

# Goldmine Tailings Stabilization using Quarry Dust and Coal Ash for Pavement Applications - A Review

Jacob Olumuyiwa Ikotun<sup>1</sup>, Gbenga Emmanuel Aderinto<sup>1</sup>, Valentine Yato Katte<sup>2</sup>, Adewumi John Babafemi<sup>3</sup>

<sup>1</sup>*Department of Civil Engineering, Durban University of Technology, Pietermaritzburg, South Africa.*

<sup>2</sup>*Department of Civil and Mining Engineering, University of Namibia, Namibia.*

<sup>3</sup>*Department of Civil Engineering, Stellenbosch University, Stellenbosch, South Africa.*

---

## Abstract

The quest to improve the properties of soil and other construction materials by incorporating industrial and agricultural wastes is a growing concern for the construction industry. Many researchers have recently focused on employing waste materials as stabilizers due to their good pozzolanic interactions with soil particles. Its significance in civil engineering projects such as foundations in buildings and pavement construction cannot be overemphasized. The construction of pavements usually involves using large quantities of natural earth/aggregate materials, often mixed with conventional stabilizers (cement, lime, and bitumen). There is already a shortage of natural aggregate materials in many developing nations. However, a significant quantity of waste, such as mining tailings, is generated by mining industries yearly. In contrast, the disposal of these wastes is not only expensive but has also resulted in various ecological and environmental problems. The literature has already explored methods of stabilization and solidification of mining tailings employing conventional agents. However, the use of traditional stabilizers indicates an important source of contamination for the environment. Therefore, alternative stabilizing materials are needed. The approach to this literature review included a systematic procedure for locating, choosing, and evaluating sources. The logic for the sources' selection prioritized contemporary, peer-reviewed studies that particularly address the geotechnical properties of industrial waste products in road construction. This study reviews the geotechnical properties of industrial waste products, such as goldmine tailings, quarry dust, and coal ash and the technical benefits of using them for pavement construction.

**Keywords:** *stabilization, pavement, goldmine tailings, quarry dust, coal ash, geotechnical properties.*

---

## 1. Introduction

Mine waste constitutes a menace to the ecosystem and environment [1], [2], with an estimated production of about  $350 \times 10^9$  tonnes per year [3]. The mining of minerals such as copper, coal, platinum, and gold, amongst others, has been the backbone of the South African economy. Goldmine tailings are among the most common waste products of these mining operations. They comprise stone chips and dust, which are the by-products of the parent rock from which the ore is extracted. Tailings

can be sandy or gravel-like or fine silt or clay, containing minerals like quartz, feldspar, mica, and silicates [4]. Other products of mineral extraction include quarry dust, which is a by-product of the extraction and processing of aggregates from rocks. Among other industrial wastes available are pulverized fuel ash, often known as fly ash or PFA, which is the most prevalent waste produced when coal is burned to generate electricity very prevalent in South Africa. Additionally, goldmine tailings and processing wastes contain high concentrations of sulfide

---

Corresponding author: *Gbenga Emmanuel ADERINTO (22176502@dut4life.ac.za)*

Received: 9 October 2024; Revised: 18 August 2025; Accepted: 26 August 2025; Published: 7 October 2025

© 2025 The Author(s). This work is licensed under a Creative Commons Attribution 4.0 International License

---

minerals, including pyrite and heavy metals, which results in acid mine drainage (AMD) [5].

