

Effect of Quarry Dust on the Geotechnical Properties of Weak Subgrade Soil

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Abstracts. This research focused on evaluating the effect of quarry dust on the engineering properties of weak soil subgrade. This study investigated the use of quarry dust to improve subgrade properties for highway construction. Laterite soil used for highway construction is mainly weak due to its availability and tends to pose challenges in road performance, strength, and durability. The soil sample was collected from Iyekhei Quarter, Etsako West, Edo State, at a depth of about 2.5 m below the surface, in an undisturbed condition. Laboratory tests carried out for this research were Atterberg limits, Moisture content, Sieve analysis, and compaction. The tests were conducted to assess the performance of different blends of quarry dust (0%, 10%, 20%, 30%, 40%, and 50%) with local soil. For a soil-quarry dust proportion of 10%, 34.25% of the sample passed sieve No 200, for 20% mixture, 29.7%, for 30% mixture, 25.5%, for 40% mixture, 24.65%, for 50% mixture, 26.3% and for 100% mix with quarry dust, 3.8% passed through sieve No 200. According to Unified Soil Classification System, soil is described as coarse-grained if 50% or more of the soil particles is retained on the sieve No. 200. Therefore, the particle size analysis of natural soil is mainly silt and sand mixtures. The obtained results showed a plasticity index of 22.44%, liquid limit 43.87% and plastic limit of 21.43% and as such, it is not suitable for soil subgrade. The change in soil grade as a result of quarry dust addition, caused a significant reduction in clay content present to 30.65% for liquid limit, 19.17% for plastic limit and 11.48% for plasticity index respectively. During the compaction, the mixture of soil and 50% quarry dust result to the highest increase in the maximum dry unit weight with a value of 1.93 g/cm³ for BSH compaction and the optimum mix CBR value observed was 30% S-QD with a CBR value of 30.60% for soaked condition.

Keywords: Compaction; Sustainability; Highway Construction; Quarry Dust; Weak Soil Improvement.

INTRODUCTION

Highways in Nigeria are critical to the movement of goods and services, which significantly contribute to the country's economic activities. Highway Construction is an integral part of infrastructure development, essential to a nation's growth and development. The provision of adequate highway infrastructure can reduce poverty, increase employment opportunities, improve infrastructure, and close the socioeconomic disparity gap [1]. The

demand for new highway projects stems from population growth to facilitate the effective movement of people and goods from one location to another. The choice of Nigeria's federal highway is premised on its socioeconomic importance and its potential to stimulate economic growth across Nigeria and neighbouring West African countries, as the federal road network forms the skeletal framework for the entire nation [2]. Extensive infrastructure projects, such as highway construction, impact society, the environment, security,

the economy, politics, and safety [3]. Therefore, the construction of highway infrastructure is crucial, as pavement strength depends on the quality of its layers. The main objective of highway pavement sustainability is to adopt measures that lead to environmentally friendly, economically viable, and people-acceptable infrastructure, both now and in the future [4]. The subgrade must meet the required pavement construction standards; therefore, it is necessary to improve the subgrade layer with an environmentally friendly material.

Road networks in Nigeria face several challenges that accelerate their ageing, leading to the deterioration of these infrastructures. According to authors [5], road failure is a discontinuity in a road pavement that results in cracks, potholes, bulges, and depressions. Also, factors such as weather can affect the highway by percolating into the pavement subgrade if poorly constructed and maintained. Road failures are mainly due to poor subgrade material, which affects the structure underneath [6]. Results of road failures significantly affect road users because they can lead to loss of lives through accidents, damage vehicles, slow traffic flow, and encourage highway robbery.

