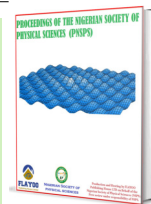


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Comparative analysis of concrete strength utilizing quarry crushed and locally sourced coarse aggregates in Jos metropolis

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ABSTRACT

This study evaluates the comparative performance of machine-crushed and hand-crushed coarse aggregates from Jos Metropolis, Nigeria, regarding their physical properties and impact on concrete compressive strength. The research was prompted by the prevalence of non-conforming hand-crushed aggregates in local construction, which often compromises structural integrity. Coarse aggregates were sourced from three machine-crushed quarries (PW, RicRock, and Moulds) and three hand-crushed sites (Tudunwada, Building Materials Market, and Domkat Bali). Physical and mechanical characterization was conducted in accordance with BS 410, BS 812, and BS EN 12520. Sieve analysis revealed that machine-crushed aggregates adhered to BS EN 12620 grading limits, whereas hand-crushed samples exhibited poor gradation. Mechanical testing confirmed the superiority of machine-crushed samples, with Los Angeles Abrasion (LAA) values of 21.6-23.4%, Aggregate Impact Values (AIV) of 17.5-18.9%, and Aggregate Crushing Values (ACV) of 19.2-20.4%, indicating higher resistance to wear and fragmentation compared to hand-crushed counterparts. Consequently, machine-crushed concrete achieved higher 28-day compressive strengths ranging from 27.4-29.1 MPa than hand-crushed concrete with values ranging from 22.5-24.0 MPa. The findings demonstrate that machine-crushed aggregates yield more consistent and superior concrete quality due to uniform particle distribution and reduced flakiness. The study recommends prioritizing machine-crushed aggregates for structural applications, while limiting hand-crushed aggregates to non-structural use.

Keywords: Concretes, Compressive strength, Aggregate crushing value, Los Angeles abrasion, Aggregate impact value.

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1. INTRODUCTION

Concrete is an important material in construction worldwide and Nigeria in particular as over 90% of structures are made from reinforced concretes [1]. The performance, workability, and dura-

bility of structures depends on this hardened concretes which are greatly enhanced by crushed aggregates; an essential components of concrete and foundational infrastructure [2]. For a dependable construction results, there's need for appropriate aggregate selection and characterization hence variations in these parameters affect the concrete's strength, density, elastic response, and fracture characteristics which may lead to structural failure.

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The compressive strength of concretes is directly impacted by aggregate size, shape, and grading, according to previous studies; angular, well-graded, and mechanically stable coarse aggregates typically result in higher concrete strengths than poorly graded or rounded aggregates [2, 3].

Although industrial quarrying and mechanical crushing have enhanced the consistency and technical applicability of aggregate production, quarry activities continue to pose environmental issues, including landscape disruption, dust pollution, slope destabilization, and habitat change [4, 5]. This highlights sustainability issues and emphasizes the necessity of reconciling ethical resource exploitation with engineering efficacy.

With the level of inconsistent grading and higher porous content, comparative studies show that concretes made with hand-crushed aggregates generally show lower mechanical performance, increased variability, and less predictable strength gain than those made with machine-crushed aggregates [4, 6]. In Jos Metropolis, over 5 cases of building cases has been reported with casualty figures calling the need to investigate the coarse aggregates suppliers and their effects on concrete performance strength and variation (NBRRI Report No. 2024).

The geological origin of most rock types depends on their geological origin having different intrinsic qualities such as strong interlocking grain patterns and low porosity which are common characteristics of igneous rocks like granite. This type of rock offer a high quality of durability and strength, bedding, foliation and the degree of weathering which can cause sedimentary and metamorphic rocks to differ greatly from texture and resistance [7]. These geological factors have a direct impact on technical parameters such water absorption, abrasion value, and aggregate crushing resistance, all of which have an impact on the performance of concrete [8]. The requirement for standardized crushing processes and thorough testing within regional settings is reinforced by recent research that shows machine-crushed aggregates generally produce stronger, more durable concrete than hand-crushed or river aggregates [3, 8].

