Techno- Economics Viability Assessment of Associate Rocks at Obu-Mines Okpella, Nigeria

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ABSTRACT

Mining and quarrying activities generate significant quantities of associated rocks and other materials that are often treated as waste despite their potential value as construction resources. This study assessed the techno-economic viability of recovering and utilizing associated rocks generated at Obu Mines, Okpella, Edo State, Nigeria, with emphasis on their engineering properties, mineralogical characteristics, resource potential, processing requirements, and economic value. Representative samples were collected from three mining pits, designated Pit 1, Pit 2, and Pit 3, and subjected to physical, mechanical, chemical, and mineralogical analyses. The physical tests included moisture content, water absorption, effective porosity, specific gravity, and particle-size distribution, while mechanical characterization involved Aggregate Impact Value (AIV), Aggregate Crushing Value (ACV), Uniaxial Compressive Strength (UCS), and flexural strength. X-ray fluorescence (XRF) and X-ray diffraction (XRD) analyses were also conducted to establish the chemical and mineralogical compositions. Results showed that Pit 1 exhibited the highest engineering quality, with a specific gravity of 3.10, AIV of 6.96%, ACV of 4.10%, and UCS of 107.0 MPa, making it suitable for high-value applications such as concrete and road aggregates. Pit 2 recorded a specific gravity of 2.64, AIV of 10.00%, ACV of 7.52%, and UCS of 79.5 MPa, indicating suitability for road base, asphalt aggregate, and general construction applications. Pit 3 showed comparatively lower strength, with AIV of 31.10%, ACV of 30.50%, and UCS of 50.1 MPa, making it more appropriate for embankment, hardcore, drainage, and other lower-grade applications. XRF and XRD results revealed significant mineralogical variations, with Pit 1 dominated by wollastonite and Pits 2 and 3 predominantly composed of quartz. Preliminary resource estimation based on an active area of approximately 400,000 m², an estimated extraction depth of 180 m, and a mean density of 2.79 t/m³ produced an indicative resource of approximately 201.12 million tonnes. The crushing plant had an installed capacity of 350 t/h but operated at an average rate of 200 t/h, representing 57.14% utilization. Estimated production was approximately 3,200 tonnes/day, with projected gross revenue ranging from ₦38.4 million to ₦44.8 million per day depending on product mix. The study concludes that the associated rocks constitute a technically and economically viable secondary resource. It recommends selective classification, continuous quality control, improved blasting and crushing efficiency, accurate production and cost records, and appropriate allocation of each rock type to suitable construction applications to enhance profitability, resource recovery, and environmental sustainability.

Keywords: Associated rocks, techno-economic viability, Obu Mines, construction materials, aggregate, resource recovery, Okpella.

INTRODUCTION

Mining and quarrying activities generate substantial quantities of materials in addition to the principal economic mineral. These materials may include overburden, interbedded rocks, wall rocks, weathered materials, rejected quarry products and other associated lithological units encountered during extraction. Although such materials are commonly classified as mine waste, they may possess useful physical, mechanical, chemical and mineralogical properties that make them suitable for construction applications. The beneficial utilization of mine rock waste has consequently become an important approach to reducing waste accumulation, conserving natural resources and improving the economic efficiency of mining operations. Agyeman and Ampadu (2016) demonstrated the techno-economic feasibility of processing mine rock waste for road construction, showing that appropriately characterized and processed waste rock can satisfy relevant pavement-material requirements.

The potential utilization of associated rocks is particularly important because construction and infrastructure development require large volumes of aggregates and other rock-based materials. However, the suitability of a rock for concrete aggregate, road base, subbase, hardcore or fill depends on its physical and mechanical characteristics, mineralogical composition and chemical stability. Parameters such as specific gravity, water absorption, particle-size distribution, aggregate crushing value, aggregate impact value, abrasion resistance and compressive strength provide important indicators of material performance. Similarly, mineralogical and chemical investigations are necessary for identifying constituent minerals and potentially deleterious elements that could influence construction performance (ASTM International, 2018, 2019, 2022; British Standards Institution, 1990, 1995).

Obu Mines, located at Okpella in Edo State, Nigeria, represents an important environment for investigating the utilization of associated rocks. The Obu operation is associated with BUA Cement and involves limestone quarrying, extraction and processing for cement production. BUA Cement reports that the Obu plant has three production lines, each with a production capacity of 3 million metric tonnes per annum, demonstrating the substantial scale of industrial activity in the area (BUA Cement, 2026). At such a large-scale quarrying operation, the occurrence of non-economic or associated rock materials during excavation and material handling presents both a waste-management challenge and an opportunity for secondary resource recovery.

