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Performance Assessment of Concrete with Quarry Dust as a Sustainable Partial Replacement for Cement

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Abstract

Quarry dust, a major by-product of stone crushing, has been widely used in construction applications such as highway surfacing, sandcrete block production, and lightweight concrete elements. This study evaluates the potential of quarry dust as a partial replacement for cement in concrete, with replacement levels of 0%, 10%, 20%, 30%, and 40% by weight. The investigation involved compressive strength, durability, and linear shrinkage tests on concrete specimens cured for 7, 14, 21, and 28 days. Results indicate that compressive strength increases with age for all mixes, with maximum strength achieved at 20% replacement (27.38 N/mm² at 28 days). Beyond 20%, strength decreased but remained higher than control in some cases. Durability tests in dilute sulfuric acid revealed enhanced abrasion resistance, especially at higher replacement levels, with 40% quarry dust showing superior wear resistance. Linear shrinkage decreased with increasing quarry dust content due to its lower water absorption capacity. The findings suggest that partial cement replacement with up to 20% quarry dust can be used for lightweight structural concrete, offering both economic and environmental benefits, though it is not recommended for applications where sulfate resistance is critical.

Keywords: Concrete, Quarry dust, Cement replacement, Compressive strength, Durability, Linear shrinkage

INTRODUCTION

Global research increasingly explores alternative sources for construction materials, driven by factors such as the high cost of conventional materials, limited access to funding for building projects, the need to recycle agricultural and industrial waste, the imperative to maintain ecological balance, and persistent housing challenges. Among these alternatives is the incorporation of pozzolana, either as an admixture or as a partial substitute for cement [1-2]. In the search for materials that address these challenges while remaining both cost effective and efficient, pozzolans have attracted considerable attention. Pozzolans are defined as “siliceous or siliceous and aluminous materials which, in themselves, possess little or no cementing properties, but which, in a finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties” [3]. Quarry dust represents one such material with notable pozzolanic potential [4].

Concrete remains one of the most widely used materials in civil engineering, employed in the construction of architectural structures, foundations, masonry walls, pavements, bridges, highways, runways, parking areas, dams, reservoirs, pipelines, footings, fencing, poles, and even boats [5]. The combination of water and a cementitious material initiates hydration, producing a cement paste that binds aggregates, fills voids, and improves workability. The construction sector relies heavily on cement for the creation of housing and infrastructure. However, the sustained increase in the price of Portland cement has been attributed to the inability of raw material production to meet the rapidly growing demand in the construction industry [1]. Quarry dust, a by-product of quarrying operations, can serve as a partial cement replacement and as a pozzolanic additive once its optimal replacement level has been determined [6].

Quarry dust, a waste product generated during the crushing of large rocks into smaller particles, has a texture similar to sand and is usually grey in colour. Nigeria is currently undertaking major infrastructure developments, including expressways, power plants, and industrial facilities, to meet the demands of globalization. Concrete plays a central role in these projects, with large volumes being produced and consumed. However, cement, one of the principal components of conventional concrete, has become increasingly expensive and scarce. In light of this, there is a growing demand for alternative construction materials derived from industrial by products. In most contexts, the term "concrete" refers to Portland cement concrete or concrete produced with other hydraulic cements, such as cement pondu which is known for its resistance to sulphate attack. In some cases, road surfaces are constructed with asphaltic concrete in which bitumen serves as the binding material [5].

On a global scale, the consumption of concrete is approximately twice that of steel, wood, plastics, and aluminium combined [7-8]. Cement paste not only binds aggregates together but also fills internal voids and enhances the flow properties of fresh concrete [9]. Concrete is used extensively for architectural structures, foundations, masonry, pavements, bridges, highways, runways, parking facilities, dams, reservoirs, pipelines, gate footings, fencing, poles, and even marine vessels [10]. Broadly, concrete can be categorized into three main types: plain, prestressed, and reinforced. Additional varieties include lightweight concrete, high density concrete, and polymer concrete, among others [11].

Since cement is typically the most expensive constituent in concrete production, partially replacing it with quarry dust can enhance the affordability of concrete, particularly for low-cost housing initiatives in Nigeria. The use of quarry dust may also lead to improved concrete quality at reduced costs while mitigating the environmental problems associated with its large-scale accumulation. Quarry dust has already been utilized in various construction activities, including road building and the manufacturing of lightweight aggregates, bricks, and tiles. The present research reports the results of experimental investigations on the use of quarry dust as a partial cement replacement [19-22].

