

# Advancing Sustainable Concrete: A Review for Eco-Friendly Construction

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**Abstract:** The most popular building material in the world is concrete, however because of its negative effects on the environment from excessive cement use and the removal of natural aggregates, sustainable alternatives must be investigated. The potential of recycled red brick powder (RRBP) and quarry limestone dust (QLD) as partial substitutes for cement and fine aggregates, respectively, in low-load concrete applications is assessed in this paper. According to the results of a review of thirty research publications, it is possible to utilize up to 20% RRBP and 40% QLD efficiently without suffering a noticeable reduction in strength. In addition to preserving adequate workability, mechanical performance, and durability, the combined use increases the sustainability of concrete. Future research goals, implementation issues, and the impact of these materials on concrete qualities are also covered in this study.

**Keywords:** Eco-friendly concrete, Quarry dust, Red Brick Powder, Cement Replacement.

## I. INTRODUCTION

Energy-efficient technologies, alternative fuels, clinker substitution, and emerging and novel technologies are the four main avenues for attaining environmental sustainability in the cement industry, according to the Cement Technology Roadmap. Further research is now being conducted on these topics. Clinker substitution, which involves replacing some of the cement with SCMs (Supplementary Cementing Materials) such fly ash, GGBFS (Ground Granulated Blast-Furnace Slag), silica fume, and limestone powder, is a popular technique that is perhaps the simplest and most cost-effective [1].

In that experiment, clinker brick waste was completely substituted, and the resulting concrete had an appreciable compressive quality comparable to ordinary concrete prepared with pulverized stone total. The evaluation did not change the coarse total degree of the clinker brick [3]. Adding limestone filler to cement formulas provides several benefits, including increased yield, lower manufacturing costs, and reduced CO<sub>2</sub> and NO<sub>2</sub> emissions per ton of cement. The European Standard EN 197 divides Portland limestone cement into two types: Type II/A-L, which contains 6-20% limestone, and Type II/B-L, which contains 21-35%. Furthermore, up to 5% calcareous filler is authorized in all cement types. In the United States, ASTM C150 was revised in 2004 to permit up to 5% limestone in ordinary Portland cement.

Limestone filler improves early-age strength in cementitious materials by increasing the availability of nucleation sites and accelerating the hydration of tricalcium

silicate (C<sub>3</sub>S), as shown in experimental study. Studies have also highlighted limestone's function in both hydration processes and production methods, particularly when mixed with clinker. While commonly used abroad, this method has yet to acquire hold in Ethiopia.

Cement costs and demand in Ethiopia have been continuously rising, owing to restricted manufacturing capacity and a narrow choice of cement kinds. Addressing this issue necessitates increasing production and researching new cement compositions with lower costs and greater environmental performance. Limestone-blended cements fit these criteria since the raw materials are plentiful, the production process uses less energy, and the emissions footprint is much reduced. Such cements present a realistic and cost-effective answer for Ethiopia, where OPC and PPC are still the leading cement types employed across all building industries [4].

Quarrying operations generate large amounts of solid waste, which is usually disposed of in open spaces without effective management. Such practices contribute significantly to environmental degradation and may constitute a health risk to nearby communities. An effective and sustainable strategy to mitigating these effects is to use quarry waste as a supplementary material in building. This technique not only handles trash disposal issues, but it also promotes environmental sustainability through resource recovery and material reuse[5]. To assure the homogeneity, durability, and engineering performance of self-consolidating lightweight foamed concrete (SCLWFC) in both fresh and hardened states, changes to the standard concrete mix design are required. Certain formulations may present issues such as bleeding, settling, and segregation. The use of superplasticizers improves flowability without compromising stability. Furthermore, optimizing combinations with moderate quantities of cementitious materials and fine fillers minimizes coarse aggregate content, improving segregation resistance and lowering costs associated with high cement and superplasticizer doses.

Limestone powder, a common mineral additive and a key source of calcium carbonate, is increasingly employed as a partial cement replacement. Its usage in Portland cement production can reduce energy consumption, save raw material resources, and reduce environmental effect. According to BS EN 197-1:2000, up to 35% limestone powder can be added to Portland limestone and composite cements. Fine limestone powder has been proven in studies to speed up cement



hydration, increase strength development, and improve the deformability and stability of fresh self-consolidating concrete.

