Results and Discussion

The results of the investigation including the compressive strength, water absorption, and efflorescence tests are discussed in the following sections. 4.1. Density of the CSQ Blocks. The density of the blocks influences the dead weight of the walls. This in turn affects the structural, thermal, and acoustic design of the buildings. Figure 5 shows the density of all the block combinations studied.

The addition of QD into the cement-sand blocks results in a reduction in the density of the blocks. The average density of the CSQ20 blocks was 2289.80 kg/m<sup>3</sup> which reduced to 2032.49 kg/m<sup>3</sup> for CQ blocks. The reduction in the density of the CSQ blocks is well correlated with the proportion of QD as seen from the  $R^2$  value of 0.9276. Kadir et al. [32] also reported a reduction in the density of QD



FIGURE 4: (a) Compression test and (b) water absorption.



substituted fired clay bricks with an increase in the QD proportion from 0 to 30%. They attributed the reduction in density due to the increase in porous nature of the blocks with QD addition. All CSQ blocks also satisfy the minimum density requirement of 1800 kg/m<sup>3</sup> required by the BIS code for concrete solid blocks [42].

4.2. Strength of the CSQ Blocks. The strength performance of the polypropylene fibre-reinforced cement-sand blocks with different replacement levels of QD has been discussed in the following sections. An attempt has been made to study the compressive strength, progression of compressive strength, percentage strength gain, and comparison with code requirements.

4.2.1. Compressive Strength. Figure 6 shows the development of strength of all the different blocks investigated in this study. The average 7-day compressive strength of the



FIGURE 6: Compressive strength development of CSQ blocks.

control specimen viz. the CS block was 7.6 MPa, which increased to 12.86 MPa at 14 days of curing and 16.17 MPa at 28 days of curing. When the block mix was modified by replacing 20% of the sand with QD, the CSQ20 block developed 8.57 MPa at 7 days of curing, which increased to 13.35 MPa and 16.76 MPa at 14 and 28 days of curing, respectively. When the replacement of sand with QD was increased to 40%, it developed 9.06, 14.61, and 17.28 MPa for 7, 14, and 28 days of curing, respectively.

This trend continued for the CSQ60 blocks as well with the corresponding strengths of 9.75, 15.2, and 17.66 MPa, respectively. On further increase in the QD content, there was a drastic reduction in the strength of the specimens. The strengths dropped to 7.45, 10.78, and 14.91 MPa for 7, 14, and 28 days of curing, respectively. When sand was completely replaced with QD, the strength of the blocks was further reduced to 6.54, 9.94, and 14.09 MPa corresponding to 7, 14, and 28 days. Thus, from the results of the compressive strength test, it can be inferred that up to 60% river sand can be replaced with QD without loss in performance. In fact, the replacement of sand with 60% QD results in the maximum strength of the CSQ blocks. Febin et al. [37] also reported 60% QD as the optimal dosage in cement concrete blocks generating a strength of more than 25 MPa. Muhit et al. [53] reported a strength of 33.5 MPa when 50% of the sand was replaced with QD. However, it must be noted that they used a cement to sand ratio of 1:2.5. Anya and Osadebe [35] reported a strength of 5.23 MPa for 1:6 cement mortar block with 40% QD replacement after 28 days of curing. Kartini et al. [38] reported a strength of 36.4 MPa for 1:3.5 ratio cement mortar blocks with 10% QD replacement at 28 days of curing. Abdullah et al. [54] reported a strength of 12 MPa for 100% QD block with a cement to QD ratio of 1: 10. However, these studies did not use any fibre reinforcement. Azrizal et al. [40] reported a strength of 27.49 MPa for 1:2.5 ratio cement mortar block with 50% QD replacement and reinforced with 0.5% kenaf fibres.

