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Optimization of Manufactured Quarry Sand Use in Concrete, Mortar and Plaster in Cameroon

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Abstract

The use of manufactured quarry sand is a subject of debate among engineers, because of quantity of fine particle size elements and the difficulty to categorize between fine, average or coarse. Another important point is the missing of regulation from Cameroun about and especially the reprimands of public control service whether the quarry sand is found in the public site work. This study aims to optimize the use of manufactured quarry sand in concrete, mortar, and plaster in Cameroon by determining the most suitable particle-size fractions for each application. Our analysis and test found the optimization of quarry sand use, based on particle-size distribution and fineness modulus. Results emphasize the best use of the sand according to the particle size. By sieving, different fractions of sand can be made from manufactured sand and usefully adapted: From 0.315 to 5 mm with average fineness modulus value of 2.64, 60% of sand found its best use in concrete; about 40% of sand up to 0.63 mm with fineness modulus value of 1.19 is better for mortar and appropriate for plaster. Manufactured sand is highly pure, offering a consistent, engineered alternative to river, pit and sea sand that is free from organic impurities, silt, and clay. Due to controlled production, washing, and screening, it typically contains negligible fine particle, within 6% limits, ensuring superior durability, strength, and structural integrity in concrete—across the entire territory of Cameroon, the rocks are exposed, and exploitation of manufactured sand is availability. Compared to river and pit sand, manufactured sand has a very low cost. The findings of this study contribute to the sustainable and optimized use of manufactured quarry sand in Cameroon and provide a technical basis for its regulation and wider application in the construction sector.

Keywords

Fineness Modulus, Manufactured Quarry Sand, Concrete, Mortar, Plaster, Cameroon

1. Introduction

Sand is one of the most essential materials used in the construction industry worldwide. It is a fundamental component of concrete, mortar, plaster, and asphalt mixtures, where it contributes to mechanical strength, durability, stability, and workability [1] [2]. The rapid growth of urbanization and infrastructure development has considerably increased the demand for natural sand resources, especially river and pit sand, which remains the most commonly used fine aggregate in many developing countries [3] [4]. In Cameroon, more than 80% of construction sand is sourced from rivers and pit, leading to increasing pressure on fluvial ecosystems and environmental degradation associated with uncontrolled sand mining [4].

The excessive exploitation of river sand has generated significant environmental concerns, including riverbank erosion, lowering of riverbeds, groundwater depletion, and destruction of aquatic habitats [5] [6]. In response to the growing scarcity of natural sand and stricter environmental regulations, manufactured quarry sand (M-sand) has emerged as a promising alternative fine aggregate for construction materials [3] [7]. Manufactured sand is produced by crushing hard rock into fine particles with controlled gradation and particle size distribution. Unlike natural river sand, M-sand generally contains angular and rough-textured particles, which may influence the workability and mechanical performance of concrete and mortar [2] [8].

Several studies have demonstrated that manufactured sand can provide satisfactory or even superior mechanical properties compared to natural sand when properly processed and graded [9]. The use of manufactured sand has been associated with improved compressive strength, better particle packing, reduced voids, and enhanced durability of concrete structures [6] [8]. Furthermore, the controlled production process of M-sand limits the presence of deleterious materials such as organic matter, clay, and silt, which are often encountered in natural sands [10] [11]. However, the presence of excessive fines and the angularity of crushed particles may reduce workability and increase water demand if the material is not adequately characterized [8].

The engineering debate surrounding manufactured quarry sand mainly concerns its particle-size distribution, fines content, and suitability for different construction applications such as concrete, mortar, and plaster [3]. Previous research has shown that the granulometric characteristics of sand strongly influence the rheological and mechanical behavior of cement-based materials [1] [8]. Fine sands are generally preferred for plastering and masonry works, whereas medium and coarse sands are more suitable for structural concrete applications due to their contribution to granular skeleton stability and compressive strength [2] [6].

In Cameroon, despite the increasing use of quarry sand in construction projects, there is still limited scientific data regarding its optimal use according to particle size fractions. In addition, no clear national regulation currently governs the classification and utilization of manufactured quarry sand in construction practices. Consequently, engineers and public control services often remain reluctant to approve its use on construction sites. Yet, Cameroon possesses abundant rock resources favorable for the production of manufactured sand throughout the national territory [4].