Despite its advantages, limestone powder is rarely studied as a major additive for SCLWFC. It is commonly utilized in conjunction with various additional materials such as silica fume, fly ash, or metakaolin. Existing research yields conflicting data on its effect on flowability and strength. This research studies the effects of limestone powder, both as an addition and as a cement replacement, on the flowability and compressive strength of SCLWFC [6]. In recent decades, substantial study has concentrated on using industrial byproducts (e.g., fly ash, blast furnace slag, micro silica) and natural resources (e.g., limestone, pozzolans) as partial replacements for coarse aggregates in concrete. Among these, limestone fillers have been widely used due to their abundance, low cost, and little environmental impact. The properties of fine particles have a substantial impact on the performance of both fresh and hardened concrete, principally via the "filler effect," necessitating comprehensive material characterization. Although rheological issues may develop, they are usually resolved with the use of admixtures and viscosity-modifying chemicals. Previous research has extensively documented the impact of limestone filler on the workability and mechanical qualities of concrete [7]. By using leftover CO<sub>2</sub> from cement manufacturing, nanotechnology—in particular, the usage of nano CaCO<sub>3</sub>—is becoming more and more popular as a partial substitute for cement clinker, providing both financial and environmental advantages [1]. CO<sub>2</sub> emissions can be decreased by utilizing cutting-edge technology like carbon capture, storage, and clinkers manufactured from substitute raw materials [8]. The building industry's demand for sand is increasing, causing resource depletion and prompting the hunt for alternatives such as Dimension Limestone Waste (DLW) [4]. Research is examining the practicality of geopolymers and the utilization of geopolymer waste aggregates. Studies indicate potential benefits in mechanical qualities compared to OPC concrete [9].

Reducing the amount of land needed for trash disposal and conserving natural aggregate resources are two benefits of using waste materials like concrete and bricks in concrete construction [10]. Solid waste from mining, including rock dusts from various geological origins, is considered a separate waste component [11]. Cement manufacture is a significant source of CO<sub>2</sub> emissions, forcing the search for alternative

materials [12]. Brick powder has been applied as pozzolana in India for years to enhance concrete qualities including permeability or resistance to sulfate attack [13]. Small concrete's low density and superior insulation make it ideal for building, lowering structural load and expenses [14]. Concrete is the most often used element for building construction in the world. In 2006 alone, the yearly worldwide production of concrete was over 25 billion tons showed that CKD effectively removes total suspended solids [15]. They used four distinct CKD samples to examine the efficiency of purification of Ca(OH)<sub>2</sub> suspended particles, with CaO quicklime serving as a control. All samples facilitated the precipitation of more than 99% of soluble zinc and iron. Furthermore, sedimentation experiments revealed that all CKD samples produced less silt by volume than samples with quicklime [16]. Annually,

millions of tons of cement kiln dust are generated in North America, with a considerable amount being landfilled due to high alkali content. This results in financial losses for the cement industry [17]. Portland cement clinker, a semi-finished product in cement manufacturing, releases significant amounts of dust. This includes dust from kiln dedusting (CKD) and bypass installation (CBPD). While CKD is regularly discharged during the cement manufacturing process, CBPD is only used in specific circumstances to reduce chlorine and alkali [18]. Alkalies were discovered to inhibit alite formation, but increase the formation of belite [19]. Portland cement is mostly utilized in concrete, mortars, and stuccos, competing with alternatives such as aluminum, asphalt, clay brick, fiberglass, glass, gypsum (plaster), steel, stone, and wood. In 2021, the total global cement production was 4.4 billion tons. In 2021, China's cement production is expected to be 2.5 billion tons, followed by 810 million tons in Vietnam, 330 million tons in India, and 92 million tons in the United States [20].