MATERIALS AND METHOD

A. MATERIALS

Cement

Ordinary Portland cement (Dangote 3X Stronger) was used for the study. It was sourced from a local dealer located opposite the main gate of Kano University of Science and Technology (KUST).

Quarry Dust

The quarry dust used in the experimental work was collected from the site of H and M Construction Company at KUST Wudil, situated along Library Road near the Faculty of Agriculture.

Fine Aggregate

Clean, air-dried river sand, free from leaves, sticks, dirt, and other foreign matter, was used as the fine aggregate. The sand was obtained from the Faculty of Engineering Laboratory at KUST Wudil.

Coarse Aggregate

Crushed stone free from impurities, with a nominal size of three quarters of an inch (approximately 19 millimetres), served as the coarse aggregate. This material was also sourced from the Faculty of Engineering Laboratory at KUST Wudil.

Water

Water is an essential natural resource that supports all life and continuously cycles between the land and the atmosphere [12] [13]. For mixing and curing purposes, clean, drinkable tap water was obtained from the Water Resources Laboratory in the Civil Engineering Department at KUST.

Tetraoxosulphate (VI) Acid

Approximately 2.5 litres of concentrated tetraoxosulphate (VI) acid were used for the durability test. The acid was procured from local suppliers in Sabon Gari, along Church Road, within Kano Metropolis.

B. TEST METHOD AND ANALYSIS

Sieve Analysis of Aggregates

The particle size distribution of the aggregates was determined following the procedure in BS 812 Part 103-1 (1985), "Method for the Determination of Particle Size Distribution."

Specific Gravity Test

The specific gravity of the aggregates was measured according to BS 812 Part 103 (1985), using a pycnometer apparatus.

Workability (Slump Test)

The workability of the fresh concrete was evaluated in accordance with BS 1881 Part 102 (1983), "Method for the Determination of Concrete Slump."

Compressive Strength Test

Concrete cubes of dimensions 150 millimetres by 150 millimetres by 150 millimetres were cast and tested for compressive strength in accordance with BS 1881 Part 116 (1983), "Method of Determination of Compressive Strength of Concrete Cubes." Tests were carried out at 7, 14, 21, and 28 days. Additional tests performed included the linear shrinkage test and the durability test [11-12].

RESULTS

The findings of experimental investigations are presented. Various tests were conducted to evaluate the effect of Quarry Dust on compressive strength, durability and linear shrinkage. Quarry Dust was used as a partial replacement of cement at the percentage of 0, 10, 20, 30, and 40%. As shown in Fig. 1.

Sieve Analysis for Quarry Dust

Table -1 and Fig. 1 shows the query dust result. From the grading curve (Fig.1), it was observed that, the particles grading of Quarry Dust fall within Zone II based on BS882, part 2, 1992. [14]. This shows that, there is a more medium size particle than fine and coarse; it has cohesive characteristics which are desirable in making concrete.

Sieve Analysis of Fine Aggregates

Table -2 Fig. 2 shows the query dust result. From Fig. 2 it was observed that, the particles grading of fine aggregates fall within Zone II based on BS882, part 2, 1992 [14]. This shows that, there is a more medium size particle than fine and coarse; it has cohesive characteristics and is well-graded which is desirable in making concrete, as the space between larger particles will effectively be filled with the finest aggregate particles to produce a well-packed structure.

Table -1 Sieve Analysis of Quarry Dust

Initial Weight (g)	

Particle Description		Diameter (mm)	Weight (g)	Retained (%)	1000 Passing (%)		
Cobles		75	0	0	100		
		63	0	0	100		
		50	0	0	100	Gravels = 11.13%	
		37.6	0	0	100		
Coarse		28	0	0	100	Coarse Sand = 20.83%	Sand = 76.85%
		20	0	0	100		
		14	0	0	100		
		10	8.0	0.8	99.20	Medium Sand = 48.05%	
Fine		6.3	13.2	2.12	97.88		
		5.0	33.1	5.43	94.57		
		3.4	57.0	11.13	88.87	Fine Sand = 7.97%	
Sand	Coarse	2.0	96.1	20.74	79.26		
		1.18	112.2	31.96	68.04		
	Medium	0.6	185.3	50.49	49.51		
		0.475	245.4	75.03	24.97	Fineness = 12.02%	
		0.3	155.5	90.58	9.42		
	Fine Clay or Silt	0.075	79.7	98.55	1.45		
		0.063	14.8	100.03	0.00		
		Pass 63 microns	0.00	0.00	0.00		
			999.90				