This study, based on particle-size distribution and fineness modulus, aims to optimize the use of manufactured quarry sand in concrete, mortar, and plaster in Cameroon by determining the most suitable granulometric fractions for each application [12]. The work also seeks to contribute to the sustainable management of construction materials and provide a technical basis for the wider application and regulation of manufactured quarry sand in the Cameroonian construction sector.

2. Data, Materials and Method

2.1. Sand

Sand used has been sampled from 3 manufactured quarries. In order to compare with natural sand, river (Sanaga) sand and pit sand have also been analyzed. Quarry manufactured sand, extracted from Nkoabang, Leboudi and Lobadjeck quarries. River Sand sampled from Sanaga River. Pit sand sampled from Okola and Lobo Quarries.

Regarding manufactured quarry sand, we carried out bulk sampling. At each site, samples were taken from the various piles and mixed together. In the laboratory, 2 kilograms of sand from each quarry were analyzed. Meanwhile, the natural sand (pit and river), which was also sampled in bulk, was collected from the construction site.

Our samples were first left exposed in the sun for 2 days and then spread out in a drying oven at 60˚C for 6 hours.

2.2. Equipment

To determine particle size distribution, particles size analysis done has primarily used sieving. Essential tools include certified test sieves, shaker machines (vibratory/electromagnetic), sample splitters, precise balances, and cleaning brushes to ensure accurate results (**Figure 1**). The series of sieves used includes mesh sizes 160 μm, 315 μm, 630 μm, 1.25 mm, 2.5 mm and 5 mm (**Figure 1(a)**, **Figure 1(c)**). Data are easily analyzed on Excel, Microsoft.

2.3. Fineness Modulus

Fineness modulus serves as a measure of aggregate coarseness or fineness,

Figure 1. Sieving. (a) sieve column; (b) root and leaves of in river sand; (c) retained in 5mm sieve of M-sand; (d) sieving of sanaga (river) sand.

commonly used to optimize concrete mix design and maintain consistency. FM is an empirical numerical index that represents the average size of particles in an aggregate sample; it has been calculated according to French NORM [13].

FM = (Σ of cumulative % retained)/100 [14].

FM = (Σ of cumulative % series of sieves (160 μm, 315 μm, 630 μm, 1.25 mm, 2.5 mm, 5 mm))/100

A sample of aggregate is passed through a standard set of sieves. The percentage of material retained on each sieve is calculated, and a cumulative percentage is calculated by adding the percentages retained on all preceding sieves. The cumulative percentages are summed and divided by 100.

Typical fineness modulus values for sand [13].

1.8 < MF < 2.2: high workability and low strength. Good for mortar.

2.2 < MF < 2.8: satisfactory workability, good strength and no risk of segregation, good for concrete.

2.8 < MF < 3.2: High strength, weak workability with risk of segregation.

Sand with an FM greater than 3.2 is generally considered too coarse for high-quality, Workable concrete.

According to French and European standards [15]-[17], the value of FM is very useful for optimizing the mix design of concrete, mortar, and plaster. Sebsadji [18] highlighted the relationship between the global fineness modulus and the particle size distribution of concrete at the skeleton scale, using fractal dimension.

- For standard concrete, FM ≈ 2.2 - 2.8; range often cited as ideal is FM≈ 2.6 - 2.9 depending on the application [15].

- Aggregates for mortar and plaster are standardized [18]; FM depends on the type of mortar, often FM ≈ 1.5 - 2.2 depending on the application [16] [17] [19].

3. Result and Comment

3.1. Aggregate Morphology and Fresh Concrete Properties

By visual inspection, it is observed that, manufactured sand is angular (**Figure 1(c)**), unlike river sand which is rolled. The angular shape increases the water demand of concrete and reduces its workability, often requiring the use of additives. Angular shapes increase strength primarily in construction materials specifically concrete and asphalt by enhancing mechanical interlocking and frictional resistance between particles; this reduces the workability of the concrete mix and increases its water demand to achieve a given slump. The sharp edges and rough surfaces of angular aggregates, often produced by crushing, lock together better than rounded, natural aggregates. This higher interlocking creates a denser, more stable matrix.