Significant strides have been made in the utilization of various techniques and methods in recycling mining waste [6]. These recycled mining wastes have been incorporated particularly in the construction industry, including cement paste backfill [7], paint production [8], and concrete production [8]. The use of tailings has also been reported as a component in road pavement materials [9]. For example, tungsten mine waste has been used as a filler in hot-mixed asphalts [10]. Similarly, magnetite has been utilized as filler in various mastic mixtures with the aim of microwave healing for asphalt pavements [11]. Within South Africa, there is no reported or may be minimal use of mine residues in pavement construction. Therefore, this study intends to investigate the use of gold mine tailings as a pavement material. This falls within the broad sphere of soil improvement techniques, incorporating waste materials. Soil stabilization techniques are one of the methods of soil improvement and have traditionally been used in enhancing the engineering properties of soils. Following the traditional soil stabilization route will involve using stabilizers such as cement, lime, and bitumen, which have a high carbon footprint. For example, cement and lime, which are the most common stabilizers, produce about 0.82–0.948 CO<sub>2</sub> eq/kg and 0.416 kg CO<sub>2</sub> eq/kg of greenhouse gases, respectively [12]. Therefore, an alternative approach must be sought that is environmentally friendly, while also meeting the appropriate engineering characteristics of strength, durability, and cost-effectiveness. This study, therefore, explores the prospects of applying quarry dust and coal ash as stabilizing agents to improve the properties of goldmine tailings, which can be harnessed for pavement construction. Using goldmine tailings as pavement material could meet the growing need or construction materials in infrastructure development while lowering dependence on traditional aggregates and binders.

So far, the utilization of goldmine tailings in the construction industry has not been given the required attention as shown in geotechnical literature. In most cases, studies are restricted to the mechanical properties of concrete with goldmine tailings incorporation. Furthermore, this study consolidates and analyses quarry dust and coal ash research on goldmine tailings stabilization, thus making a significant contribution to the

existing body of knowledge. It presents a detailed assessment of the current state of knowledge in this specific domain and provides useful insights into the possible benefits, potential problems, and engineering considerations of employing stabilized goldmine tailings as pavement construction material.

## 2. Methodology

This systematic literature review aimed to evaluate the geotechnical properties of industrial waste products, such as goldmine tailings, quarry dust, and coal ash, and the technical benefits of using them for pavement construction. A structured and rigorous methodology was adopted to ensure relevance, transparency, and reproducibility. The scope included studies published between 2000 and 2024, emphasizing peer-reviewed journal articles, conference proceedings, book of abstracts, and credible industry reports that examined the utilization of industrial and agricultural waste products in civil engineering constructions, majorly pavement/ road construction. A comprehensive search was conducted using databases such as Scopus, Web of Science, ScienceDirect, SpringerLink, and Google Scholar. Search terms included “Stabilization AND Solidification,” “conventional stabilizers,” “physical, chemical, mechanical (strength), and durability properties of conventional stabilizers,” and “natural construction materials” “goldmine tailings” “quarry dust” and “Pavement” OR “Road”. A keyword in combination with the Boolean operators “OR” and “AND” was used to retrieve all relevant information. Filters were applied to limit results to English-language publications. Studies were selected based on specific inclusion criteria, such as focusing on MT, FA, and QD in pavement applications, providing quantitative data on geotechnical properties, and employing experimental or analytical methods. Data were extracted systematically, capturing details such as physiochemical properties, mix proportions, stabilizer replacement levels, measured mechanical properties, and experimental conditions. Findings were categorized into thematic groups to identify trends, patterns, and inconsistencies. A critical quality assessment of each study ensured that only methodologically sound research with complete and reliable data was included in the synthesis. Despite some variability in reported results, the review highlights the potential of goldmine tailing

stabilization with quarry dust and coal ash at optimized replacement levels as a potential pavement construction material.

### 3. Goldmine Tailings: Composition, Sources, and Availability

Goldmine tailings are the materials left over after extracting gold from the ore. These materials are often kept in tailings storage facilities (TSFs), also referred to as tailings ponds, massive piles, or containment systems. The composition of goldmine tailings varies depending on factors such as the type of mining operation, the characteristics of the ore, and the processing techniques employed [4], [13]. According to 419 mine tailing samples tested at four different mine sites in South Africa, the attributes of tailing depend on the mineral type because different minerals co-exist with other compounds like iron and silicon, minerals like quartz and pyrite, and heavy metals like uranium, arsenic, and lead [14], [15], [16]. Tailings applications are rendered impracticable in construction plants due to the heavy metals present in them.