Table 2 Sieve Analysis of Fine Aggregates

			Initial Weight (g)		1000		
Particle Description		Diameter (mm)	Weight (g)	Retained (%)	Passing (%)		
Cobles		75	0	0	100		
Coarse		63	0	0	100		
		50	0	0	100	Gravels = 17.30%	
		37.6	0	0	100		
		28	0	0	100	Coarse Sand = 14.87%	Sand = 72.26%
		20	0	0	100		
		14	0	0	100		
		10	14.0	1.40	98.60	Medium Sand = 51.19%	
Fine		6.3	31.2	4.51	95.49		
		5.0	51.4	9.65	90.35		
		3.4	76.5	17.30	82.70	Fine Sand = 6.20%	
Sand	Coarse	2.0	111.3	28.43	71.57		
		1.18	149.2	43.35	56.65		
	Medium	0.6	259.2	69.27	30.73		
		0.475	165.6	85.83	14.17	Fines = 10.44%	
		0.3	82.8	94.12	5.88		
	Fine Clay or Silt	0.075	31.9	97.31	2.69		
		0.063	26.9	100.00	0.00		
		Pass 63 microns	0.00	0.00	0.00		
			1000.0				

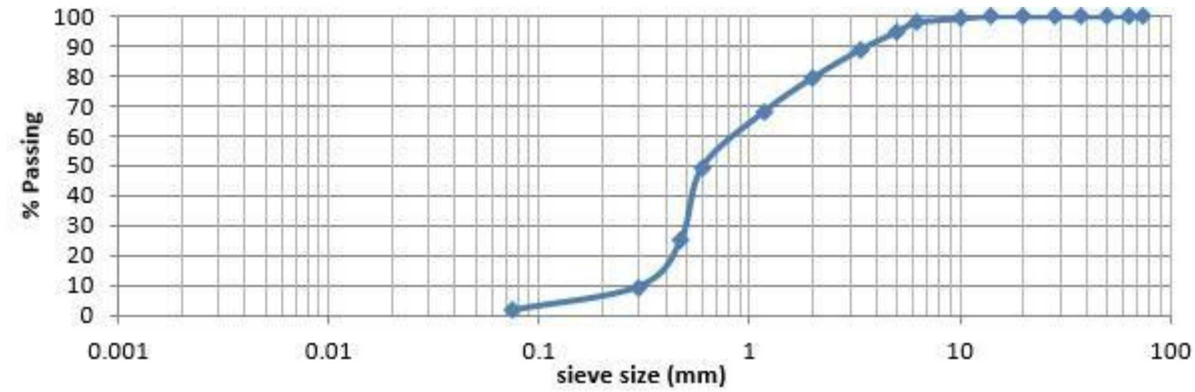


Fig .1 Grading Curve for Quarry Dust

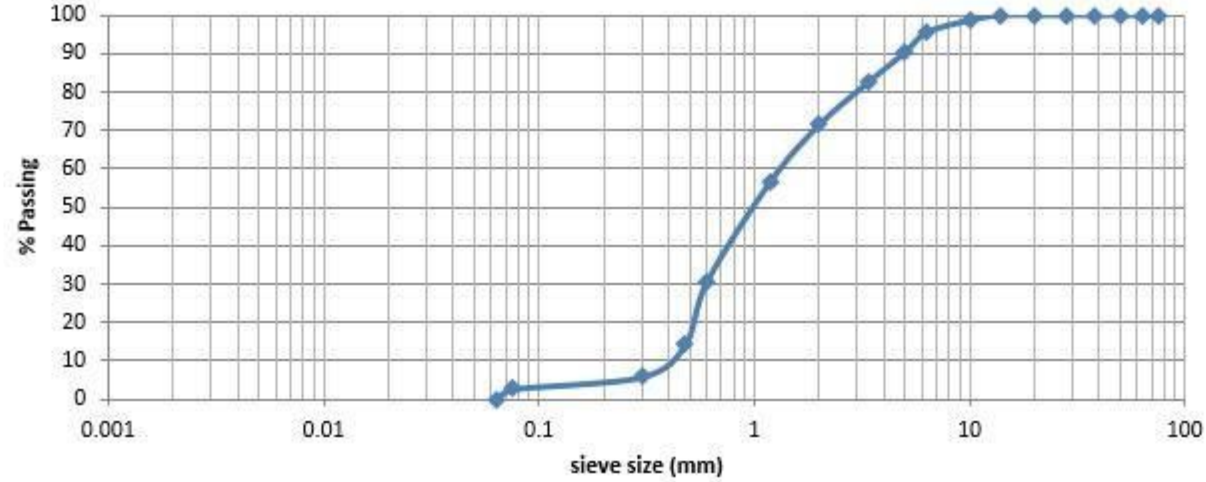


Fig. 2 Grading Curve for Fine Aggregates

Sieve Analysis for Coarse Aggregates

Table -3 and Fig. 3 shows the query dust result. From Table - 3, the majority of coarse aggregates used are coarse gravels, uniformly graded having required properties.

Table -3 Sieve Analysis of Course Aggregate

			Initial Weight				
Particle		Diameter	(Weight)	Retained	Passing		
Description Cobles		(75mm)	(0g)	(0%)	(100%)		
		63	0	0	100		
Coarse		50	0	0	100		
		37.6	0	0	100	Gravels = 100%	
		28	0	0	100		
		20	0	0	100	Coarse Sand = 0.00%	
		14	1062.2	53.11	46.89		
		10	783.3	92.28	7.72		