3.2. Cleanliness: Purity, Organic Impurities, and Durability

Visual inspection and sieving show that manufactured sand, compared to river and pit should be pure. Impurities observed in river and pit sand (**Figure 1(b)**) are organic elements including shell, bones, roots, leaves and twigs which can significantly reduce the strength of concrete and compromise its integrity and durability. The purity of manufactured sand is an important and great quality. To avoid weakness in concrete, mortar or plaster, element used for mixture, sand is characterized by purities. These organic impurities are highly deleterious to structural concrete. They retard the setting time of cement, inhibit the chemical hydration process, and leave physical voids upon decomposition. These voids create weak points that drastically reduce compressive strength and long-term durability [20] [21].

3.3. Sieving and Particle Size Analysis

The optimization of manufactured quarry sand used is the main objective of this research. Thus, sand from five samples of sand has been analyzed; three samples from manufactured quarries that we compared results to one river and two inland sand.

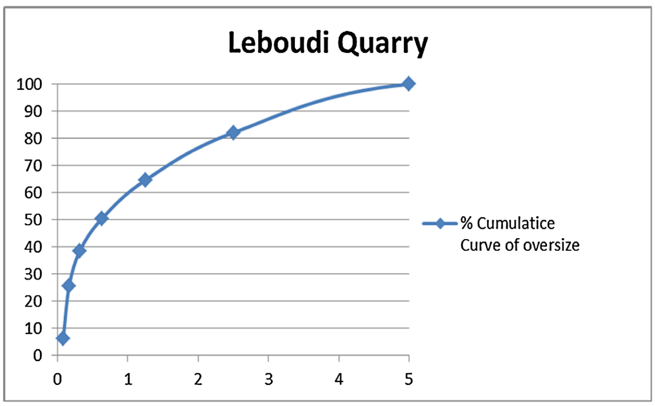
The analysis of the three manufactured quarry sand shows that, amount of particles distribution according to size varies little from on sieve to the other (**Figure 2**). Average distribution shows a maximum percentage of particles retained on 2.5 mm mesh sieve; *i.e.*, 18.49%. Sieves 5 mm, 2.5 mm, 1.25, 0.63, 0.315, and 0.16 have average distribution of 16.2%, 18.49%, 14.9%, 13.2%, 13.6 and 17.12% retained respectively; we consider these results closes (**Table 1**). The distribution of particles is almost equilibrated according to size from 0.16 mm to 5 mm sieve. We can observe that manufactured quarry product is constituted to about 1/3 of fine, 1/3 of medium and 1/3 of coarse sand. It is then complicated to classify manufactured sand in fine, medium or coarse category. In general, sand is used in concrete, mortar or plaster. To be high quality, proper proportion of sand as well as water and cement are critical in the mixture. To consider quantity of sand, it has to be classified in fine, medium or coarse. It is then clear that, we cannot use manufactured quarry sand as it is. It can also be observed that, a proportion of 6,496% (sieve 0.08 mm) of this sand is dust generated by drilling crushing and grinding; the necessity of washing and cyclone treatment are then essential to optimize quality.

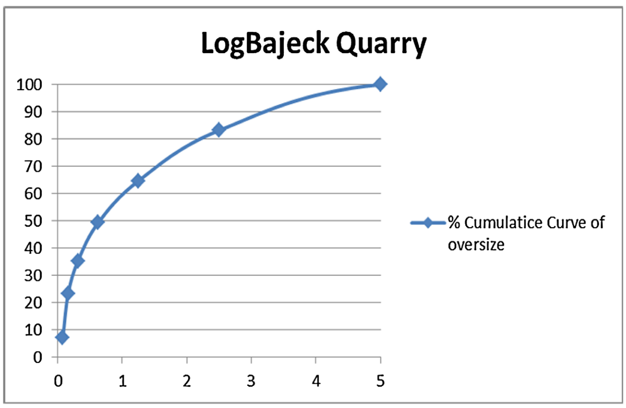
Considering river and pit sand, the classification is clear (Figure 3 and Figure 4). River sand analyzed is constituted to retained from 0.315, 0.63 and 1.25 sieves; what gives a total of about 80%. This range of sieve classified river sand as medium aggregate required for concrete. Pit sand analyzed shows that retained on 0.8, 0.16 and 0.315 is made with about 93.5% of fine particles; what ranges it in the category of fine sand (Figure 4) mandatory for mortar. From 0.08 and 0.16 sieves, the retained is about 80%, good range for aggregate to mix high quality plaster.

Table 1. Distribution of particle size in percentage for each quarry.