#### 3.1. Physical properties of goldmine tailing

The physical properties of tailing influence its engineering properties, like compressive strength, durability, density, acid resistance, water absorption, and abrasion of tailing during geopolymerization. Different studies present various physical properties of the goldmine tailings, depending on the location of the mining site and other factors. Table 1 shows some physical properties of goldmine tailings that were reported by Ikotun et al., [16]. It can be observed from the table that the properties considered are like the normal sand utilized in engineering and construction works [16], [17]. The properties shown in the table present goldmine tailings as a potential alternative to aggregate in the production of concrete [18].

In another study, it was reported that the relative density of the goldmine tailings was  $2.8064 \text{ g/cm}^3$  [19], which is within the range of the result presented in Table 1. A pH value of 8.94 was reported for the material, which makes it a non-acidic but moderately alkaline material [19]. Several reports show that goldmine tailings have a

high relative density compared to clays, silica beach sand, and red/brown sand with 2.5, 2.65, and 2.65, respectively. Goldmine tailings can develop dry densities of up to  $1600 \text{ kg/m}^3$  when compacted, and these densities can mobilize unconfined compressive strength higher than 6 MPa in several cases with fly ash and lime [20].

**Table 1.** Physical properties of a typical goldmine tailing [16].

Properties	Value
Fineness modulus	0.28 – 2.84
Specific gravity	2.6 – 3.46
Density ( $\text{g/cm}^3$ )	1.40 – 6.7
Water absorption range (%)	7.15
Specific surface area range ( $\text{m}^2/\text{g}$ )	0.036 – 7.2
Shape	Angular

#### 3.2. Chemical properties of goldmine tailings

The chemical properties of goldmine tailings are the chemical components of the mine and can be classified as major compounds and trace elements [13]. A typical example of the chemical properties of goldmine is presented in Table 2. It was noticed that goldmine contains high levels of  $\text{SiO}_2$  and a significant percentage of  $\text{Al}_2\text{O}_3$ . This shows the availability of aluminosilicate minerals in the tailings, which is vital for the geopolymerization [21]. Also noticed is the presence of high concentrations of  $\text{MgO}$ ,  $\text{CaO}$ ,  $\text{Na}_2\text{O}$ , and  $\text{K}_2\text{O}$ , which implies the availability of soluble basic components. The soluble basic oxides available in the tailing could neutralize the acid potential of the tailing's dumps [21].

Another study observed that apart from Hg, other heavy metals are present in the goldmine tailings [22]. This includes Cd, As, Pb, and Ni, but their observed result was still lower than the recommended environmental quantities and can therefore be ignored [23], [24]. The work of Mapinduzi et al., [25], reported the tailing to be alkaline-silty materials with low plasticity and organic contents of 1.99–2.45% and 0.9–1.0 mg/kg nitrogen contents. The pH value typically ranges from 7.2 to 7.5 for a soil with a higher percentage of magnesium and calcium. The range of the cation exchange capacity is dependent on the amount of clay present and ranges from 6.0 to 7.5 meq/100 g. Alumina ( $\text{Al}_2\text{O}_3$ ) with 9.6–14.6 w/w, silica ( $\text{SiO}_2$ ) above 50% w/w, sulphur ( $\text{SO}_3$ ) with 11.4–12.1% w/w, and iron ( $\text{Fe}_2\text{O}_3$ ) with 10.4–17.5% w/w are the principal oxides present in the sample [26].

**Table 2.** Chemical composition of a typical goldmine tailing [21].

Major Elements	Weight (%)	Trace Elements	Contents (ppm)	Trace Elements	Contents (ppm)
Fe <sub>2</sub> O <sub>3</sub>	16.30	Pb	15.0	Cl	7.6
SiO <sub>2</sub>	63.80	Mo	1.0	F	100.0
Al <sub>2</sub> O <sub>3</sub>	5.50	As	33.9	Zn	54.4
TiO <sub>2</sub>	0.30	Ga	8.5	Cr	533.3
MnO	0.1	Cu	49.9	S	11526.5
Na <sub>2</sub> O	1.1	Ni	144.0	Co	46.1
MgO	4.30	Nb	2.2	Zr	38.8
CaO	3.10	Rb	23.8	Sc	12.1
K <sub>2</sub> O	0.6	Sr	79.1	Cs	26.4
NiO	0.01	U	3.0	La	8.9
P <sub>2</sub> O <sub>5</sub>	0.1	Y	3.9	V	80.7
Cr <sub>2</sub> O <sub>3</sub>	0.1	Th	3.0	Ce	8.5
V <sub>2</sub> O <sub>5</sub>	0.01	W	237.1	Ba	174.9
CuO	<0.01				
ZrO <sub>2</sub>	<0.01				
Total	99.90				