The geological setting of Okpella further supports the need for detailed characterization of associated rocks. The area is characterized by diverse lithological units, including marble, schists, quartzites, calc-silicate rocks, metasedimentary rocks and granitoid–charnockite associations. Petrographic and geochemical investigations have demonstrated considerable lithological and compositional variability within the Okpella geological environment (Ogunyele et al., 2020). Investigations of the Obhu Hill marble deposit have also established the geochemical characteristics of carbonate-bearing rocks within the area (Sanni et al., 2018). Such geological variability suggests that associated rocks generated during quarry development may differ substantially in mineralogy, texture, strength, durability and potential construction applications.

The conversion of associated rocks from waste into construction materials, however, requires more than technical characterization. Economic considerations such as recoverable quantity, excavation and handling costs, crushing and screening requirements, transportation, market demand and potential selling price must also be evaluated. A material may satisfy engineering specifications but remain commercially unattractive if the cost of processing and transportation is excessive. Conversely, an associated rock requiring limited processing and located close to a suitable market may provide an economically viable alternative to conventional aggregates. Therefore, integrating engineering characterization with economic evaluation is essential for determining the practical value of mine-associated materials (Agyeman & Ampadu, 2016).

Despite the geological and industrial importance of Okpella, there is limited integrated information on the engineering suitability and economic potential of associated rocks generated within the Obu Mines environment. Previous studies have primarily addressed the geology, geochemistry, marble resources and geophysical characteristics of the area rather than the systematic conversion of associated quarry rocks into construction materials (Emenike et al., 2024; Ogunyele et al., 2020; Sanni et al., 2018). This study therefore assesses the techno-economic viability of associated rocks at Obu Mines by integrating physical, mechanical, chemical and mineralogical characterization with economic evaluation. The study aims to identify appropriate construction applications, evaluate recoverable materials and potential revenue, and develop a utilization framework for transforming suitable associated rocks into economically valuable construction resources.

Research Gap

Despite the considerable geological and industrial significance of the Okpella area, existing studies have largely concentrated on the characterization, exploration and economic potential of the principal mineral resources, particularly limestone and marble, rather than on the systematic evaluation of the associated rocks generated during quarrying activities. Geological and geochemical investigations have established the occurrence of diverse lithologies, including marble, schists, quartzites, calc-silicate rocks, metasedimentary rocks and granitoid–charnockite associations within the Okpella area (Ogunyele et al., 2020; Sanni et al., 2018). Similarly, geophysical investigations have focused on delineating ore and marble deposits rather than determining the engineering and commercial potential of associated quarry materials (Emenike et al., 2024). Consequently, there is limited site-specific information linking the lithological characteristics of associated rocks at Obu Mines to their physical, mechanical, chemical and mineralogical properties and, ultimately, to their suitability for construction applications.

METHODOLOGY

The methodology adopted for this study involved the systematic collection, preparation, laboratory characterization, resource estimation, economic evaluation, and proposed utilization of associated rocks generated at Obu Mines, Okpella, Edo State, Nigeria. Representative rock samples were collected from three selected mining pits, designated Pit 1, Pit 2, and Pit 3, using systematic sampling, quartering, and riffling techniques to ensure that the samples obtained were representative of the different lithological and weathering conditions within the study area. The collected samples were transported to the laboratory, properly labelled, air-dried where necessary, and reduced to suitable sizes using a jaw crusher. Physical properties of the samples were determined through moisture content, water absorption, effective porosity, specific gravity, and particle-size distribution tests, using relevant British Standards and ASTM procedures.

Mechanical properties were evaluated through Aggregate Impact Value, Aggregate Crushing Value, Uniaxial Compressive Strength, and flexural strength tests to determine the resistance of the associated rocks to impact, crushing, compression, and bending. Chemical and mineralogical characteristics were also investigated by pulverizing representative samples and subjecting them to X-ray fluorescence (XRF) analysis using the Genius IF Xenemetrix XRF system and X-ray diffraction (XRD) analysis using the Rigaku MiniFlex 600 XRD system, with mineral phases identified using the ICDD PDF-4 database. The results obtained from these tests were used to classify the associated rocks according to their engineering quality and determine their suitability for construction applications such as concrete aggregates, road base, hardcore, embankment, and general fill. In addition, the economic potential of recovering the associated rocks was assessed by estimating the available volume and tonnage from field mapping, geological observations, and three-dimensional modelling using Surpac software.