The subgrade plays a critical role in distributing traffic loads to deeper soil layers; when its strength and stiffness are insufficient, distress such as rutting, potholes, cracking, and overall pavement deformation can develop [7]. The subgrade is considered the foundation of the pavement and receives all loads from pedestrians and vehicles. Most of these failures are the result of poor subgrade materials, poor design and specification, road usage, poor drainage, inadequate soil properties (e.g., low bearing capacity, high plasticity), and insufficient compaction during construction [8, 9]. These factors reduce the subgrade's load-bearing capacity, leading to pavement distress and premature failure of road structures. Regular geotechnical evaluation and proper soil stabilisation are key to improving subgrade performance and extending pavement life. The technique of soil improvement improves the properties of subgrade soil to meet engineering requirements.

Quarry dust is a by-product of crushing stones during quarrying activities. It is often used as a substitute for fine aggregate in various construction projects, especially in concrete production and highway construction [10]. Typically, quarry dust consists of fine particles with a particle size distribution similar to that of sand, but it may vary

depending on the type of rock being crushed. It is often composed of silica, alumina, and iron oxide, which are common in sandstones, granite, and other rocks. Quarry dust can be used as a stabilising agent in the construction of foundations and highways as it improves the engineering properties of soil, such as its shear strength, durability, compressibility, permeability and load-bearing capacity and also, quarry dust improves the compaction and physical properties of the soil by absorbing and chemical binding of moisture [11]. Soils with high plasticity can cause damage and cracks in roads, buildings, foundations, and other civil engineering infrastructure. Quarry dust in soil helps reduce soil plasticity, minimising its tendency to shrink or swell with changes in moisture content; this improves the soil's engineering properties, making it more suitable for construction applications [12]. Authors [13] investigated the stabilisation of expansive black cotton soil using a combination of bamboo charcoal, quarry dust, and lime. The results indicated significant improvements in the soil's plasticity index, swelling potential, and California Bearing Ratio (CBR), making it suitable for rural road subgrade applications. Authors [14] evaluated the use of quarry by-product fines in aggregate subgrade layers for pavement construction. The findings demonstrated that quarry by-products could be effectively used to improve the strength and stability of subgrade layers, offering a sustainable alternative to traditional materials. Authors [15] explored the stabilisation of subgrade soil using stone quarry dust. The study found that adding quarry dust improved soil compaction characteristics and CBR values, enhancing its suitability for pavement subgrade applications.

METHODOLOGY

Materials. The research team collected the soil sample from Iyekhei Quarter in Etsako West, Edo State (7.054192°N, 6.266791°E). They obtained the sample undisturbed from a depth of about 2.5 m, approximately 0.3 m below the surface. The team also collected the quarry dust sample from Zhongxin Mining Limited (Chinese Quarry) in Iyuku community, Uzairue clan, Etsako West Local Government Area, Edo State. This quarry dust is a by-product of crushing activities, such as blasting, milling, and screening of quarried rocks [16].

Experimental Details. The experimental design for this research involves preparing soil-quarry dust

mixtures in specified ratios and conducting tests to determine soil strength when mixed with quarry dust as a subgrade material. Laboratory testing is carried out according to ASTM standards for soil at different percentages. Thereafter, the quarry dust will be added in increments of 10%, 20%, 30%, 40%, and 50%, respectively, to improve the engineering properties of the soil subgrade. The American Society for Testing and Materials (ASTM), as shown in Table 1, will be adopted for this study.

Table 1 – Test and Codes (ASTM)

Test Name	Code Used
Atterberg limits	ASTM D4318
British Standard Heavy	ASTM D1557
Sieve Analysis	ASTM C136
California Bearing Ratio	ASTM D1883

RESULTS AND DISCUSSION

Atterberg Limits. The soil used in this study has a plasticity index of 22.44 %, a liquid limit of 43.87 %, and a plastic limit of 21.43 %, and, as such, it is not suitable for soil subgrade because $PI > LL - 30$ [17]. The change in soil grade was a result of quarry dust addition, which caused a significant reduction to 30.65 % for liquid limit, 19.17 % for plastic limit and 11.48 % for plasticity index, respectively, which is more than 30% reduction for each consistency limit taken as quarry dust content is introduced from 0 to 50%.