Coarse aggregates are obtained from both mechanized quarries and unofficial, locally run hand-crushing facilities in Jos Metropolis, Plateau State, Nigeria. There is no region-specific information on how different sources and production techniques impact concrete performance, especially under standardized mix designs like the Department of Environment (DOE) method, despite the fact that these aggregates are widely used in construction and infrastructure projects. This study conducts a thorough evaluation of the geological and engineering characteristics of both machine-crushed and market-sourced aggregates due to the reported heterogeneity of aggregate properties and their significant impact on structural concrete performance. Furthermore, this study attempts to ascertain the applicability and dependability of locally available aggregates in fulfilling contemporary concrete performance standards by contrasting concrete strengths generated utilizing DOE mix design with conventional 1:2:4 techniques. In Jos, this findings will be crucial to stakeholders and many others in the built environment on reducing structural failures, selection of best materials and enhancing safe building techniques.

2. MATERIALS AND METHODS

2.1. MATERIALS

The materials used in this research includes; a 50kg Dangote Ordinary Portland cement, naturally occurring washed river sand from the banks of the River Benue as fine aggregate, machine-crushed and hand-crushed coarse aggregates from PW, Moulds (MO), RickRock (RR) quarries and Tudunwada (TW), Domkat-Bali (DB), Building material (BM) markets in Jos and its surroundings. Rock boulder samples were also collected from the same quarry sources for the microscopic study of the rocks. Standard equipment from the Nigerian Building and Road Research Institute (NBRRI) laboratories in Jos and Geology Department of the University of Jos, Plateau State, such as a universal testing machine (UTM), petrographic microscope (see Figure 1), cube moulds, slump cone, sieves, curing tank, weighing balance, oven, Los Angeles abrasion machine, aggregate impact and crushing value apparatus and pycnometer, were used for laboratory testing and characterization. Clean portable water was used throughout the experimental program.

2.2. DETERMINATION OF THE GEOLOGICAL PROPERTIES OF THE ROCK

The rock samples were geologically characterized using a combination of megascopic and microscopic methods. In order to help with preliminary categorization and the selection of appropriate samples for additional investigation, representative rock boulders were first submitted to megascopic (visual) assessment to determine rock type, colour, grain size, texture, structure, weathering condition, and surface features. In order to ascertain the mineralogical composition, texture, and micro-structural characteristics pertinent to engineering performance, thin sections of the chosen rocks were then produced and inspected under a petrographic microscope. According to conventional geological and materials characterization studies by Refs. [9, 10], this comprehensive methodology is widely recommended for evaluating the geological and engineering compatibility of construction aggregates.

2.3. DETERMINATION OF THE PHYSICAL PROPERTIES OF THE AGGREGATE

To evaluate the coarse aggregates' viability for concrete manufacture, their physical characteristics were ascertained in compliance with the British Standards. The aggregates were completely cleaned, oven-dried (see Figure 2), and manually sieved through a conventional set of sieves ranging from 50 mm to 12.5 mm in order to establish grading features and homogeneity. The particle size distribution was assessed using sieve analysis utilising BS 410:1986. In order to calculate the percentage of water absorbed, the aggregate samples were oven-dried, submerged in water for a predetermined amount of time, and then weighed again (Figure 3). The results were compared to the recommended maximum limit of 2% for high-quality aggregates as reported in Refs. [11, 12].

The aggregates' specific gravity was calculated using BS 812-2:1995 and BS EN 1097-3:1998. The results were then used in the Department of Environment's (DOE) concrete mix design computations. Additionally, using the method outlined in Ref [13], samples were oven-dried at $105 \pm 5^\circ\text{C}$ until a consistent mass was reached in order to assess the moisture content of the



Figure 1. A petrographic microscope.



Figure 2. Oven-drying samples for water absorption, specific gravity and moisture content (left); determining weight of opc for doe design (right).

aggregates. Together, these experiments produced crucial input parameters for assessing aggregate quality and precise proportioning in the construction of concrete mixes.