Sieve opening (mm)	Manufactured quarries sand				River sand	Pit quarries sand			Type
	% Leboudi	% LogBadjeck	% Nkoa-Abang	% Average	% Sanaga (River)	% Okola (pit)	% Lobo (pit)	% Average	
5	17.86787	16.83367	14.04213	16.24789	1.001502	0.551378	0.401808	0.476593	Coarse
2.5	17.46747	18.48697	19.50853	18.48766	1.452178	1.102757	0.602712	0.852735	
1.25	14.21421	15.23046	15.24574	14.8968	13.92088	0.701754	1.557007	1.129381	Medium
0.63	11.91191	14.07816	13.49047	13.16018	37.85679	3.508772	4.018081	3.763427	
0.315	13.11313	11.92385	15.74724	13.59473	29.24387	15.18797	14.11351	14.65074	
0.16	19.11912	16.18236	16.04814	17.11654	14.97246	74.68672	76.29332	75.49002	Fine
0.08	6.306306	7.264529	5.917753	6.496196	1.101652	4.160401	3.013561	3.586981	

3.4. Particle Size Analysis Curve





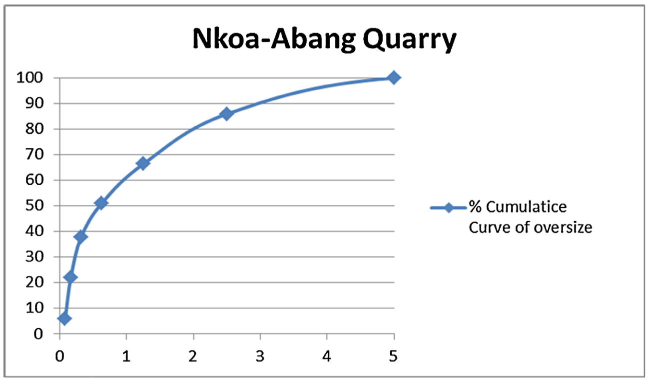


Figure 2. Cumulative curve from manufactured quarries sand.

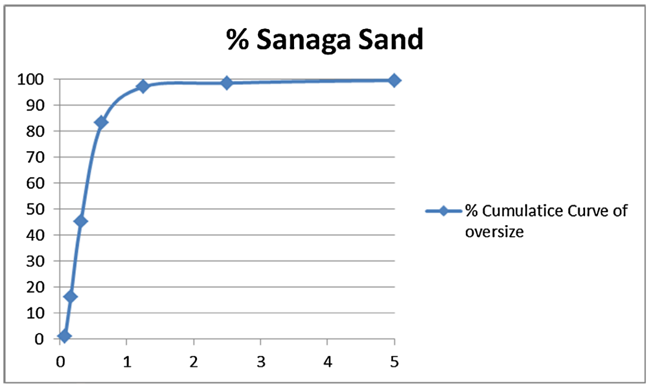


Figure 3. Cumulative curve from river (Sanaga) sand.

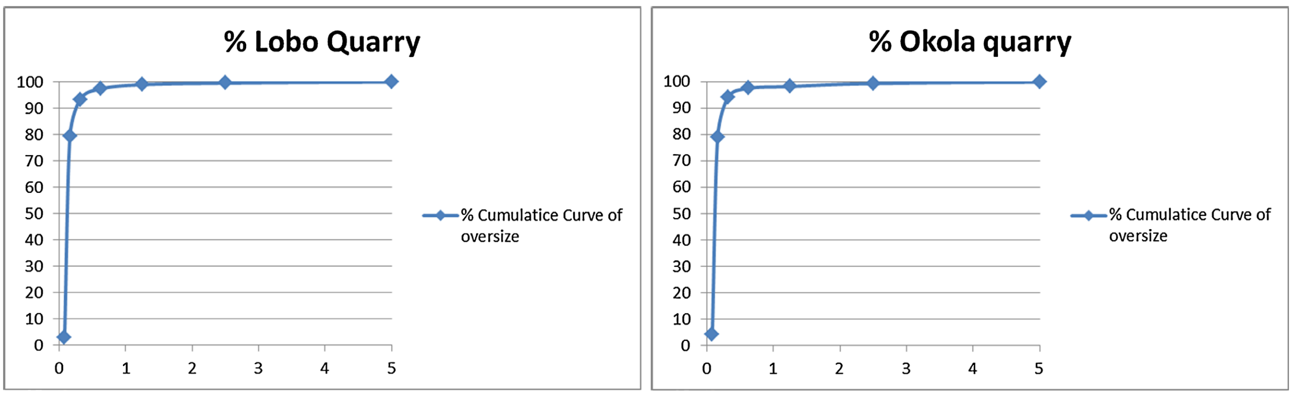


Figure 4. Cumulative curve from pit quarries sand.