## II. MATERIALS

### A. Quarry Limestone Dust as a Cement Replacement

By choosing building materials, the infrastructure's structural stability or strength is still the major consideration. The second crucial factor to take into account while choosing building materials is the structure's economy. As a result, these two serve as the cornerstones for choosing appropriate building materials. Additionally, using construction materials that are byproducts and are deemed environmentally detrimental due to their difficulty in being disposed of is one strategy for creating a sustainable structure. It has been shown that limestone, also known as calcium carbonate (CaCO<sub>3</sub>), is a key ingredient in the production of cement and accounts for a significant amount of 75% of the process. It is well known that limestone lowers the quantity of water required to make concrete workable. Additionally, because limestone particles range in size from 4 to 15 μm, they are the ideal filler between spaces and assist lower the cement's porosity by filling in the voids and preventing water from

seeping in. This ultimately leads to a lower water-to-cement ratio and increases the structure's endurance [21].

### B. Recycled Red Brick Powder as a Fine Aggregate Replacement

The most widely used building material for creating walls, roofs, columns, paving floors, and other structures is brick. A excellent brick clay is composed of lime, magnesium, potassium, sodium, and iron oxide, with 20 to 30 percent silica. Brick debris was gathered from building sites close to Jagat Farm Market and ground in a crusher to produce a finer powder that, after appropriate sifting, may be used as fine aggregate [22].

### C. Clinker Dust from cement industries

As the clay brick-making procedure is often done in a traditional manner, the brick's quality varies greatly. The three primary ingredients of clay bricks clay, sand, and water Clay is extracted at the start of the production process, combined with water, and molded using wooden molds. After molding, the

dough is left to dry for a few days in the sun. The bricks are transported to the brick kiln after drying, where they are manually burnt using firewood without temperature control. A consequence of over burning is clinker brick which becomes useless for construction because of the distortion of its structure and color to reddish-black after combustion. Even if clinker bricks are submerged in water for a long time, the high temperature will prevent further degradation. The physical properties of clinker bricks are hard, sharp, and unyielding. The properties of clinker bricks are influenced by the geological environment in which the material is found. Research indicates that a concrete mix that substituted 100% clinker aggregate was able to reach its desired compressive strength of 20 MPa and is hence eligible to be classified as structural concrete. The strength-to-density ratio improves as a result of an 8.8% decrease in concrete densities when compared to crushed stone. However, because of its density, which exceeds 2000 kg/m<sup>3</sup>, clinker aggregate concrete cannot be classified as lightweight concrete [3].

### III. METHODOLOGY

Three 150 mm x 150 mm x 150 mm specimens and three 150 mm x 150 mm x 700 mm beams were cast in the experiment utilizing limestone as a partial cement substitute in the amounts of 10%, 20%, and 30% by mass of the limestone powder. Following IS 10262:2009, the concrete was mixed, and after the cement was added, limestone powder was added to the drum mixer in predetermined amounts. The freshly made slurry was tested for workability after the cement was added. For testing, the freshly mixed concrete is then formed into molds with predetermined measurements. After seven and twenty-eight days after the casting date, their compressive and flexural strengths are

evaluated [21]. Globally, the construction sector has a high demand for raw materials, especially sand, which is a necessary ingredient for concrete. The United Nations Environmental Programme reports that due to factors such as growing urbanization, population growth, infrastructure development, and shifting consumer habits, the demand for sand has quadrupled in the past 20 years [4]. In order to determine the slump, flowability, and compressive strength characteristics of SCLWFC with varying percentages of LP as an additive and cement replacement—0%, 5%, 10%, 15%, 20%, and 25% of cement content by mass—this study was conducted. Concrete's water-to-cement ratio is 0.53. The features of SCLWFC that are obscured in this study are compressive quality in the solidified state and flowability in the new condition. No specific mix percentage procedures to concentrate on foamed concrete qualities. Therefore, employing some trial-and-error techniques with suitable mix design methods and fixing the value of water/cement content or water/binder content is a suitable alternative calculation strategy to propose the required strength of foamed concrete.