Alumina and silica are crucial ingredients in the production of construction materials, and they can change into an amorphous state with only a small amount of thermal processing. This substance may have pozzolanic reactivity, which might promote the production of various building materials that could replace the traditional binder, such as cement. It was noticed that the chemical properties of goldmine tailings are not universal, and they vary with location and extraction methods.

### 3.3. Mineralogical composition of goldmine tailing

The mineral phases in the goldmine tailings can be studied with X-ray diffraction (XRD) when the sample is subjected to the X-ray diffractometer machine. Pyrophyllite, Jarosite ( $KFe^{3+}_3(OH)_6(SO_4)_2$ ), albite, hornblende, sepiolite ( $Mg_4Si_6O_{15}(OH)_2 \cdot 6(H_2O)$ ), anthophyllite ( $Mg_3Si_4O_{10}(OH)_2$ ), clinocllore ( $(Mg, Fe^{2+})_5Al_2Si_3O_{10}(OH)_8$ ), chlorite, quartz, and magnetite ( $Fe_3O_4$ ) are some of the major minerals in goldmine tailing [21]. It was noticed that quartz has the highest concentration of around 42.98 %; next to that is hornblende, with about 14.10 %. Jarosite, the iron-sulfate mineral available in goldmine tailings, shows acidic or sulphate-rich conditions [27]. Minerals of aluminosilicate, like chlorite, plagioclase, and muscovite, can neutralize acid at a lower rate and reaction than carbonate minerals like calcite [28].

Because of its physical characteristics (hardness), quartz has no potential for acid neutralization [27]. The availability of Al, Ca, Mg, Fe, and K-containing minerals like bornite, chalcopyrite, biotite, silicate gangue minerals, and quartz was discovered under optical microscopy analysis in a study [21]. The XRD and optical microscopy results indicate that goldmine tailing has significant Al-Si-bearing mineral phases and can be used as materials for geopolymerization.

### 4. Uses of Goldmine Tailings

Goldmine tailings' prospective uses and advantages have gained increasing attention in recent years. Indigenous methods have been developed to take advantage of their economic and environmental potential rather than abandoning them as mere by-products of the mining process. Goldmine tailings are used in land reclamation [19], [28], [29], [30], [31], [32], [33], suggesting leveling the tailings, establishing natural slopes and contours to restore the land's aesthetics and functionality; building construction [34],[35], [36], [37], [38], [39], [40], in a variety of construction applications, tailings, after undergoing the appropriate processing and treatment, can function as viable alternatives to more conventional raw materials; and residual gold extraction [41], [42], amongst others.

## 5. Stabilization Techniques for Goldmine Tailing

Stabilization is the process of modifying the properties of soil and hazardous wastes, such as goldmine tailings, to enhance their engineering performance. Stabilization can either be mechanical, chemical, or a combination of both, whereby its techniques in civil engineering projects, such as foundation bases of buildings and pavement construction, have been intensively used for the improvement of engineering properties of foundation soil. This expected improvement from this process includes improving the weight-bearing abilities, tensile strength, and general performance of in-situ subsoil, sand, and waste materials, and consequently, strengthening road surfaces [43].