Rock volume was estimated from the cross-sectional area and average thickness of the deposits, while tonnage was obtained by multiplying the estimated volume by the corresponding rock density. Potential revenue was then calculated by multiplying the estimated saleable tonnage of each rock type by its prevailing market price, while total operational cost incorporated extraction, processing, transportation, and other associated expenses. The net revenue was subsequently determined by subtracting the total cost from the gross revenue to establish the economic viability of recovering the materials.

Finally, a utilization, recovery, and processing system was developed based on the quality of the associated rocks, involving selective extraction, controlled recovery, crushing, screening, classification, and separate stockpiling of the resulting products. High-quality and durable materials were proposed for concrete and pavement aggregates, whereas relatively weaker materials were designated for road sub-base, hardcore, embankment, and general filling purposes. The proposed processing system incorporated primary and secondary crushing followed by screening into different size fractions, including stone dust, fine aggregate, 5–10 mm, 10–20 mm, and 20–40 mm coarse aggregates, with periodic quality-control testing to ensure compliance with required engineering properties.

RESULT AND DISCUSSION

Physical Characterization Results

The moisture Constraints Samples recorded minimal moisture values (Pit 1: 0.13%, Pit 2: 0.13%, Pit 3: 0.00%), ensuring strong structural matrix stability without moisture retention risks. Effective porosity and absorption for Pit 1 (0.03%) and Pit 2 (0.00%) demonstrated exceptionally dense profiles. Pit 3 showed a higher porosity value of 0.75%, making it more vulnerable to moisture damage. Specific gravity divergence Pit 1 achieved a high specific gravity of 3.10, ideal for heavy-duty structural concrete mixes. Pits 2 and 3 settled at 2.64, which fits standard civil engineering baselines.

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Sieve Analysis Summary

Pit 1 (Granular Base) Composed of 92% gravel, 8% sand, and 0% fines. Ideal for high-drainage, heavy-load road base profiles. Pit 2 (Balanced Coarse) Composed of 93% gravel, 6% sand, and 1% fines. Displays an even mass spread peaking at the 10 mm sieve aperture (44.80%). Pit 3 (Fine-Skewed Material) Composed of 74% gravel, 22% sand, and 4% fines. High sand and fine ratios restrict its standalone use in high-grade concrete.

Mechanical Properties Evaluation

Table 1: Mechanical Properties Evaluation

Mechanical Property Tested	Pit 1	Pit 2	Pit 3	Industrial Standard Threshold Alignment
Aggregate Impact Value (AIV)	6.96%	10.00%	31.10%	Pits 1 & 2 pass heavy wearing course limits. Pit 3 fails high-impact metrics.
Aggregate Crushing Value (ACV)	4.10%	7.52%	30.50%	Pit 1 & 2 exhibit strong load-bearing durability. Pit 3 prone to degradation.
Uniaxial Compressive Strength (UCS)	107.0 MPa	79.5 MPa	50.1 MPa	Pit 1 is exceptionally strong. Pit 2 is highly competent. Pit 3 suits general fill.
Flexural Strength (σf)	16.2 MPa	15.5 MPa	14.6 MPa	All three pits provide adequate bending resistance for pavement use.

Chemical and Mineralogical Properties

XRF Composition Analysis that Pit 1 is highly calcareous, featuring 39.84% Calcium Oxide (CaO) and 32.67% Silica (SiO_2) while Pit 2 and Pit 3 are strongly siliceous, yielding 67.39% and 62.92% (SiO_2), alongside minor Alumina (Al_2O_3) fractions (10.47% and 9.84%).

XRD Mineral Phase Quantification shows in Figures 3,4 and 5 that Pit 1 is Dominated by Wollastonite (73.7%), a high-strength calcium silicate mineral that explains the sample's high density and exceptional mechanical properties. It also contains minor Orthoclase (16.8%) and Goethite (9.5%). Pit 2 is Highly quartzose, consisting of 72.0% crystalline Quartz along with Orthoclase (17.2%) and Albite (10.0%). This hard quartz matrix provides strong resistance to physical weathering and mechanical abrasion. Pit 3 is Composed of 65.0% Quartz, but contains higher percentages of weaker minerals like Orthoclase (26.0%) and Muscovite mica (6.0%). The presence of platy muscovite creates planes of weakness that explain the sample's higher degradation rate during crushing and impact testing.