Therefore, the concrete mix design process is split into two phases for this study. The first step involves determining the suggested quantity by weight of the cement content, free water, and total aggregates using the British approach, which was amended by the Department of Environment in 1988. The essential components of the mix compositions of SCLWFC are

the same as those used in normal weight concrete [6]. Pastes were made and evaluated using isothermal calorimetry and initial setting time. Variable water-to-powder ratios (w/p) were produced on a mass basis for these mixes by replacing cement with limestone or silica powder at a 1:1 volume-to-volume ratio while keeping the water volume fraction (content) constant. We looked at systems that ranged from 100% OPC to 5% OPC: 95% LS. Furthermore, mixes containing SA were made, substituting 20–40–60–80% of the cement content. The purpose of these mixes was to give a foundation for comparing the performance of silica powder and limestone [23]. A Type I/II ordinary Portland cement (OPC) with a limestone addition was employed, as well as limestone powder (LS) from a commercial aggregate manufacturing plant and silica powder (SA) produced by blending laboratory-grade powders. Pastes were made with varied mixes of OPC, LS, and SA while keeping a constant water volume fraction and were tested for initial setting time and isothermal calorimetry. Rheological studies were run to determine the initial consistency and yield stress of mixes with 40% limestone or silica volume replacements, as well as a 100% OPC control [23]. Ordinary Portland cement, sea sand, coarse aggregate (12 mm nominal size), and a mixture of dust of bricks and limestone powder (75 mic) were all utilized in the experiment. Brick dust and limestone powder were added in various proportions (0, 10, 15, and 20%) to concrete mixes that had a ratio of 1:1.5:3 (cement: sand: coarse aggregate). After 28 days of curing, 150x150x150 mm cube specimens were subjected to compressive strength experiments, while fresh concrete was subjected to slump tests [24].

### IV. RESULT & DISCUSSION

#### Compressive strength:

The results for hardened concrete are summarized in Table:1, and Fig:1 illustrates how the compressive strength varies with brick dust and the proportion of limestone powder. For 10, 15, and 20% ratios of combination brick dust and limestone powder additive, the concrete's compressive strength increased.

The findings show that as the ratio of brick dust and limestone powder increases, so does compressive strength. The highest

28-day compressive strength of 44.7 MPa was achieved at 15% ratios of limestone powder to brick dust. Following table explain the effects of different combinations of dust and limestone [24].

TABLE I. EFFECT OF COMBINATION BRICK DUST AND LIMESTONE POWDER ON COMPRESSIVE STRENGTH

Mix no	Brick dust and limestone powder (%)	Compressive strength (Mpa)
M 0	0	34.5
M 1	10	34.6
M 2	15	44.7
M 3	20	40.0

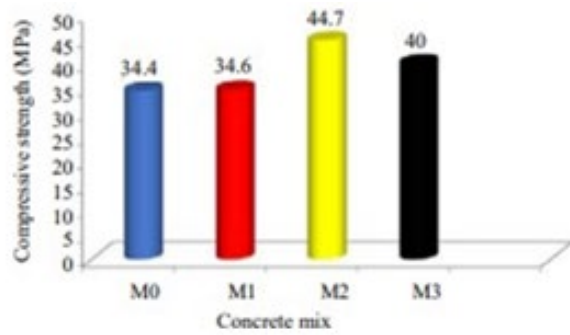


Fig. 1. Compressive strength of various normal concrete mixes at 28 days

**Split tensile strength:** The test subjects were thirty ordinary concrete cylinders. These cylindrical devices have a diameter of 150 mm and a depth of 300 mm. The results of these analyses are shown in the table below. We applied the following formula to get each cylinder's split tensile strength (ft): Split Tensile Strength (ft) is calculated by dividing the maximum load on the cylinder (W) by the product of the cylinder's diameter (D) and length (L).

**Flexural strength:** 30 beams, each 150 x 150 x 500 mm, were tested. All of the specimens shattered inside the center third of the beam during these testing. We applied the following formula to get each beam's FS (f): Flexural strength (f) is calculated by dividing the maximum load on the prism (W) by the product of the prism's length (L), width (B), and depth (D) [25]. The effect of lime stone additive concrete is displayed in table 3 [21].