2.4. DETERMINATION OF THE MECHANICAL PROPERTIES OF COARSE AGGREGATES

In compliance with existing British Standards, the mechanical characteristics of the coarse aggregates were assessed to assess their strength, toughness, and resistance to wear under applied loads. In accordance with Refs. [14, 15], aggregate toughness was evaluated using the aggregate impact value (AIV) test. The impact value was calculated using the standard expression given in Chapter Two, and the mean result from five replicate tests was noted to guarantee reliability. The aggregate crushing value (ACV) test was used to assess the aggregates' resistance to crushing [14, 16].

The samples were subjected to progressive compressive loading using aggregate fractions that passed the 12.5 mm sieve and were kept on the 10 mm screen; the average outcome of five tests was reported. Additionally, the Los Angeles abrasion test was used to assess the aggregates' abrasion resistance in compliance with [17]. This test involved rotating aggregates of a given grading for 500 revolutions in a steel drum filled with abrasive charges, and calculating the percentage of mass loss that resulted. In accordance with the process and interpretation suggested by Ref. [18], the Los Angeles abrasion value (LAAV) was expressed as a measure of aggregate durability.



Figure 3. Oven-drying samples for water absorption, specific gravity and moisture content (left); determining weight of opc for doe design (right).

2.5. DETERMINATION OF MIX DESIGN DATA ACCORDING TO DEPARTMENT OF ENVIRONMENT (DOE) METHOD

The proper concrete mix proportions used in this investigation were determined using the Department of Environment's (DOE) mix design procedure. The procedure was used methodically by first defining the desired mean compressive strength based on the necessary characteristic strength, and then choosing the appropriate water-to-cement ratio in accordance with the criteria for strength and durability. The maximum nominal size of coarse aggregate was selected to fit the aggregate properties and intended

Table 1. Summary of the doe mix design calculations.

Stage	Item	Ref. or Cal.	Values	
1	1.1	Characteristic strength	Specified	25 N/mm ² at 28 days
	1.2	Standard deviation	Table 2	5.0 N/mm ²
	1.3	Margin (K × SD)	$k\delta$	$1.64 \times 5 = 8.2$ N/mm ²
	1.4	Target mean strength (F _m)	F_m	$25 + 8.2 = 33.2$ N/mm ²
	1.5	Cement type	Specified	OPC 42.5N
	1.6	Aggregate type		20 mm crushed granite (coarse), river sand (fine)
	1.7	Free water/cement ratio	Table 8, fig. 2	0.50
	1.8	Max. free water/cement ratio	Specified	0.55 → use 0.50
2	2.1	Slump	Specified	30-60 mm (medium workability)
	2.2	Max. aggregate size	Specified	20 mm
	2.3	Free water content		185 kg/m ³
3	3.1	Cement content		$185 \div 0.50 = 370$ kg/m ³
	3.2	Max. cement content	Fig. 3	450 kg/m ³
	3.3	Min. cement content		300 kg/m ³
	3.4	Modified w/c ratio		0.50
4	4.1	Specific gravity of aggregates (SSD)		Fine = 2.65, Coarse = 2.70
	4.2	Concrete density		2400 kg/m ³
	4.3	Total aggregate content		1880 kg/m ³
5	5.1	Grading of fine aggregate	Percent passing 600 μ m	≈45% passing 600 μ m
	5.2	Proportion of fine aggregate (by vol.)	Fig. 6	36%
	5.3	Fine aggregate content		680 kg/m ³
	5.4	Coarse aggregate content		1200 kg/m ³
Quantities per m ³ (to nearest 5 kg)	Cement (kg)	Water (kg or L)	Fine aggregate (kg)	Coarse aggregate (kg)
Trial mix (0.065 m ³)	370	185 (185)	680	1200
	24	12 (≈12)	44	78

concrete application, while workability was determined using the required slump.

To create a balanced, workable mix with sufficient strength and durability, the quantities of aggregate, water, and cement were determined based on these factors. The usual DOE criteria as published by Refs. [18, 19] were followed in all mix design procedures and computations. Table 1 provides an overview of the DOE mix design calculations used for the concrete manufacturing in this study.