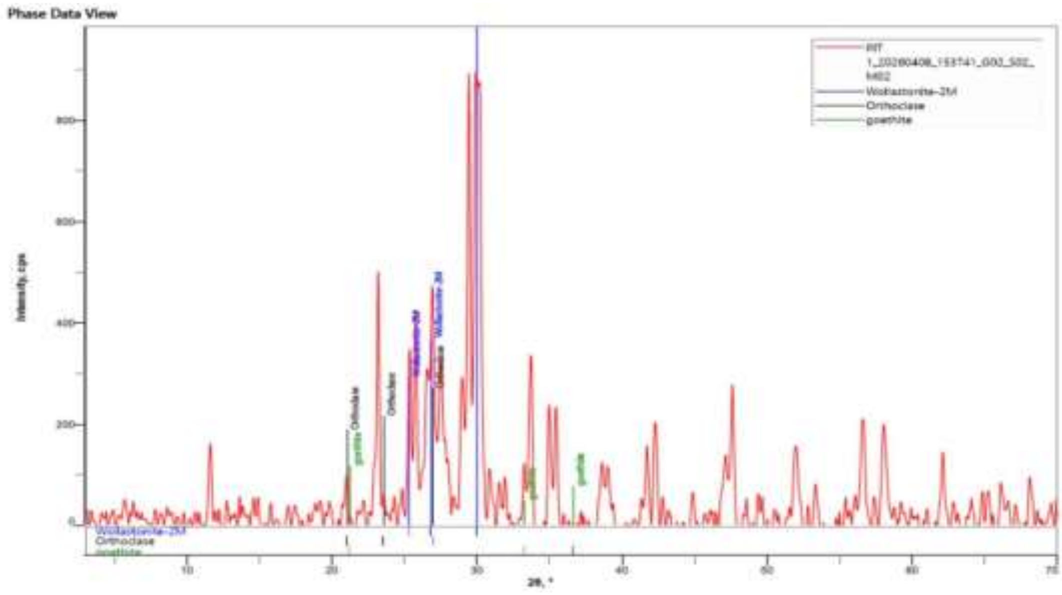

Figure 3 Diffractogram Obtained for PIT 1

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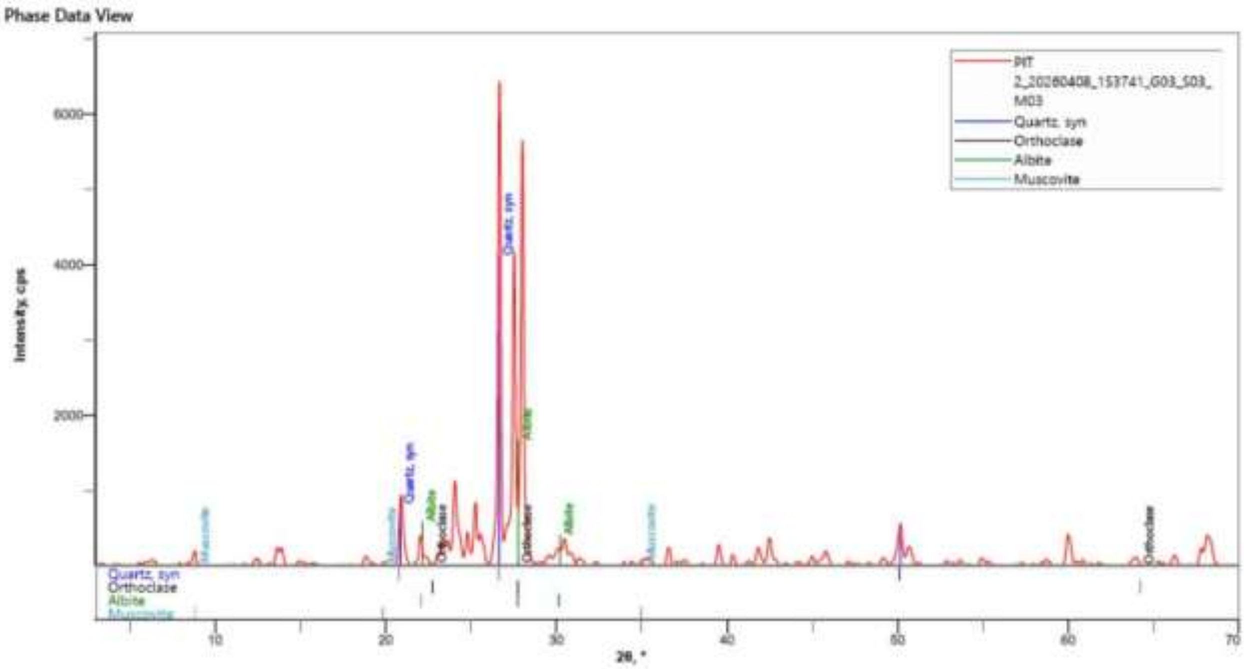