The surface texture of the QD particles is rough, and the individual particles are angular in nature. These characteristics play a vital role in the strength modification of the blocks with QD. The increase in strength of the blocks with the increase in QD replacement of sand is attributed to the improved bond strength between the binder and the QD [55]. QD, in general, has a rougher surface texture when compared to natural river sand due to the difference in the process of formation. This rough surface texture induces better frictional interaction between the fine aggregate and the cement paste in the matrix resulting in augmentation of the compressive strength of the block. In addition, the angular nature of the QD enhances the resistance to crack propagation through the interlocking of particles within the matrix of the stabilized block [56]. The reduction in strength beyond 60% QD replacement can be attributed to the finer particles present in QD. Based on the analysis of grain size distribution data for QD, only around 18.5% of the particles are of coarse size whereas the remaining particles are of medium and fine size. The specific surface area of the particles increases with the reduction in particle size. Increased specific surface area required more binder content to coat and bind the aggregate phase in the matrix [55]. As a result, there is insufficient binder paste available in the matrix to coat and bind the particles resulting in poor interlocking between the aggregate and binder with a detrimental effect on the mechanical strength [57]. In addition, the increased water absorption tendency of QD reduces the availability of free water in the matrix, thereby reducing the degree of compaction leading to more voids and poorer microstructure of the blocks [56], further contributing to the reduction in strength of the blocks beyond the optimum dosage of 60%.

4.2.2. Progression of Strength. Looking at the strength development of the blocks, it was seen that there is a clear difference in the progression of strength up to 14 days and

then beyond. To better put the progression of strength in to perspective, a strength progression rate (SPR) was worked out for the progression between 7 and 14 days considered as stage 1 and 14 to 28 days considered as stage 2. Figure 7 shows the SPR of the stages 1 and 2 of the reinforced CSQ blocks with an increase in QD content. At the outset, from the pattern of the curves, there seems to be an opposing behaviour in SPR for stages one and two. On closer observation, however, for stage 1, the SPR of the CS block decreases from 0.75 MPa/day to 0.68 MPa/day for CSQ20. Thereafter, it increases to 0.79 MPa/ day for CSQ40 after which it decreases to 0.48 MPa/day for CSQ80. Beyond CSQ80, the SPR marginally increases to 0.49 MPa/day. On the other hand, the SPR of stage 2 increased marginally from 0.237 to 0.244 MPa/day for CSQ20, followed by a steady dip to 0.175 MPa/day for CSQ60. Thereafter, it steadily increases to 0.296 MPa/day till CQ. The second inference that can be deciphered from the figure is that there is significant variation in the SPR in stage 1 of the curing when compared to stage 2 of the curing. Thus, the variation in the composition of the CSQ block significantly influences the strength progression in stage 1 when compared to stage 2 of curing. This is in line with the established theories that early curing plays a significant role in the development of strength of cement/lime-based materials.

4.2.3. Percentage Strength Gain. Figure 8 shows the percentage strength gained by the CSQ blocks. The percentage strength gain increases with an increase in the QD content till 60% irrespective of the curing duration. Beyond 60% replacement of sand with QD, there is a loss in strength when compared to the control CS block as seen from negative percentage strength gain values. CSQ20 block can achieve 3.65% gain after 28 days of curing. This further increases to 6.81% gain for CSQ40. The highest gain after 28 days of curing is achieved for CSQ60 at 9.17% beyond which there is a strength loss with CSQ80 and CQ losing strength by 7.84% and 12.88%, respectively. Moreover, it can also be seen that the highest percentage strength gain happens after 7 days of curing and the percentage strength gain reduces with increase in curing. For CSQ20, the 7-day gain was 12.7% which reduces to 3.81% and 3.65% for 14 and 28 days of curing, respectively. For CSQ40 and CSQ60, the corresponding values were 19.21%, 13.61%, and 6.81% and 28.22%, 18.22%, and 9.17%, respectively. Thus, 60% of the sand can be saved by replacing it with QD while also achieving a 9.2% increase in strength of the blocks.

4.2.4. Comparison with Code Requirements. Figure 9 shows the comparison of the strength of the QD blocks with minimum strength requirements from BIS codes. BIS code IS1725 [41] recommends two classes of SSBs viz. class 20 SSB and class 30 SSB having compressive strengths of 1.96 MPa and 2.94 MPa, respectively. BIS code IS 2185 [42] recommends two classes of concrete solid blocks (CSBs) viz. C4 and C5 with compressive strengths of 4 and 5 MPa, respectively. It also recommends 8 classes of concrete hollow blocks (CHBs) viz. A3.5 to A15 with corresponding compressive strengths ranging from 3.5 MPa to 15 MPa.