Fine		6.3	121.4	98.35	1.65	Medium Sand = 0.00%	
		5.0	33.1	100	0.00		
		3.4	0.00	100	0.00		
	Coarse	2.0	0.00	100		Fine Sand = 0.00%	Sand = 0.00%
		1.18	0.00	100	0.00		
	Medium	0.6	0.00	100	0.00		

Sand		0.475	0.00	100	0.00	Fines = 0.00%
		0.3	0.00	100	0.00	
	Fine Clay or Silt	0.075	0.00	100	0.00	
		0.063	0.00	100	0.00	
		Pass 63	0.00	0.00	0.00	
		microns	2000.0			

Table 5 Summarized Values of Compressive Strength for Normal Water

Quarry Dust (%)	Average Compressive Strength (N/mm^2)			
	7 days	14 days	21 days	28 days
0	20.00	24.94	27.18	28.46
10	16.90	21.41	23.50	24.70
20	19.10	23.92	26.12	27.38
30	16.00	20.37	22.41	23.59
40	14.20	18.27	20.20	21.33

Workability (Slump Test)

The results obtained for the workability test using the testing procedures described are presented in (Fig. 4). From Fig. 4, the slump of all the concrete mixes increases with increase in quarry dust content. This is imputable to the ability of quarry dust to absorb less water than cement. Since water absorption is present it increases the water added to the dry mix.

Compressive Strength

Compressive strength test of (150mm x 150mm x 150mm) test cube specimen was performed according to BS1881: part 116 1983 [15]. Cube specimens were tested at 7, 14, 21 and 28 days using Universal Testing Machine at a constant loading rate. The maximum strength of each specimen was recorded and the average of four samples was considered the compressive strength at the specific day.