Figure 4 Diffractogram Obtained for PIT 2

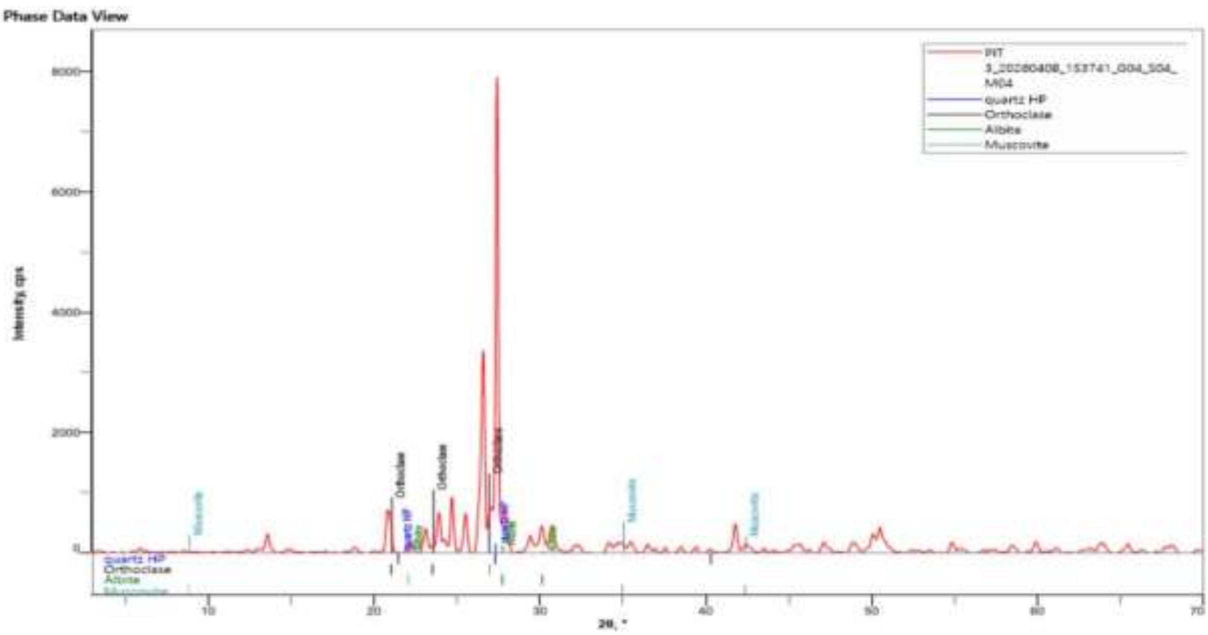

Figure 5:Diffractogram obtained for PIT 3

Mining Area and Volume Estimate

The mining lease area covers 1.8 km², which is equivalent to 1,800,000 m². The active mining area supplied for the result is less than 400,000 m². Using 400,000 m² as the planning boundary and 180 m as the estimated extraction depth, the in-situ volume is 72,000,000 m³. When the mean density value of 2.79 t/m³ is applied, the provisional tonnage becomes 201,120,000 tonnes. Since the density values used here were taken from the laboratory specific gravity result, the tonnage should be treated as an indicative planning estimate until mine survey data, recovery factor, bulk density and dilution factor are finalised.

Drilling and Blasting Parameter

The drilling result shows in Table 2,the average of 120 holes per blast round, with each hole drilled to approximately 30 to 33 m. The calculated total drilling meterage is therefore 3,600m to 3,960m. This calculation

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is important because drilling cost, bit life, compressor cost, rig utilisation and explosive charging all depend on meterage. The field note stated 120 holes at 30 m each, and the mathematical product gives 3,600 m. Thus, the value should be recorded as 3,600m for a 30m average hole depth.