3.5. Calculated Fineness Modulus

Fineness modulus calculated from the different sample of sand gave results of Table 2.

Table 2. Values of fineness modulus from different sample.

Type of quarry name	Manufactured quarries sand			River sand	Pit quarries sand	
	Leboudi	LogBadjek	NkoaAbang	Sanaga	Okola	Lobo
Fineness modulus	3.324	3.366	3.308	2.591	1.279	1.282

FM obtained from manufactured quarries is greater than 3.2 (Table 2). Quarry sand is then considered as too coarse for high quality workable concrete.

Sand from river has FM of 2.591; what offers a satisfactory workability. Concrete mixed with this sand is the required quality with good strength and no risk of segregation.

Sand from pit quarries of Okola and Lobo has FM lower than 1.8; what is typically used for finishing applications rather than structural concrete.

4. Optimization

The optimization we advocate is based on sieving and separation. Sieving is a simple, cost-effective physical separation method we used to separate solid particles of different sizes by passing them through a mesh of sieve. It is important to note that the sieving to optimize the use of manufacturing sand is not a new or additional step. In fact, sieving is always performed on construction sites to remove impurities. This should not be considered an extra task that financial or time implications need to be assessed.

4.1. Simulation of Fineness Modulus

We decide to separate particle at a mesh 0.315. Considering the sieving of manufactured sand at a mesh of 0.315, sand retained include particle size from 0.315 to 5 mm; mixed of medium and coarse sand. The calculation of fineness modulus from the formula **FM =** (Σ of cumulative % retained)/100 is applied.

According to French norm NFP 18-540, we should use series of sieves 160 μm, 315 μm, 630 μm, 1.25 mm, 2.5 mm, 5 mm. Since particles with size lower than 0.316 are not included, retained percentage of 160 μm is excluded.

FM = (Σ of cumulative % series of sieves (160 μm, 315 μm, 630 μm, 1.25 mm, 2.5 mm, 5 mm))/100.

Fineness modulus calculated for these sands are grouped on the Table 3.

Table 3. Fineness modulus for sample of manufactured quarry sand.

	Opening	Leboudi	LogBadjeck	NkoaAbang	Average
Retained sand for concrete	5	17.86787	16.83367	14.04213	16,24789
	2.5	35.33534	35.32064	33.55065	34,73554
	1.25	49.54955	50.5511	48.79639	49,63235
	0.63	61.46146	64.62926	62.28686	62,79253
	0.315	74.57457	76.55311	78.03411	76,38726
Passing sand for plaster and mortar	**0.163**	**93.69369**	**92.73547**	**94.08225**	**93,5038**
		100	**100**	**100**	**100**
Fineness modulus of row sample		3,324	3.366	3.308	3.333
Fineness modulus without 0.163 mm sieve		3.202013	3.185864	3.033419	3.140432

Table 4. Fineness modulus (FM).

Sieves opening	Leboudi			LogBadjeck			NkoaAbang		
	Mass (g)	%	Cumul. %	Mass (g)	%	Cumul. %	Mass (g)	%	Cumul. %
5	357	23.95973	23.95973	336	21.98953	21.98953	280	17.99486	17.99486
2.5	349	23.42282	47.38255	369	24.14921	46.13874	389	25	42.99486
1.25	284	19.0604	66.44295	304	19.89529	66.03403	304	19.53728	62.53214
0.63	238	15.97315	82.41611	281	18.39005	84.42408	269	17.28792	79.82005
0.315	262	17.58389	100	238	15.57592	100	314	20.17995	100
Total	1490		320.2013	1528		318.5864	1556		303.3419
FM		**3.202013**			**3.185864**			**3.033419**	
Average fineness modulus = 3.140432									

Retained sand is coarse, and angular, ranging from 0.315 to 5 mm in size. These jagged, large particles lock together to provide superior structural strength for driveways, pouring slabs, foundations, and footings; what fulfills the conditions of good sand for concrete. The percentage of this coarse and medium sand is about 76% of the row sample (Table 4).