TABLE II. EFFECT OF COMBINATION BRICK DUST ON FLEXURAL STRENGTH

% of C-4B	%GF	7Days (1 week) (N/mm <sup>2</sup> )	28Days (4 week) (N/mm <sup>2</sup> )
0	0	18.2	30.07
5	1	16.94	31.69
10	1	21.86	31.86
15	1	15.87	35.93
20	1	15.83	35.31

TABLE III. EFFECT OF COMBINATION LIMESTONE ON FLEXURAL STRENGTH

Grade of Concrete	Average Flexural Strength with 10% Replacement	Average Flexural Strength with 10% Replacement
	7 Day	28 Day
M 10	1.55	2.34
M 15	1.89	2.87
M 20	2.18	3.30
M 25	2.43	3.69
M 30	2.66	4.04
M 10	2.89	4.33
M 10	3.05	4.62
M 10	3.22	4.90

Although the measured maximum packing percentage for the LS mixture is lower than that of the OPC and SA systems, limestone improves mixture flowability as seen by its reduced yield stress. According to the isothermal calorimetry results, cement hydration reactions are accelerated and amplified by both LS and SA, with LS having a marginally stronger effect. Pastes made with SA took a little longer to set than pastes made with LS [23].

The capacity of concrete to withstand the detrimental effects of weathering, chemical assault, and other degradation processes is measured by durability performance. Concrete's capacity to endure long-term caused deterioration is what it is. Sorptivity and resistance to sulphate assault were used in this study to evaluate durability. The capacity of concrete to absorb water is a major factor in its durability. The term "sorptivity" is frequently used to describe the concrete's capacity to take in water and transfer it by capillary action. It offers clues about the connection and pore structure, which are crucial elements that affect how resistant concrete is to aggressive substances' attacks in harsh environments. Rapid concrete degradation may result from increased sorptivity potential. Observe that absorption peaked during the first six hours of the test and then tended to progressively decline after that.

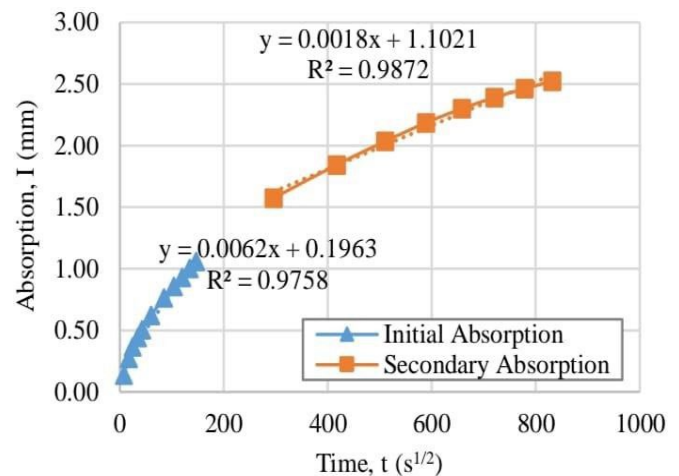


Fig. 2. Absorption capacity of concrete with respect to time.

Using linear regression analysis with all the points from 1 minute to 6 hours, the initial sorptivity—the rate of absorption over the first 6 hours—is equal to the slope of the line that best fits absorption plotted against the square root of time. Conversely, the slope of the line that best suited the absorption against square-root of time plot utilizing all data from day 1 to day 8 was determined to represent the secondary sorptivity. Table 4 provides a summary of the sorptivity test results, while Figure 2 shows them. The addition of DLW typically lowers the sorptivity values, according to a comparison of the data obtained at test ages of 28 and 90 days[4].

TABLE IV. EFFECT OF COMBINATION LIMESTONE ON FLEXURAL STRENGTH

Sample ID	28 days		90 days	
	$S_i$	$S_s$	$S_i$	$S_s$
C-L0	0.0068	0.0017	0.0061	0.0022
C-L20	0.0050	0.0014	0.0062	0.0018
C-L40	0.0054	0.0015	0.0061	0.0018
C-L60	0.0057	0.0022	0.0056	0.0016

Note:  $S_i$  – initial sorptivity in  $mm/s^{1/2}$ ;  $S_s$  – secondary sorptivity in  $mm/s^{1/2}$

Effect of Brick Powder on Concrete Compressive Strength: Compressive strength tests were performed on concrete samples. The specimens were water-cured during the procedure. Each concrete specimen was examined on days 7, 14, 28, and 56 following a full day of drying. Three specimens were used to get the average result. The universal testing machine was used to acquire the compressive strength data. The compressive strength values for each specimen are shown in Table 3. The data indicate the outcomes for several sand substitutes, such as brick powder at 5%, 10%, 15%, 20%, and 25% rates. Table [26]