Table 2: Drilling and Blasting Result

Parameter	Reported Field Data
Number of shifts per day	2 shifts
Type of drilling machine	Tameock drilling machine
Bit size	6 inches (152 mm)
Number of blast holes	Average of 120 holes
Hole depth	30 to 33 m
Total drilling meterage	3,600 to 3,960 m
Spacing	4 m
Burden	3 to 4 m
Blasting time	12 noon to 4 pm
Explosive type	Gel 125 mm and Super 90 mm for priming
Delay system	Nonel 500 ms down-the-hole and 25 ms surface delay
Solar gel (125mm)	2,150/kg
Super power (90mm)	2,400/kg
12m nonel	4,615/No
Electric detonator	1,250/No
Cord	800/m
Diesel consumption	900 litres
Price of bits Price if hammer	₦350,000 ₦1,250,000
Meterage before bit change	2000-2500m (it varies)

Estimated Blast Volume and Broken Rock Tonnage

The result in Table 3 shows the blast design relationship based on burden, spacing, hole depth and number of holes, the estimated volume of rock broken per blast round ranges from 43,200 m³ to 63,360 m³. At the provisional mean density of 2.79 t/m³, this gives an estimated broken rock tonnage of about 120,528 to 176,774 tonnes per blast round. This result should be read as a design estimate because the final broken tonnage depends on bench geometry, hole deviation, powder factor, rock structure, sub-drilling, collar loss, stemming height and the proportion of blasted rock that is actually recoverable for aggregate production.

The blast recovery sequence begins with spacing, burden and depth confirmation. This is followed by drilling, hole cleaning, charging with explosive materials, stemming, connection after charging, safety clearance and blasting. The use of down-the-hole and surface delay detonators helps to control the order of detonation so that rock breaks progressively instead of detonating as a single uncontrolled mass. Proper stemming also helps to retain explosive energy in the hole and improve fragmentation. Good fragmentation reduces secondary breaking and supports smoother feeding into the jaw crusher.

Table 3: Estimated Blast Volume Based on Burden, Spacing, Depth and Number of Holes

Case	Blast design basis	Estimated volume (m³)	Estimated tonnage
Lower case	B=3 m; S=4 m; H=30 m; holes=120	43,200	120,528
Upper case	B=4 m; S=4 m; H=33 m; holes=120	63,360	176,774

Result Of Processing Design For Associated Rocks

Processing Flow

The crushed material then passes through screens that classify the product into 25.4 mm aggregate, 12.7 mm aggregate, 9.5 mm aggregate, and dust/fines. Each product is conveyed to a separate stockpile to prevent contamination and to make sales and loading easier.