FIGURE 7: SPR of reinforced CSQ blocks.



FIGURE 8: Percentage strength gain of CSQ blocks.



FIGURE 9: Comparison of the CSQ block strength with various BIS specifications.

BIS code IS3115 [58] recommends a minimum compressive strength of 3.5 MPa for lime-based blocks (LBBs). BIS code IS12894 [59] recommends a total of 10 classes of lime-flyash bricks (LFABs) ranging from class 3.5 to class 30 with strengths from 3.5 MPa to 30 MPa, respectively. From the figure, the CSQ blocks with up to 60% QD replacement can meet the specifications of almost all blocks except for the LFAB class 20 and above. Even CSQ80 and CQ blocks are able to meet the strength requirements of C4 and C5 concrete blocks and almost meet the requirements of A15 concrete hollow blocks which is the highest class of hollow blocks as per the BIS code [42].

4.2.5. Comparison with Other Investigations. To gauge the performance of the fibre-reinforced CSQ blocks in relation to similar previous studies, a comparative graph on strength gain ratio (SGR) vs. QD to sand ratio (QSR) was plotted. The SGR is defined as the ratio of the strength of the QD replaced cement-sand block with that of the control cement-sand block. The QSR is defined as the ratio of sand to QD in the mix. For the purpose of the comparison, the selection of the studies for comparison was made on the following criteria: (1) cement used as binder, (2) sand used as fine aggregate without the use of soil/solid waste additives/coarse aggregates, and (3) use of fibre reinforcement, if any. The inherent limitations of the comparison were (1) use of different mix ratios of cement and sand, (2) differences in water to binder ratio, and (3) differences in the method of casting of the blocks. Based on the above criteria, the studies selected for the comparison are shown in Table 4.

Figure 10 shows the comparison of the present study with previous investigations using QD as a replacement for sand in the cement-sand blocks. For the purpose of clarity, the data from the present study were limited to a QSR of 1.5. Only the work done by Azrizal et al. [40] involved the use of fibre reinforcement, while the rest of the investigations only used QD replacement.

Based on the comparison of the different studies, there are no clear trends or patterns that can be inferred from the graph. With the exception of the work done by Azrizal et al. [40], all the other investigations reported SGR greater than 1 for atleast one combination. The maximum SGR of all the studies was reported by Anya and Osadebe [35]. They reported SGR values of up to 1.27 for a QSR of 0.67. However, their absolute compressive strengths were the lowest of all studies compared, in the range of 4.1 to 5.2 MPa. In the present study, Anya and Osadebe [35] and Rai et al. [60] reported only positive beneficial impact of QD replacement in cement-sand blocks. Their SGR values ranged from 1.036 (reported in the present study) for a QSR of 0.25 to 1.27 for a QSR of 0.67. The work reported by Kartini et al. [38] showed the influence of binder on the fine aggregate ratio. However, even their investigation did not reveal a clear relationship between the binder mix ratio and compressive strength with SGR values fluctuating significantly. One trend which could be traced from their investigation was the reduction in QSR values with the reduction in cement content in the cement-sand block. This indicates that there is a reduction in the quantity of QD that was valorized in the block for achieving maximum SGR, with the reduction in the binder content. This inference, however, cannot be generalized as the trends shown by others do not conciliate with the postulation due to variation in several factors including the characteristics of the sand and QD used in the block

TABLE 4: Studies selected for comparison.

Author(s)	Mix ratio	QD replacement (%)	w/c ratio	Fibre name and content (%)
Present study	1:4	20, 40, 60, 80, 100	0.5	PPF, 0.5
Kartini et al. [38]	1:2.5, 1:3, 1:3.5	10, 15, 20, 30, 40	0.5	
Anya and Osadebe [35]	1:6	10, 20, 30, 40, 100	DNR	
Azrizal et al. [40]	1:2.5	50	0.5	Kenaf fibre, 0.5, 1, 1.5
Rai et al. [60]	1:3	20, 50, 100	0.44	

DNR, data not reported.