The passing sand which represents about 24% is finer and can be used for smooth finishes in walls, stucco, and mortar masonry. This offers smoother, more compactable results for coating, whereas "sharp sand" is better for high-strength structural.

Table 5. Cumulative percentage of sieve (2.5; 1.25; 0.63; 0.315 mm).

Opening sieve apertures	Leboudi		LogBadjeck		NkoaAbang		Average
	Qte (g)	Cumulative %	(g)	Cumulative %	(g)	Cumulative %	
2.5	349	30.8032	369	30.9564	389	30.4859	30.7485
1.25	284	55.8694	304	56.45976	304	54.31035	55.5465
0.63	238	76.87557	281	80.03358	269	75.39186	77.43367
0.315	262	100	238	100	314	100	100
Total	1133		1192		1276		
Cumulative %		263.5482		267.4498		260.1881	
FM		2.635482		2.674498		2.601881	2.637287

From the row sample of manufactured sand, it is possible to have 76% of coarse sand to mix good concrete providing superior structural strength (Table 5). The 24% of sand remaining constitutes fine sand which is interested to make mortar and plaster for smooth coating.

From Table 6, fineness modulus of row and separated sand by sieving are presented. It clearly appears that, row manufactured quarry sand (A) has fineness

Table 6. Fineness modulus for row and optimized samples.

		Leboudi	LogBadjeck	Nkoa-Abang	Average
A	Fineness modulus of row sample	3.324	3.366	3.308	3.333
B	Fineness modulus minus 0.163 mm sieve	3.202013	3.185864	3.033419	3.140432
C	Fineness modulus minus 0.163 and 5 mm sieves	2.635482	2.674498	2.601881	2.637287

modulus more than 3.2; what means this sand is too coarse for high-quality, Workable concrete. It is generally unsuitable for high-quality, workable concrete because it creates harsh, unworkable mixes prone to segregation and honeycombing. In some condition, this sand can be used when looking for very strength concrete, or can be just rejected. Sand sample (B) separated with 0.315 mm sieve has average of 3.14 for Fineness modules which is comprised between 2.8 and 3.2, what means it provides with high strength to the concrete. Sand with a fineness modulus (FM) around 3.0 is classified as coarse sand**,** ranging between 2.9 and 3.2, indicating a relatively high average particle size suitable for producing high-strength, low-shrinkage concrete. While excellent for structural concrete, this sand may require more cement and water to maintain workability compared to medium sand. The separation at 0.315 means that 0.163 mm sieve is excluded to the calculation of FM, because the retained from this sieve is considered to be zero. Sand sample (C) constituted with retained by sieve 0.315 mm and passing of 5mm sieve; what means retained from 0.163 mm and 5mm sieve are removed, and then are not considered for the calculation of FM. Sand with a fineness modulus of around 2.63 is generally classified as medium sand. It falls within the desirable range (2.3 - 3.1) for creating quality concrete, offering a good balance between workability and strength. An FM of 2.63 indicates that the average particle size is well-balanced, sitting at the transition point between fine and medium sand, typically falling within the ideal Zone. Sand with this modulus specifically between 2.2 and 2.8 is known to produce concrete with high workability and low segregation. The particle distribution is likely favorable, reducing the need for excess water and allowing for higher strength and durability.

The production of medium sand suitable for good concrete leads simultaneously to the production of the fine sand needed for mortar. This dual-production method is a highly efficient approach to construction material sourcing, maximizing resource utility by aligning the production of medium-grade sand (essential for concrete) with the finer byproduct needed for mortar and plastering. By utilizing crushed rock or aggregate, this process creates a sustainable, zero waste approach, as all fractions of the crushed material are tailored to specific, in demand construction applications.

The fraction constituted by passing of 0.63 mm sieve, provide us with fine sand with an average fineness modulus of 1.63. It is considered very fine sand and is ideal for general structural mortar, and can be used for specific finishing plastering applications, provided it is clean and properly graded [11]. According to standard building codes [11] [22], the recommended FM range for plastering sand is 1.2 to 2.2.