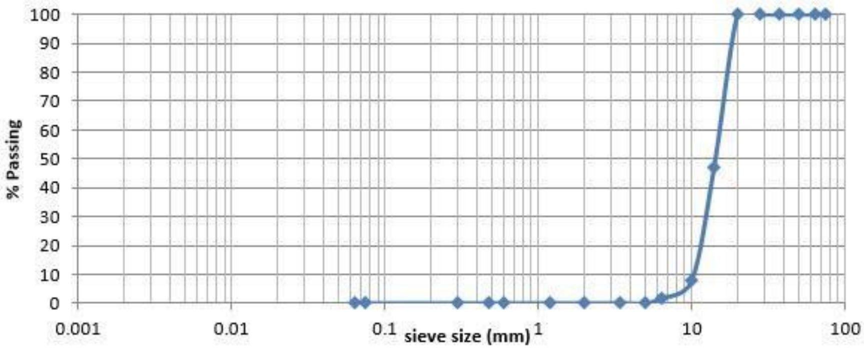


Fig.3 Grading curve for coarse aggregate

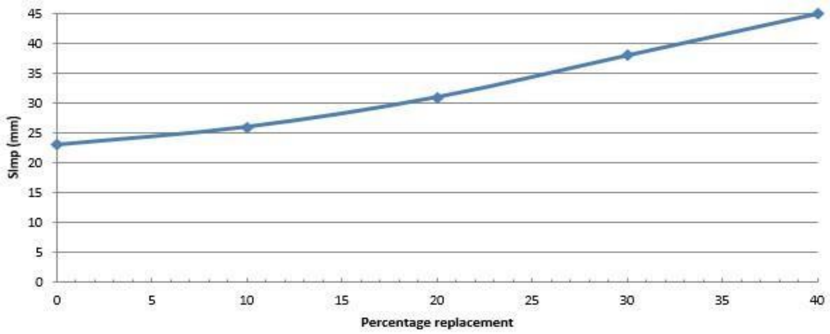


Fig. 4 Slump versus %replacement

Effects of Age on Compressive Strength

Effect of age on compressive strength of concrete is shown in Fig .6, it is evident that compressive strength of concrete mixes increased with age. At the age of 7 days, compressive strength of concrete mix (0% QD) was 20.00N/mm^2. It increases to 28.46N/mm^2 (29.73% greater) at 28 days. With the addition of quarry dust, there was an increase in compressive strength with increase in age. There is also a decrease in compressive strength with addition of the dust in comparison with 0% dust addition. There was a remarkable increase in compressive strength with the addition of the dust up to 20% replacement. Beyond 20% replacement, the compressive strength keeps decreasing simultaneously.

Table 6 Summarized Values of Compressive Strength in Sulphuric Acid

Quarry Dust (%)	Average Compressive Strength (N/mm^2)			
	7 days	14 days	21 days	28 days
0	21.30	26.40	28.70	30.00
10	19.10	23.92	26.12	28.34
20	17.30	21.87	23.98	25.20
30	15.60	19.90	21.92	23.09
40	13.80	17.80	19.71	20.82

Fig. 5(A-D) shows the compressive strength versus quarry dust Variation. It was found that, at the age of 7 days, compressive strength of concrete mix with (0% QD) was 20.00N/mm^2 and mixes with (10%QD), (20%QD), (30% QD) and (40% QD) were 16.90, 19.10, 16.00 and 14.20N/mm^2, respectively. At the age of 14 days, compressive strength of concrete mix with (0% QD) was 24.94N/mm^2 and mixes with (10%QD), (20%QD), (30% QD) and (40% QD) were 21.41, 23.92, 20.37 and18.27N/mm^2, respectively. The Percentage decrease in compressive strength was 15.39, 4.09, 18.32, and 22.73% for mixes 10, 20, 30 and 40% (Quarry Dust) than (0%QD) mix of (24.94N/mm^2). At 21 days, compressive strength of concrete mix with (0% QD) was 27.18N/mm^2 and mixes with (10%QD), (20%QD), (30% QD) and (40% QD) were 23.50, 26.12,
22.41 and 20.20N/mm^2, respectively, concrete mixes exhibited decreases in compressive strength of 13.54, 3.89, 17.55, and 25.68% respectively than (0%QD) with (27.18N/mm^2). Likewise, at the age of 28 days, compressive strength of concrete mix with (0% QD) was 28.46N/mm2 and mixes with (10%QD), (20%QD), (30% QD) and (40% QD) were 24.70, 27.38, 23.59 and 21.33N/mm2, respectively. There was 13.21, 3.79, 17.11 and 25.05% decrease in compressive strength for concrete mixes with 10, 20, 30, and 40% (QD), in comparison to control mix (0%) having a compressive strength of (28.46N/mm^2).

It was observed that the compressive strength of concrete decreased with the increase in Quarry Dust content by 10%, and increases at 20% then, decreases beyond 20% partial replacement of cement.