FIGURE 10: Comparison of the present study with previous studies.

manufacture. However, the postulation can act as a starting point for future investigations to focus on the relationship between QD valorization and cement content of the block. The work done by Azrizal et al. [40] did not vary the QD content but only the fibre content. Their results indicated a negative SGR with increase in fibre content for stable QSR. This can also form the fulcrum for future investigations where the influence of fibres on the valorization quantum of QD can be studied.

4.3. Sorption Performance of the CSQ Blocks. The sorption performance of the CSQ blocks was analysed by studying the water absorption and sorptivity of the CSQ blocks.

4.3.1. Water Absorption. Figure 11 shows the water absorption of the different CSQ blocks studied in the investigation. The water absorption of the CSQ blocks cured for different periods indicates that there is an increase in the water absorption of the CS blocks with an increase in the replacement of sand with QD. There is no big difference between the water absorption levels of CS and CSQ20 with the values of water absorption lying very close to each other. The water absorption of CSQ20 cured for 28 days increases



FIGURE 11: Water absorption of CSQ blocks.

marginally from 5.52% to 5.55%. With further increase in the QD content in the mix, the water absorption values increase further. The water absorption values for CSQ40, CSQ60, CSQ80, and CQ were 5.65%, 5.83%, 6.06%, and 6.5%, respectively, after 28 days of curing.

The BIS code recommends a maximum water absorption of 20% up to class 12.5 of LFABs [59] and 15% for higher classes of LFABs [59] and for SSBs [41]. Thus, it is evident that the water absorption of the CSQ blocks is well within the requirements expected by standards. As expected, the water absorption of the CSQ blocks, irrespective of the QD content, reduces with the increase of curing period. This is primarily due to the formation of reaction products due to the hydration of cement in the blocks resulting in deposition of calcium silicate hydrate and calcium aluminium hydrate gels with increase in curing, which render the blocks less permeable. The influence of QD content on the water absorption is also significant only after 60% replacement of sand with QD as seen from the gap between the curves for different QD replacements.

4.3.2. Sorptivity. The sorptivity is calculated by taking the volume of water absorbed in various combinations of the stabilized block [61]. It was felt that the volume of water absorbed after 28 days of curing showed a minimal value for the combination CSQ60. With no QD in the stabilized block (control specimen), the volume of water absorbed was 200.93 cc; this further reduced very marginally with the addition of QD [37]. However, the control specimen had the maximum volume of absorption and a similar value was



FIGURE 12: Volume of water absorbed for various combinations.



observed for the specimen with 100% sand replaced by QD (200.85 cc). The maximum reduction is observed at 60% QD replacement with a percentage reduction which came out to be 0.574% (Figure 12). When the amount of water absorbed is less, it indicates that the capillary rise of moisture through the specimen is influenced by the addition of QD. Figure 12 shows an almost flat trend.

In continuation, the sorptivity behaviour of the specimen was also studied using the formula shown in the following equation:

$$\frac{Q}{A} = k\sqrt{t}, \qquad (1)$$

where Q is the volume of water (cc), A is the cross-sectional area of the specimen (cm<sup>2</sup>), k is the sorptivity coefficient (cm/ $\sqrt{\text{sec}}$ ), and t is the time (sec).

The agenda of understanding the sorptivity was to study the capillary suction in its surface. The "*k*" value indicates the obstacles faced by the water on its surface because of suction. The sorptivity of the block for the control specimen was taken as the reference value; in the current study, the value is  $1.52698 \times 10^{-4}$  cm/ $\sqrt{\text{sec}}$ . With further addition of QD, the pattern remains similar to that of the volume of water absorption. With 20, 40, 60, 80, and 100% QD replacement, the value changes to 1.5212, 1.5214, 1.5182, 1.521, and  $1.5264 \times 10^{-4}$  cm/ $\sqrt{\text{sec}}$ , respectively. These values show that there is no significant change in the sorptivity behaviour (Figure 13).

As sorptivity can give an indication of the durability of the specimen, a lower value indicates a more suitable combination. From the results, it is understood that at 60% QD replacement, the sorptivity value is the least of all combinations with QD replacement. However, it must be noted that the sorptivity values of QD replaced specimens are like the control specimen, and hence more direct durability tests can give a clear indication of the durability performance of the QD-replaced samples in comparison with the control specimen.