2.6. PRODUCTION AND TESTING OF CONCRETE CUBES

In compliance with applicable British Standards, concrete production and testing were conducted to assess the fresh and hardened qualities of concrete made using the chosen aggregates. The cement and fine aggregate were initially dry-mixed to create consistency before the coarse aggregates and a measured amount of water were added and well mixed. Batching was done manually by weight to ensure accuracy. After that, fresh concrete was put into 150 × 150 × 150 mm standard cube moulds Figure 4, compacted in three layers to remove trapped air, and then demoulded after a day.



Figure 4. Fresh concrete placed into cube moulds.

Concrete production and testing were carried out to evaluate the fresh and hardened properties of concrete produced using the



Figure 5. Concrete cubes in curing tank.



Figure 6. Performing slump test using abrams cone.

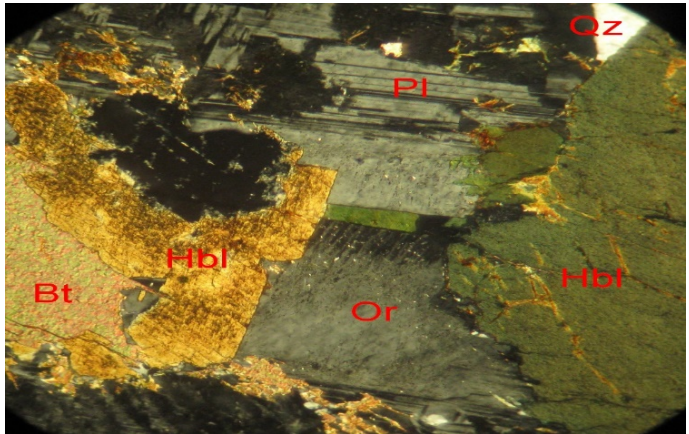


Figure 7. Micrograph of moulds rock sample.

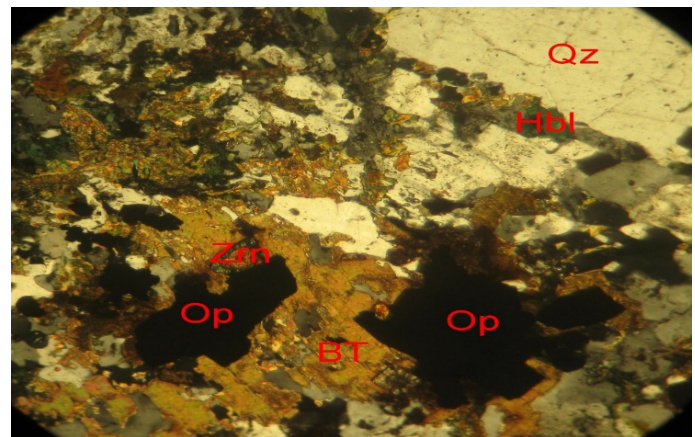


Figure 8. Micrograph of pw rock sample.

selected aggregates, in accordance with relevant British Standards. Batching was conducted manually by weight to ensure accuracy, after which cement and fine aggregate were first dry-mixed to achieve uniformity before the coarse aggregates and measured quantity of water were added and thoroughly mixed. Fresh concrete was then placed into standard cube moulds of size $150 \times 150 \times 150$ mm, compacted in three layers to eliminate entrapped air, and demoulded after 24 hours. In accordance with [20], the Abrams cone slump test was used to assess the workability of the fresh concrete as presented in Figure 6. The cone was filled in three equal layers, each of which was tamped 25 times using a standard steel rod. The vertical subsidence of the concrete that resulted was measured as the slump value to show consistency and ease of placement.

In accordance with Ref. [20], the concrete cubes were cured by immersion in water tanks kept at a temperature of 20 ± 2 °C until testing at curing ages of 7, 14, 21, and 28 days (Figure 5). Using a universal testing machine (UTM) in compliance with [21], the compressive strength of the cured cubes was then calculated as the ratio of the failure load to the cube's cross-sectional area. To ensure consistency, the average strength of three cubes was reported for each curing age.