TABLE V. SPLIT TENSILE STRENGTH OF CONCRETE WITH BRICK POWDER

Mix designation	Concrete's Split Tensile Strength (MPa)			
	7 days	14 days	28 days	56 days
SB0	2,76	3,09	3,43	3,60
SB5	2,74	3,04	3,39	3,48
SB10	2,85	3,12	3,73	3,82
SB15	2,82	3,02	3,58	3,67
SB20	2,78	2,95	3,52	3,56
SB25	2,66	2,85	3,37	3,45

As the proportion of brick powder increases, the compressive strength usually increases as well. The mixture with 10% substitution (SB10) performed the best in terms of compressive strength when compared to the control concrete, rising by 26.66%, 14.99%, 25.55%, and 19.92% at 7, 14, 28, and 56 days, respectively. This is explained by the enhanced density and effective pore filling caused by the pozzolanic process. The compressive strength of cement falls when the replacement rate increases over 10%. This is most likely due to either an insufficient reaction or an overabundance of inert material, which makes the cement matrix more porous. A reasonable replacement rate is advised for the best mechanical qualities [26].

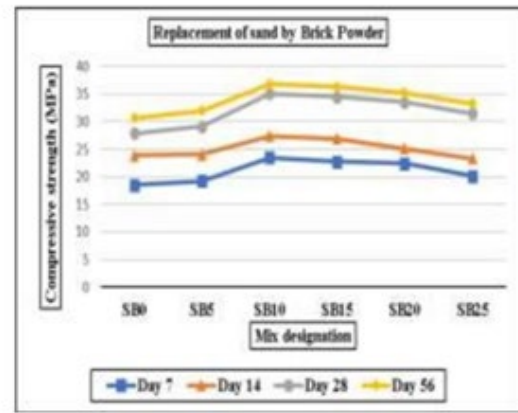


Fig. 3. Compressive Strength of Brick Powder Concrete.

According to Figure 3, substituting sand with 10% brick powder improves splitting tensile strength. We observe this improvement at different time intervals, showing increases of 3.26%, 0.97%, 8.74%, and 6.11% at 7, 14, 28, and 56 days, respectively, in comparison to conventional concrete [26].

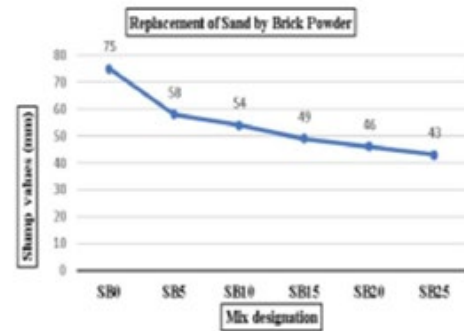


Fig. 4. Workability of Brick Powder Concrete.

## V. CONCLUSION

1. The Additive Mix had the highest slump flow at 10% limestone powder, while the Replacement Mix had the highest compressive strength at 5% limestone powder. Adding limestone powder up to 10% by mass maximizes compressive strength, while a 40% replacement increases slump flow [6].

Substituting 10% sand with brick powder improves the mechanical characteristics of concrete, increasing compressive strength by roughly 29.94% and split tensile strength by 8.74%. Despite these improvements, workability decreases by 42.66%, indicating a direct relationship between compressive strength, ultrasonic pulse velocity (UPV), and rebound number [26].

2. By partially replacing fine aggregate with brick dust, we may create an eco-friendly mortar that alleviates the stagnation of destroyed brick debris by correctly utilizing it. It is possible to partially substitute fine aggregate with brick debris produced during building site deconstruction. The greatest compressive strength was recorded at 15% brick powder replacement for 7

days, 14 days, and 28 days of curing in M30 grade concrete [22].

3. Limestone waste (LSW) can be utilized as a partial substitute for sand by up to 25%, improving workability and strength while encouraging sustainable practices. The addition of silica fume enhances mechanical qualities, making it appropriate for a variety of concrete applications. Excessive replacement (over 50%) may diminish strength owing to chemical and physical impacts; yet, overall, quarry waste offers an environmentally benign alternative in concrete production [27].

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