Table 2 – Atterberg's limit against quarry dust proportions

Quarry dust, %	Liquid Limit	Plastic Limit	Plastic Index
0	43.87	21.43	22.44
10	41.52	12.13	29.38
20	37.55	17.84	19.71
30	37.47	19.58	17.89
40	31.93	18.98	12.46
50	30.65	19.17	11.48
100	31.76	10.59	21.16

This shows a significant reduction in plasticity, indicating that the soil has transitioned from a highly plastic clay to a soil of moderate or low plasticity; this makes it more stable, less moisture-sensitive, and more suitable for subgrade use. The reduction in PI from 22.44% to 11.48% implies lower shrink-swell potential, better compaction behaviour, improved load-bearing capacity, and

enhanced durability under varying moisture conditions.

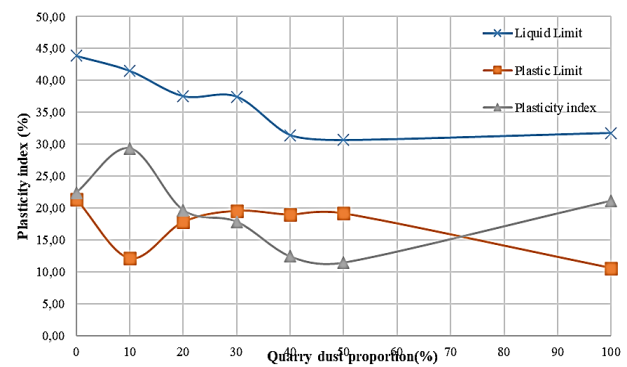


Figure 1 – Variation of Plasticity index of soil and quarry dust content

From Figure 1, at 50 % quarry dust content, the soil's plasticity index decreased from 22.48% to 11.48%, satisfying the AASHTO and FMHW specifications for a highway subgrade layer. The results show that stabilisation with quarry dust increases the consistency limit of laterite, as defined by the American Association of State Highway and Transportation Officials (AASHTO) and the Federal Ministry of Works and Housing (FMWH) [18].

Compaction. The unstabilised soil has a maximum dry unit weight of 1.79 g/cm³ in the British Standard Heavy compaction method. The soil maximum dry unit weight increased with the addition of quarry dust content, as shown in Figure 2. The mixture of soil and 50 % quarry dust results in the highest increase in the maximum dry unit weight, with a value of 1.93 g/cm³ representing a 7.8 % increase from the maximum dry unit weight of the unstabilised soil.

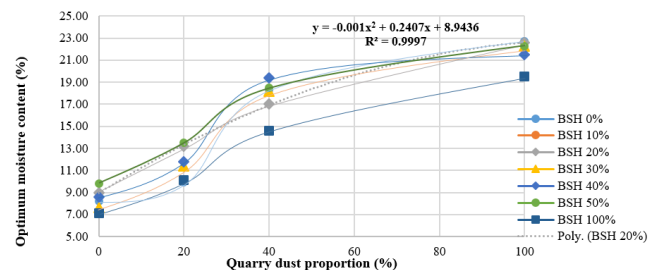


Figure 2 – Variation of MDUW with QD proportions

Figure 3 shows the variation of OMC with QD proportions. Quarry dust consists of very fine particles, often finer than those in natural soil, which tend to increase the moisture content of the mixture; this is reflected in the highest OMC increase observed at 100% QD.