4.4. Efflorescence of the CSQ Blocks. Table 5 presents the results of the efflorescence test performed on the CSQ blocks based on the procedure laid down in BIS code [52]. The efflorescence tests revealed that there is no perceptible deposition of salts on the surface of the CSQ blocks, and hence all blocks were considered to have nil efflorescence. This is well within the expected standards of BIS [59], according to which the LFAB should not have an efflorescence rating poorer than "moderate" for classes up to 12.5 and "slight" for higher classes of blocks.

TABLE 5: Efflorescence test results.

Block designation	Description	Efflorescence rating
CS	No perceptible deposit	Nil
CSQ20	No perceptible deposit	Nil
CSQ40	No perceptible deposit	Nil
CSQ60	No perceptible deposit	Nil
CSQ80	No perceptible deposit	Nil
CQ	No perceptible deposit	Nil



FIGURE 14: Linear regression.

4.5. Regression Analysis. A regression analysis was performed to understand the influence of quarry dust and its associated characteristic density in addition to the influence

of curing period on compressive strength through the following equation:

compressive strength = 
$$0.07772$$
 (quarry dust) +  $0.028322$  (density) +  $0.36$  (curing period) -  $60.62$ . (2)

ANOVA (analysis of variance) shows a threshold p value of 0.021. A graph (Figure 14) is plotted for actual and the predicted compressive strength in MPa with a  $R^2$  value as 0.8819 which is almost equal to 0.9, which depicts a linear regression of 88.19% goodness of fit.

The developed equation shows a major influence of curing period for 7, 14, and 28 days. It is a well-established theory that as the curing period increases, mortar/concrete tends to gain strength and improved durability behaviour. The next influencing factor is the quarry dust followed by the density. This gives a major confidence in using the quarry dust as a replacement material for sand which is a natural depleting source.

# 5. Conclusions

A laboratory study was conducted to understand the behaviour of polypropylene reinforced cement-sand blocks with QD as replacement for sand. The influence of the various combinations on the strength behaviour, efflorescence, and sorptivity was investigated, and the following conclusions were drawn based on the experimental results:

 The addition of QD reduces the density of the block from 2290 kg/m<sup>3</sup> to 2032.5 kg/m<sup>3</sup> while also meeting the minimum strength required for earthquakeprone regions as per BIS recommendations. Thus, it can be concluded that QD replacement of sand in the fibre-reinforced cement-sand blocks can be an effective technique for achieving lighter weight construction units, also suitable for earthquake prone regions.

- (2) The compressive strength of the fibre-reinforced cement-sand blocks increased from 16.17 MPa for the control specimen (CS) to 17.66 MPa for 60% replacement of sand by QD (CSQ60). There was a reduction in the compressive strength of the blocks on further increase in QD proportion in the mix. Thus, it can be concluded that up to 60% of the sand can be effectively replaced using QD without loss in performance of the blocks. This may have been due to the improved frictional resistance of the mix due to QD based on the spread of its particle size and surface characteristics when compared to sand.
- (3) The water absorption of CSQ blocks increased from 5.52% for CS blocks to 6.5% for CQ blocks. However, this water absorption was well within the permissible limit of 15% for SSBs as prescribed by BIS. Thus, it can be concluded that the replacement of sand with QD does not detrimentally affect its water absorption behaviour. Compared to all the QD replaced

specimens, CSQ60 blocks showed the least sorptivity value indicating a better resistance to water exposure. The volume of water absorption and sorptivity decreases marginally when compared to that of the control specimen with the addition of QD. However, the 100% QD replaced specimen shows similar behaviour to that of the control specimen.

(4) From the efflorescence tests, the presence of perceptible deposition of salts is absent. Thus, it can be concluded that the absence of efflorescence in the CSQ blocks indicates that the introduction of QD does not contribute to or modify the efflorescence behaviour of the blocks thereby ensuring soundness and structural integrity of the blocks and the resulting masonry.

# **Data Availability**

The data used to support the findings of this study are available from the corresponding author upon reasonable request.

# **Conflicts of Interest**

The authors declare that they have no conflicts of interest.

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