The Schmidt rebound hammer test was also conducted on hardened concrete cubes as an extra non-destructive assessment. The resulting rebound numbers were compared with compressive

Table 2. Specific gravity, water absorption rate and moisture content.

Aggregate	Sample code	Specific gravity	Water absorption (%)	Moisture content (%)
Machine crushed	PW	2.68	0.64	1.1
	RR	2.71	0.48	0.9
	MO	2.65	0.82	1.3
Hand crushed	TW	2.38	1.20	2.4
	BM	2.34	1.05	2.1
	DB	2.32	1.32	2.7

strength values in compliance with [22] standards in order to establish relationships. Finally, the reliability of the experimental results was evaluated by statistical analysis using Microsoft Excel. To ensure the quality, consistency, and repeatability of the results, all measured data were meticulously documented and analyzed.

3. RESULT AND DISCUSSION

Figures 7, 8 and 9 present the results of the microscopic properties of the rock samples of PW, RicRock, and Moulds quarries. The findings indicates that this rock samples are competent igneous rocks whose megascopic and petrographic features signif-

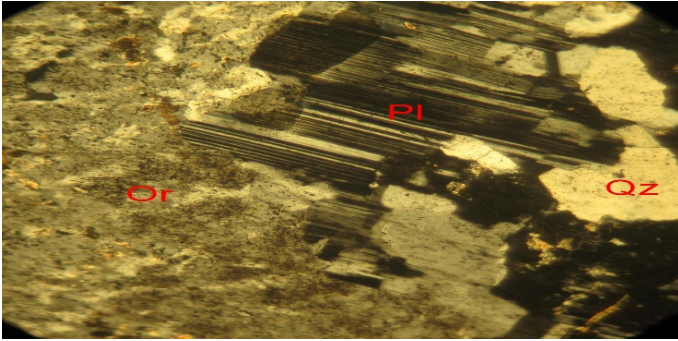
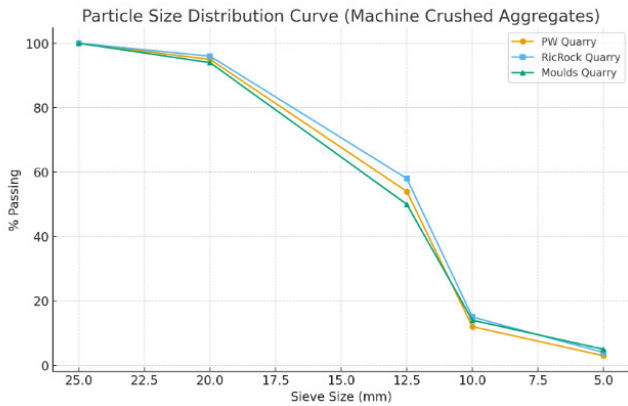
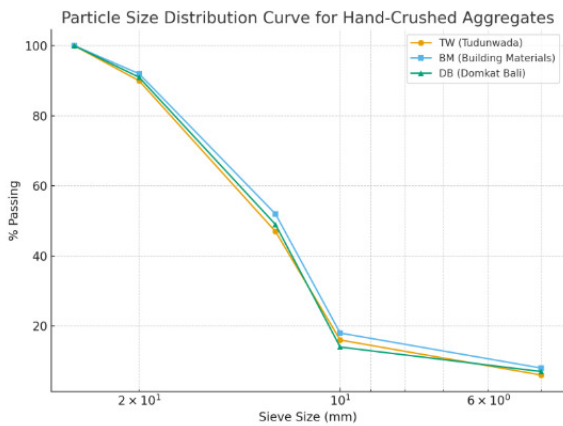


Figure 9. Micrograph of ricrock sample.