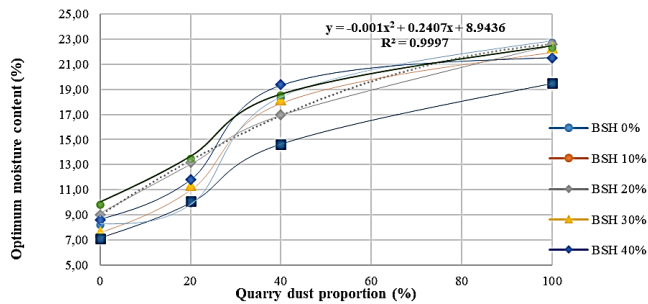


Figure 3 – Variation of OMC with QD proportions

CBR for BSH Compaction Energy. The soaked CBR for natural soil was 7.8%, and with a 10% S-QD mixture, the CBR increased to 14.04%. The CBR value at 20 % decreases to 12.6 %, and at 30 % quarry dust, it increases by 30.5 % before continuing to decline.

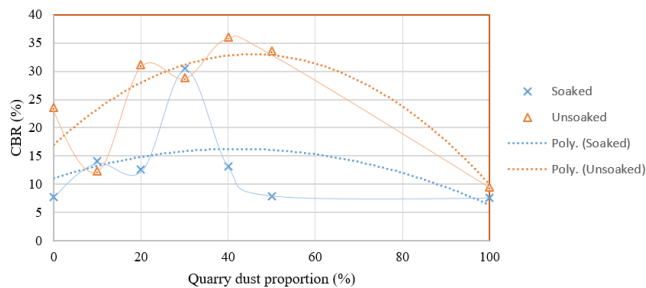


Figure 4 – Regression analysis of CBR and QD for soaked and unsoaked (BSH)

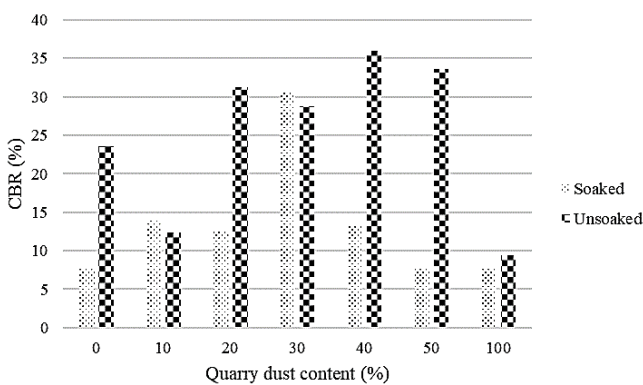


Figure 5 – Variation of CBR of soil and soil mixture with quarry dust (BSH)

CBR Soaked improves with QD addition up to 30 %, then drops sharply, suggesting that 30 % is optimum for soaked strength. The highest CBR unsoaked (36 %) occurs at 40 % quarry dust. Suggests peak performance under unsoaked conditions around 40 to 50 % dust. The BSH compaction effort CBR value for the soaked condition with 30 % quarry dust added was 30.6 %, indicating that subgrade quality can be improved when BSH compaction effort is used with 30 % quarry dust added.

CONCLUSIONS

The study aimed to improve the geotechnical properties of natural soil used as a pavement subgrade, with emphasis on sustainable highway construction. The target was to find a more creative way to utilise quarry dust, a waste product of stone crushing, for soil stabilisation, thereby reducing or eliminating its negative environmental impact during disposal. The research team conducted laboratory analyses of the natural soil and soil–quarry dust mixtures. They performed Atterberg limits, the Compaction test (BSH), and the California Bearing Ratio test. They used these analyses to compare the performance of the stabilised soil with that of the natural soil.

The geotechnical properties of the natural soil indicated that it was not suitable for use as subgrade material; this is because, first, both the plasticity index and liquid limit exceed the recommended limits of 12 % and 35 %, respectively, as set by FMWH (1997) for pavement subgrade. Secondly, the CBR values obtained at the three compaction energies used were all less than 10 %. FMWH (1997) states that a CBR below 10% falls below the minimum acceptable specification for subgrade, making the soil unsuitable for direct use in road foundations without improvement [19]. The addition of quarry dust improved the measured geotechnical properties of the natural soil. The researchers recorded a significant improvement in the CBR value to 30.06% when they stabilised the soil with 30% QD and compacted it at BSH compaction energy.

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