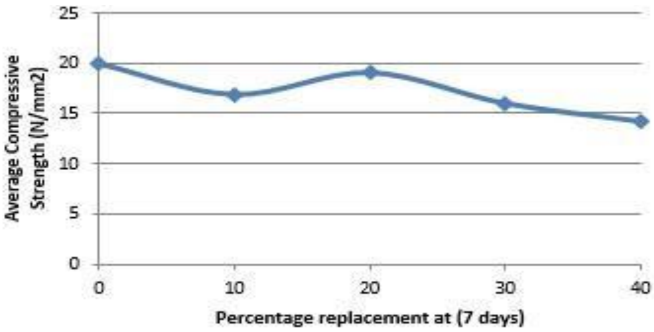


Fig. 5A

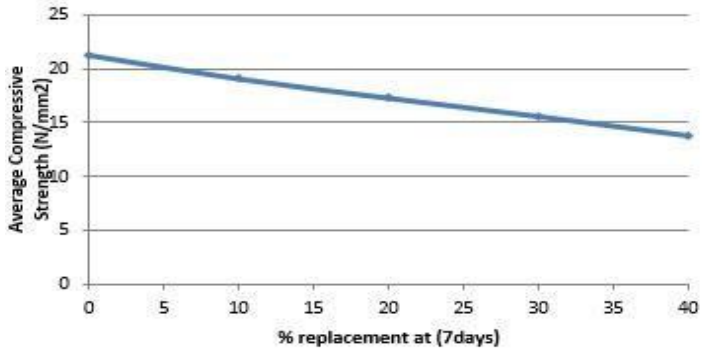


Fig. 6A

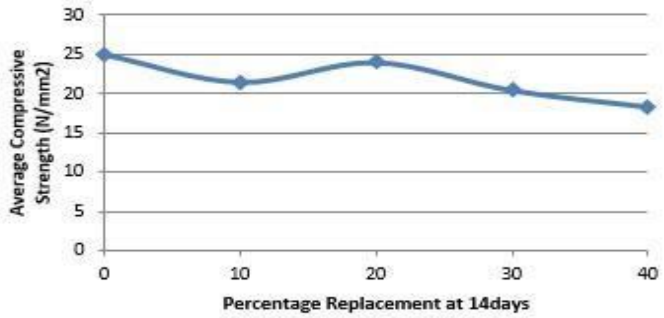


Fig. 5B

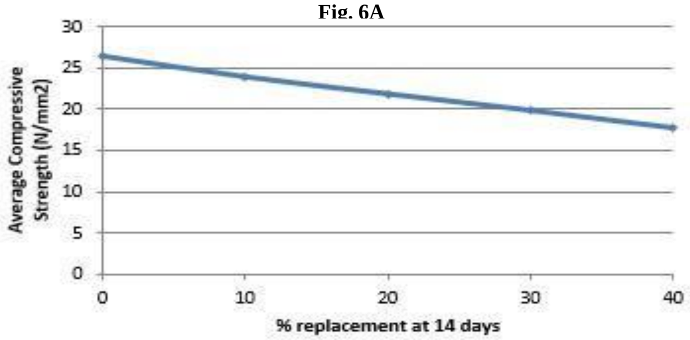
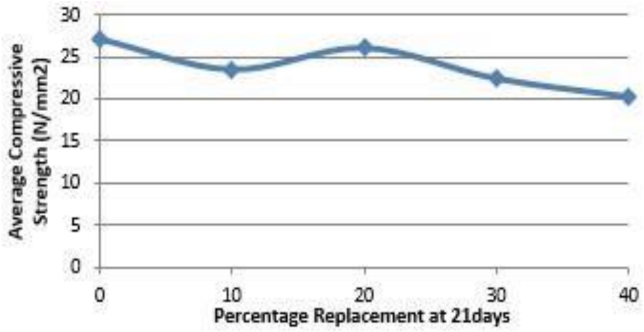