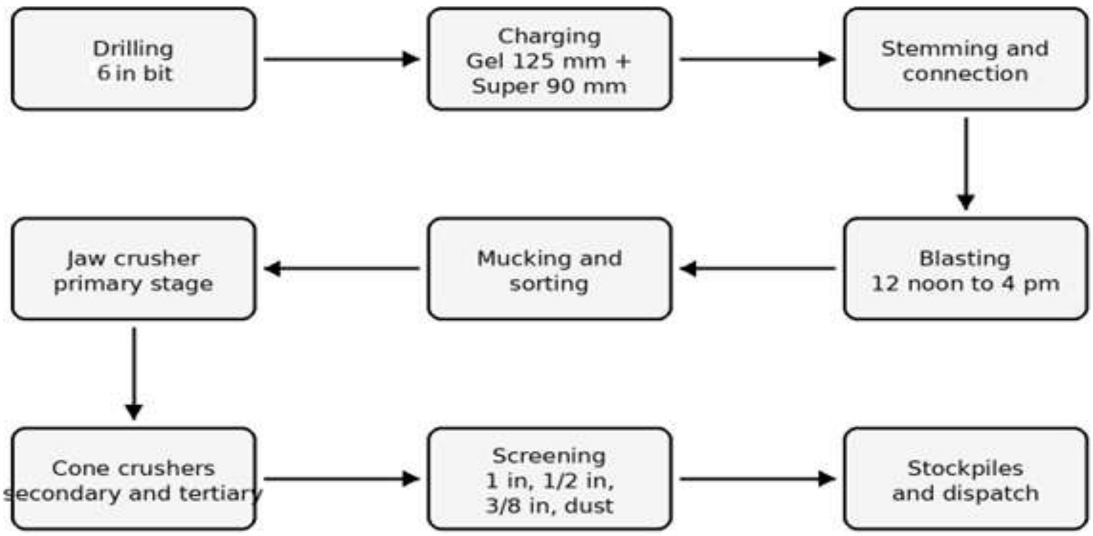

Figure 6: Processing Flow for Recovery, Crushing, Screening and Stockpiling

Crusher Capacity, Operating Time and Downtime

The installed crusher capacity is 350 t/h, while the observed average crushing rate is 200 t/h. The plant is therefore operating at about 57.14% of its installed hourly capacity. This indicates that the installed plant has unused capacity that could be recovered through improved feed control, reduced stoppage, better crusher maintenance, regular screen cleaning and more stable loading. The reported downtime is about 4 h/week. Under a two-shift operation with 16 scheduled hours per day and seven working days as the projection reference, weekly availability is approximately 96.43%. At the average crushing rate of 200 t/h, the adjusted weekly production after downtime is about 21,600 tonnes.

Table 4: Crushing Plant Operating Result

Parameter	Result
Primary crusher	350 t/h jaw crusher
Secondary and tertiary crushers	Cone crushers
Screen product sizes	25.4 mm aggregate, 12.7 mm aggregate, 9.5 mm aggregate, and dust/fines.
Installed crusher capacity	350 t/h
Average actual crushing rate	200 t/h
Capacity utilization	57.14%
Operation time	All working hours except breakdown
Assumed working hours for projection	16h/day
Daily production at actual rate	3,200 t/day
Daily production at installed capacity	5,600 t/day
Crusher downtime	4 h/week
Weekly plant availability	96.43%
Adjusted weekly production	21,600 t/week

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Diesel Consumption and Production Efficiency

The result in Table 5 shows the crusher consumes about 800 litres of diesel per day, while drilling consumes about 900 litres for the reported drilling operation. Using the projected production of 3,200 tonnes per day, the crusher diesel intensity is 0.250 litres per tonne, while total drilling and crusher diesel intensity is 0.531 litres per tonne. The average daily dispatch of 80 truckloads shows strong market movement. If the 3,200 tonnes per day production estimate is divided by 80 truckloads, the implied average truck payload is about 40 tonnes per truck. This value should be confirmed from actual weighbridge tickets or truck capacity records before it is used for final royalty or tax calculation.

Table 5: Diesel Consumption and Production Efficiency

Parameter	Values
Drilling diesel consumption	900 litres
Crusher diesel consumption	800 litres/day
Total drilling and crusher diesel	1700 litres/day
Crusher diesel use per hour	50.00 litres/h
Crusher diesel intensity	0.250 litres/tonne
Total diesel intensity	0.531 litres/tonne
Average truckloads per day	80 truckloads/day
Implied average load per truck	40.0 tonnes/truck

Market Demand, Product Prices And Revenue Projection

Product Prices and Market Demand

The result in Table 6 shows the Market demand was reported as high, and the quarry dispatches an average of 80 truckloads per day. Dust sells at ₦12,000, while the 1 inch, 1/2 inch and 3/8-inch aggregate products sell at ₦14,000. Since the percentage product split among the four products was not supplied, the revenue projection was calculated as a range. The lower projection assumes that all saleable output is dust, the upper projection assumes that all saleable output is the higher-priced aggregate products, and the middle projection assumes an equal product mix across dust, 1 inch, 1/2 inch and 3/8 inch aggregate.

Table 6: Market Prices of Aggregate Products

Product	Reported unit price/toone
Dust	₦12,000
1 inch aggregate	₦14,000
1/2 inch aggregate	₦14,000
3/8 inch aggregate	₦14,000

Gross Revenue Projection

The result in Table 7 observed average crushing rate of 200 t/h and an assumed 16-hour working day, the quarry can produce about 3,200 tonnes per day. The lower daily gross revenue projection is ₦38,400,000 if all output is priced as dust. The middle projection is ₦43,200,000 per day if the product mix is evenly distributed across dust and the three higher-priced aggregate sizes. The upper projection is ₦44,800,000 per day if all output is sold as 1 inch, 1/2 inch or 3/8 inch aggregate. After allowing for 4 h/week downtime, the middle adjusted weekly revenue is ₦291,600,000, while the estimated monthly revenue is approximately ₦1,252,800,000.