This statement highlights the shift toward sustainable, high-performance construction materials by emphasizing that manufactured sand is not just a substitute for river sand, but often a superior alternative due to its controlled production process. The crushing process allows for precise control over the particle size distribution, ensuring a mix of fine, medium, and coarse fractions that provide denser packing in concrete. Different fractions can be utilized for different purposes: finer fractions can be used for plastering or as mineral fillers, while coarser fractions (up to 4.75 mm) are used as concrete aggregates. Modern crushing methods, such as Vertical Shaft Impactors (VSI) produce angular or cubical particles, which provide superior interlocking compared to the rounded particles of river sand, leading to higher compressive strength and better durability.

Manufactured sand is processed in a controlled factory environment, reducing contaminants. Unlike river sand, which often contains silt, clay, and organic matter, M-sand is clean. This absence of impurities helps in preventing the reduction of cement strength and prevents corrosion of reinforcement steel. The chemical and mineral composition is consistent throughout, eliminating the variations often found in natural sourcing.

While initial processing requires investment, the overall project cost is often reduced. M-sand can be produced near construction sites significantly reducing the high logistics costs associated with transporting river sand. Proper grading and shape often allow for a lower cement-to-sand ratio, saving on overall material costs while achieving the same or higher strength.

4.2. Particle Size Distribution and Grading Challenges

The sieve analysis reveals that the raw manufactured quarry sands (Leboudi, Log-Badjeck, Nkoa-Abang) display an atypical, overly uniform particle size distribution: Fine Particles (~1/3), Medium Particles (~1/3) Coarse Particles (~1/3) This nearly equal tri-distribution (roughly 33% each of fine, medium, and coarse fractions) makes it impossible to classify the raw product into a standardized single category.

For high-quality concrete, mortar, or plaster, the sand must be clearly classifiable to ensure a dense particle packing layout:

Highly optimized for structural concrete, with 80% of its particles retained on medium sieves (1.25 mm to 0.315 mm), yielding an ideal fineness modulus (FM) of 2.591. This ensures excellent workability and no risk of segregation.

Distinctly fine, with up to 93.5% of particles are into the fine category. While unsuitable for structural concrete (FM < 1.8), it is mandatory for high-quality finishing plasters and mortars.

Raw manufactured sand contains an average of 6.496% ultra-fine micro-dust (0.08 mm sieve) generated during drilling and crushing. This excess of micro-fines increases water absorption and weakens the cement-aggregate bond, demonstrating that raw quarry sand cannot be used in its as-received state. Washing and cyclone treatments are mandatory to strip away this micro-dust.

5. Conclusions

Based on the analysis of the fineness modulus for the different sand samples, the following conclusions can be drawn: Raw quarry sand (Sample A): With an FM exceeding 3.2, this sand is too coarse, resulting in harsh, unworkable mixes prone to segregation. It is generally unsuitable for high-quality concrete, though it may be used for specific high-strength applications or rejected. The position of engineer to reject this sand is fundamentally understandable and widely supported in engineering practices. While it may be used in specific, modified, or less-critical applications, such sand is generally unsuitable for high-quality, durable, or high-strength concrete for several key, so mainly segregation risk, hard workability and a lot of fine particle influencing the strength.

Separated sand (Sample B - 0.315 mm sieve): With an average FM of 3.14 (range 2.8 - 3.2), this sample is classified as coarse sand. It is well-suited for producing high-strength, low-shrinkage structural concrete, though it may require higher cement and water content to maintain workability.

Separated sand (Sample C - Retained on 0.315 mm/Passing 5 mm): With an FM of 2.63, this sample represents the ideal, well-balanced medium sand. It offers the best combination of workability and strength, reducing the risk of segregation and lowering the demand for excess water. Sample (C) provides the best balance for general high-quality concrete, while sample (B) is preferable for high-strength requirements, and raw sample (A) requires modification to be viable.

The production of medium sand suitable for good concrete leads simultaneously to the production of the fine sand needed for mortar. Consequently, this dual-production method maximizes resource utility, creating a sustainable, without waste approach that supplies both the concrete and construction industries from a single source.

The conclusions and subsequent recommendations presented in this study should be considered as preliminary rather than universal. Sand produced from the three manufactured quarries can be different to some others in one hand and in the other hand this evaluation is based strictly on granulometric analysis. In perspective, to establish comprehensive national guidelines, further testing is important across a wider geographic variety of quarries, probably incorporating physical and chemical analysis and concrete trial mix data.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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