Fig. 6B



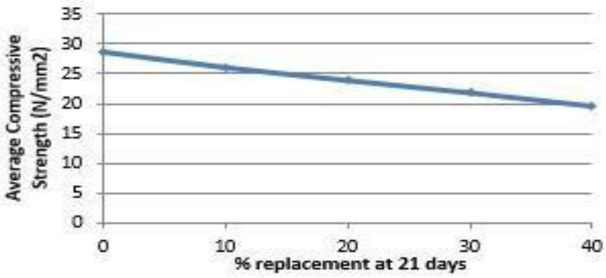


Fig. 6C

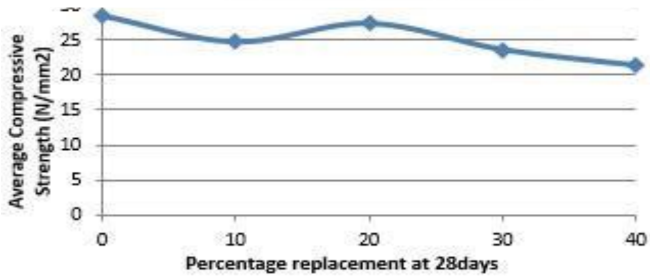


Fig. 5D

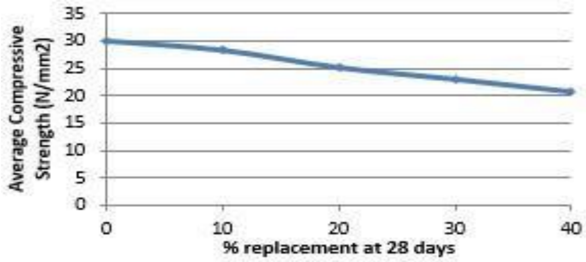


Fig. 6D

Fig. 6 (A-D) Compressive Strength versus Quarry Dust (Durability)

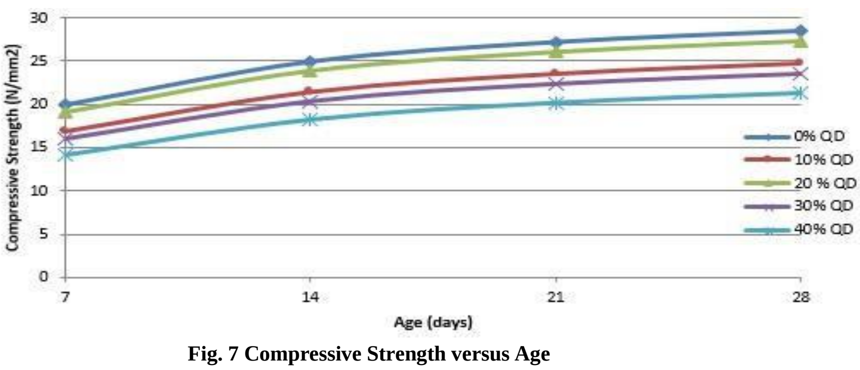


Fig. 7 Compressive Strength versus Age

Linear Shrinkage

After the cubes were removed from the mold, the length of the cube was measured as (L_0 mm) at 0 days of curing. The cubes were cured in water for the number of days (7, 14, 21 and 28 days), the cubes were allowed to dry after the curing period, and the new length of the concrete cube was measured as (Li). The percentage linear shrinkage for each specimen was estimated using the equation 1.

$$L_S = [1 - (Li / L_o)] \times 100 \qquad (1)$$

Figure 9, shows that the percentage linear shrinkage decreases with the increase in Quarry Dust replacement, this is because, the gel of cement is finer than that of Quarry Dust. The drying shrinkage occurs as a result of loss of water held by the gel pores, and the finer the gel is, the more the loss of water from the gel. Similarly Quarry Dust has a water absorption of (1.20 – 1.50%) as reported by [7]. Which is less than that of cement, this allows Quarry dust to absorb less moisture than that absorbed by the cement, and the less the water absorption rate is, the less the drying shrinkage. Linear shrinkage decreases with the increase in quarry dust content; this is due to low water absorption property of the dust used. Linear shrinkage also increases with the increase in age of curing (curing period) [7].