Table 7: Gross Revenue Projection Based on Average Crushing Rate

Case	Price (₦/t)	Daily revenue	Weekly revenue	Monthly revenue
Lower	12,000	₦38.4m	₦259.2m	₦1,113.6m
Middle	13,500	₦43.2m	₦291.6m	₦1,252.8m
Upper	14,000	₦44.8m	₦302.4m	₦1,299.2m

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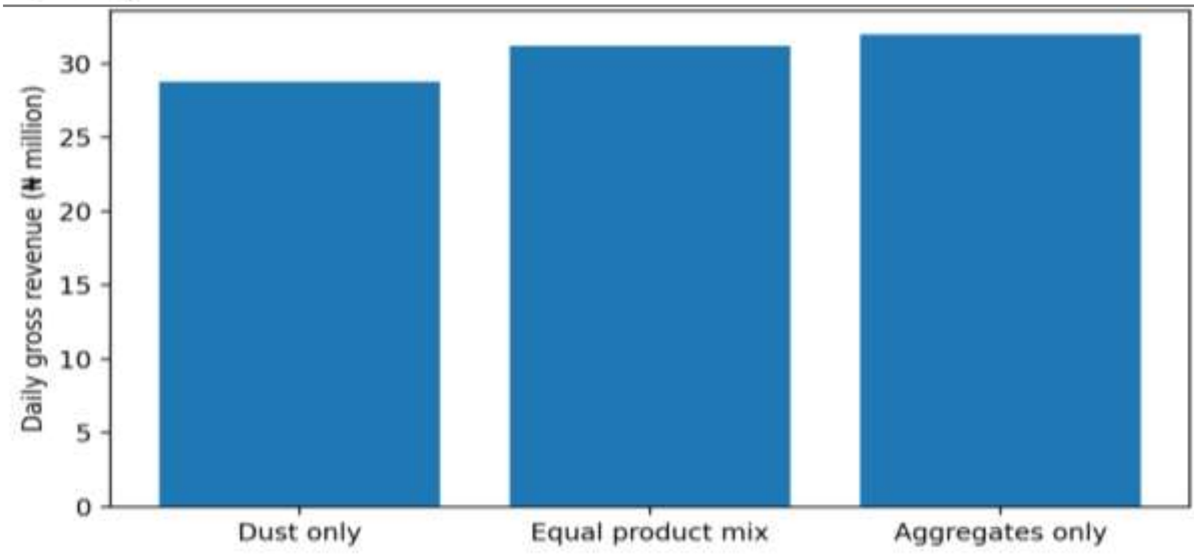

Figure 7: Projected Daily Gross Revenue at Average Production Rate

CONCLUSION AND RECOMMENDATION

The study concludes that the associated rocks generated at Obu Mines, Okpella, Edo State, constitute a potentially valuable secondary mineral resource that can be recovered and utilized as construction materials rather than being treated solely as mining waste. The physical, chemical, mineralogical, and mechanical characterization of the rocks provides a technical basis for determining their suitability for concrete aggregates, road construction, asphalt works, hardcore, embankment, and other civil engineering applications, subject to compliance with relevant standards. The techno-economic assessment further indicates that systematic recovery and processing of the associated rocks can generate additional revenue for the quarry, reduce waste-handling requirements, minimize dependence on newly extracted construction materials, and promote more efficient utilization of mineral resources. The study therefore recommends that the rocks from each pit should be classified according to their engineering quality before large-scale utilization. Pit 1 should be prioritized for higher-value applications such as concrete aggregate and road base, while Pit 2 may be used for road base, asphalt aggregate, general construction, and selected concrete works. Pit 3 should mainly be considered for embankment fill, drainage materials, hardcore, low-grade aggregates, or blended products unless further testing confirms higher-quality applications. Continuous quality-control testing should be conducted on blasted materials, crusher feed, screened products, and stockpiles, including particle-size distribution, specific gravity, water absorption, Aggregate Impact Value, Aggregate Crushing Value, abrasion resistance, XRF, and XRD analyses where necessary. Proper drilling and blasting records should also be maintained, including hole depth, burden, spacing, explosive quantity, stemming, drilling costs, and blast performance, with the existing blast design reviewed regularly to improve fragmentation and reduce oversize materials. Overall, implementing these recommendations will enhance resource recovery, profitability, environmental sustainability, and the long-term utilization of associated rocks at Obu Mines.

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