(a)



(b)

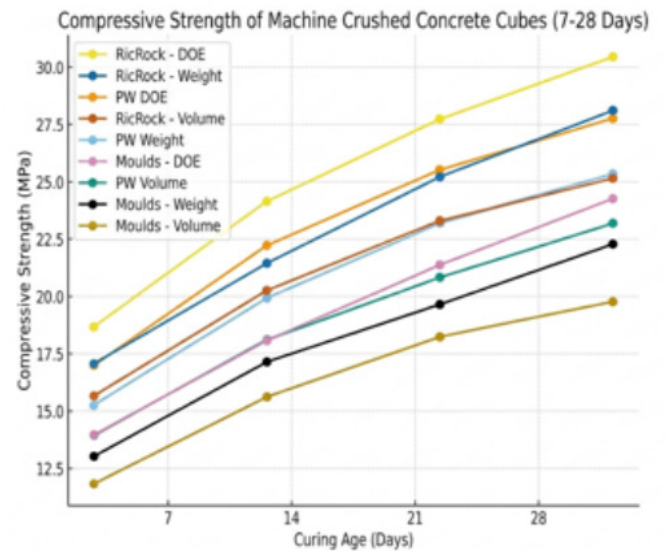
Figure 10. Particle size distribution curve (a) machine-crushed aggregates (b) hand-crushed aggregates.

icantly influence aggregate and concrete performance. The PW and RicRock exhibit well-interlocked granitoid textures rich in quartz and feldspar, which account for their higher specific gravity and durability (see Table 2) in comparison to the comparatively more mafic Moulds rock [23–25].

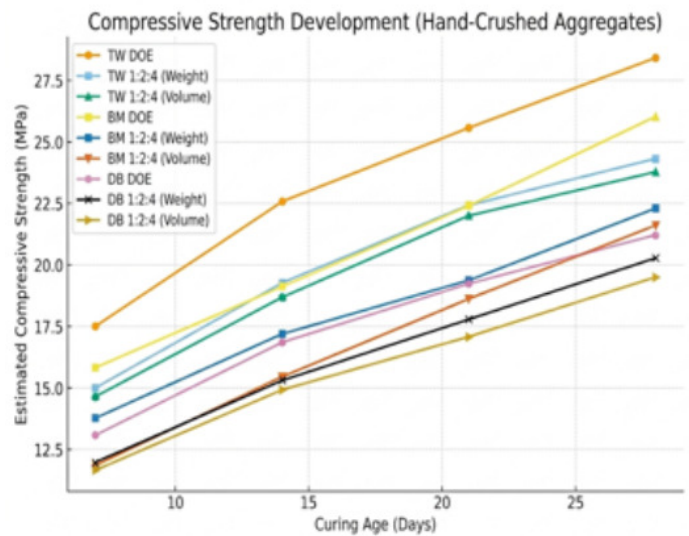
The results of the engineering properties of the aggregates in Table 2 and Figure 10 revealed that machine-crushed aggregates consistently satisfied BS EN 12620 and ASTM C33 international grading and strength limits with higher specific gravity 2.65, 2.71 and 2.65, lower water absorption between 0.48-0.82%, mois-

Table 3. Aggregate impact value, aggregate crushing value and los angeles abrasion value.

Aggregate	Sample code	AIV (%)	ACV (%)	LA AV (%)
Machine crushed	PW	19.5	22.4	26.3
	RR	15.2	18.7	22.8
	MO	21.8	24.1	28.6
Hand crushed	TW	27.4	29.3	34.8
	BM	25.6	27.9	33.1
	DB	28.1	30.4	35.6



(a)



(b)

Figure 11. Compressive strength for of 7, 14, 21 and 28 days (a) machine-crushed aggregate concrete (b) hand-crushed aggregate concretes.

ture content of 1.1%, 0.9% and 1.3% for PW, RR and MO rock samples respectively. The machine-crushed aggregates demonstrated superior mechanical indices with AIV between 15.2-