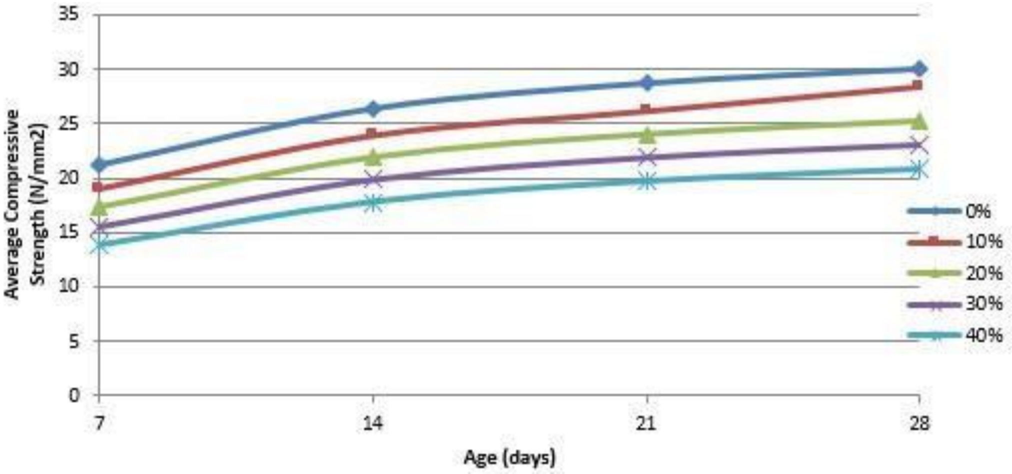


Fig. 8 Compressive Strength versus Age (Durability)

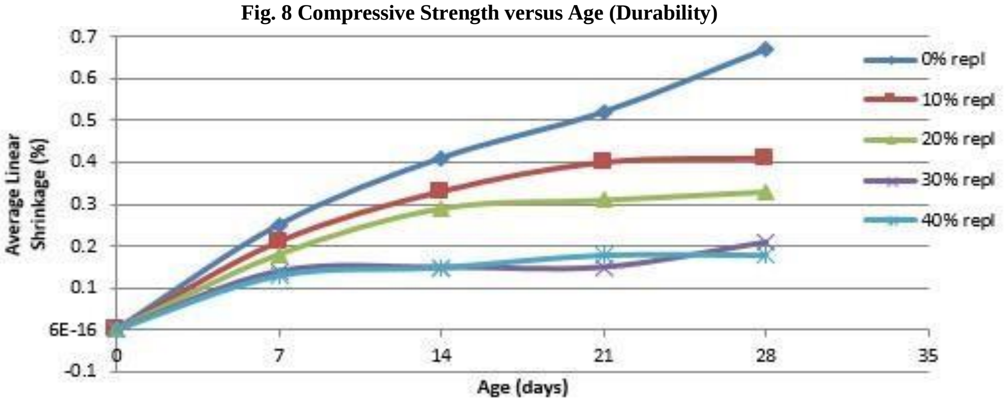


Fig. 9 Linear Shrinkage versus %Replacement

CONCLUSION

The findings from this experimental investigation provide strong evidence that quarry dust can serve as a viable partial substitute for cement in concrete production, offering both structural performance and sustainability benefits. The compressive strength results demonstrated that concrete containing quarry dust consistently gained strength with curing age, irrespective of the replacement level. The most notable improvement occurred at 20% replacement, where the 28day strength reached 27.38 N/mm², indicating that an optimal balance between cement hydration and pozzolanic activity of the quarry dust was achieved at this proportion. While strength declined at higher replacement levels, the performance at 30% and 40% remained within acceptable ranges for certain construction applications, particularly where ultra-high compressive strength is not the primary requirement.

Durability assessments further reinforced the suitability of quarry dust in concrete. Abrasion resistance improved progressively with higher replacement levels, with 40% quarry dust mixtures exhibiting the lowest wear depth, which is beneficial for concrete structures exposed to significant mechanical surface stress. However, exposure to sulphuric acid revealed that mixes with higher quarry dust content exhibited slightly reduced resistance compared to control specimens, highlighting the importance of considering environmental exposure conditions in design decisions.

The linear shrinkage results revealed a consistent decrease in shrinkage with increasing quarry dust content, a trend attributable to the lower water absorption capacity of quarry dust compared to cement. This characteristic can be advantageous in reducing drying-related deformations and improving dimensional stability in hardened concrete. The overall findings therefore indicate that quarry dust, when used judiciously, can enhance the performance of concrete while simultaneously reducing the reliance on conventional cement. This not only leads to cost savings but also contributes to environmental sustainability by minimizing the disposal of quarrying by-products. For structural applications, a replacement level of up to 20% is considered optimal, while higher percentages may be strategically employed in projects where abrasion resistance and shrinkage reduction are prioritized over maximum compressive strength.

Conflicts of Interest: All authors declare that they have no conflict of interest associated with this research work.

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