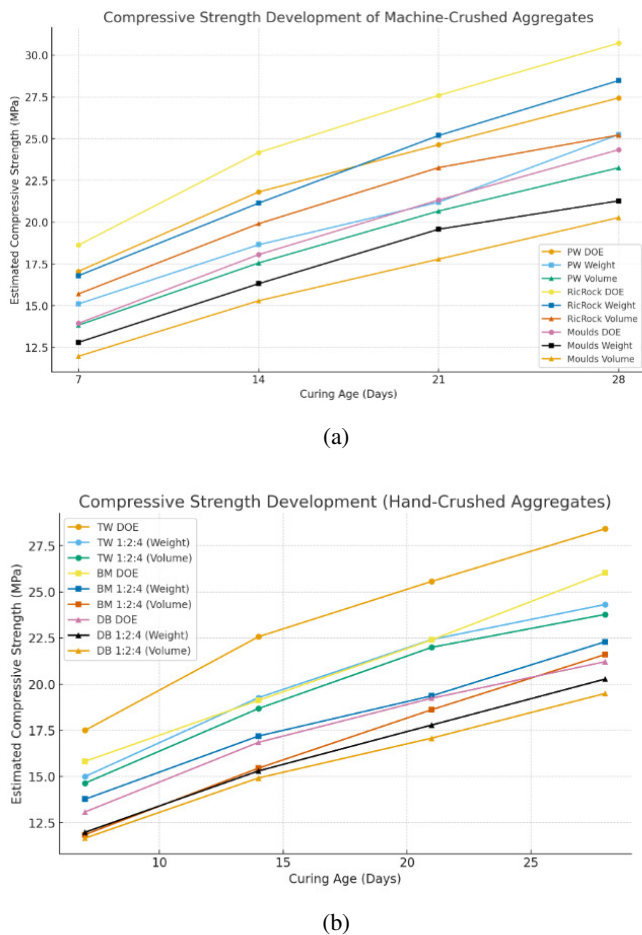


Figure 12. Estimated compressive strength for 7, 14, 21 and 28 days with schmidt rebound harmer (a) machine-crushed aggregate concretes (b) hand-crushed aggregate concretes.

21.8%, ACV between 18.7-24.1%, and LAAV between 22.8-28.6% which were all within the recommended standard limits than hand-crushed aggregates, which exhibited lower density between 2.32-2.38, higher water absorption between 1.05-1.32%, with marginal mechanical values AIV up to 28.1%, ACV up to 30.4%, LAAV up to 35.6% as presented in Table 3 are all in agreement with Refs. [18, 26].

The result of the compressive strength in Figures 11(a & b) and 12(a & b) of the cured concrete samples for 7, 14, 21 and 28 days for both the machine-crushed and hand-crushed aggregates indicates that the cubes produced using the DOE mix design consistently outperformed the traditional mixes of 1:2:4 by volume and weight. The machine-crushed aggregates had superior compressive strength, ranging from 28 to 30 MPa after 28 days of curing for all rock samples, in contrast to the traditional mixes, which exhibited inferior strength as recommended by BS EN 206 and BS 8500 verifying the superiority of regulated proportioning [6, 25]. Overall, aggregate petrography, crushing method, and mix design jointly governed concrete strength development, with DOE mixes using machine-crushed aggregates providing the most reliable structural concrete, a trend further validated by Schmidt rebound correlations [22, 27].

4. CONCLUSION

This study assessed the properties of rocks, corresponding market-sourced aggregates, and the suitability of the Department of Environment (DOE) mix design for concrete production in Jos Metropolis, and it established that aggregates from PW, RicRock, and Moulds quarries are derived from competent crystalline rocks suitable for construction, with machine-crushed aggregates exhibiting superior grading uniformity, higher specific gravity, lower water absorption and moisture content, and markedly better mechanical performance with lower AIV, ACV, and LAAV than market-sourced hand-crushed aggregates, whose variability reflects informal production practices. The concrete tests further showed that mixes produced with machine-crushed aggregates consistently achieved higher rebound numbers and compressive strengths at all curing ages, while among mix methods the DOE design outperformed the traditional 1:2:4 mixes by weight and by volume, confirming DOE as the most reliable and structurally efficient approach for concrete production in Jos. The results highlight the need to prioritize machine-crushed aggregates, widely adopt DOE mix design, enforce quality control on market aggregates, and avoid volume batching for structural applications.

DATA AVAILABILITY

The data will be available on request from the corresponding author.

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