The most popular stabilization techniques include adding binders like cement, fly ash, and lime to the aggregate [44]. One of the first studies that addressed this might be the one by Sultan [45], who investigated copper MT stabilized with ordinary Portland cement (OPC) as an alternative road construction material. The highest unconfined compressive strength (UCS) of 3.45 MPa was found at 8 % of OPC by the MT solid weight. The results showed that the OPC stabilized MT has acceptable engineering properties and can be adapted to road construction. Swami et al. [46] stabilized kimberlite tailings with 5 % OPC for their use in base and subbase layers. The specimens were compacted with modified Proctor energy and obtained optimum moisture content and maximum dry unit weight, which met the strength requirements of the Indian Roads Congress Specifications. They concluded that the kimberlite tailings are suitable to be used for base and subbase course layers in road construction. Qian et al. [47] studied granite MT stabilized with 5 % cement for their use in road sub-base layer. The stabilized specimens reached a UCS of 4.37 and 7.17 MPa after 7 and 29 days of wet curing, respectively, which satisfied the strength requirement of stabilized road material specification.

## 6. Common Stabilization Materials for Goldmine Tailings

The use of stabilization materials in goldmine tailings is crucial for mitigating environmental impacts. The generation of acid mine drainage (AMD) from mine

tailings depends on their mineral composition [48]. Stabilization typically involves using alkaline binding agents like cement and lime in reactive tailings to prevent AMD. However, the choice of stabilizing materials should consider factors such as tailings composition, moisture content, and pollutants present in the tailings. Characterization and laboratory testing are essential to identify the most suitable materials and optimize their use. Additionally, project-specific factors like soil conditions, engineering requirements, and environmental impact must be considered when selecting and deploying these materials. Understanding the effectiveness, limitations, and long-term impacts of stabilizing materials is vital for maximizing their benefits and minimizing risks. This study highlights the significance of stabilizing materials in addressing the environmental impacts of goldmine tailings.

### 6.1. Cement

Cement, specifically Portland Limestone Cement, is a commonly used stabilization material for goldmine tailings [49], [50], [51], [52]. It strengthens tailings by hardening and stabilizing them. Hydration occurs when water and calcium silicates in Portland cement mix, while the cementitious paste binds tailings particles after this reaction [50]. The paste bonds the tailings by filling the voids between particles. The cement matrix solidifies the tailings, strengthening the composite and enhancing its load-bearing capacity. In addition, cement stabilization reduces the permeability of goldmine tailings as the cementitious paste fills tailings pores, blocking water and pollutants [51]. Reduced permeability protects water quality and prevents contaminant spread by reducing leaching. Further to this, cement stabilization prevents gold mine tailings erosion while it increases tailings cohesiveness and stability by binding particles [52].

### 6.2. Fly ash

Fly ash is a byproduct of coal combustion in power plants [53]. It is powdery and contains silica oxide, which reacts with calcium hydroxide from cement hydration to form a binding agent [54]. It can react with goldmine tailings and water to generate binding chemicals in a pozzolanic process [55]. Furthermore, fly ash in goldmine tailings stabilization increases mechanical strength while

hydration and binding properties of tailings increase due to fly ash and calcium hydroxide's pozzolanic reaction, which forms cementitious compounds [56]. Fly ash can improve the stability of goldmine tailings by reducing their permeability. The tiny particles and pozzolanic reaction products present in fly ash can block water, pollutants, and leachates from penetrating the tailings, thus making them more stable [57].

### 6.3. Lime

Lime-based stabilizers, including quicklime (calcium oxide) and hydrated lime (calcium hydroxide), are prominently used in the stabilization of goldmine tailings [58], [59]. Their application neutralizes acidity, minimizes acid mine drainage, and improves tailings' geotechnical qualities. Sulfide minerals in goldmine tailings can oxidize, creating acidic conditions. Acid mine drainage can leak heavy metals and other toxins into waterways in this acidic environment. Lime-based stabilizers decrease tailings acidity by reacting with acidic components, minimizing acid mine drainage and environmental consequences [60].

While lime-based stabilizers reduce goldmine tailings' metal ion mobility and leaching, they can precipitate and immobilize metal ions, inhibiting their movement into the soil and water [61]. In addition, Lime stabilization enhances the geotechnical properties of goldmine tailings by improving their cohesion, plasticity, and compaction. These enhancements lead to increased stability, shear strength, and load-bearing capacity [62]. The effectiveness of lime-based stabilizers in goldmine tailings depends on the composition of the tailings, acidity levels, and lime dosage. [59].

### 6.4. Bentonite clay

Bentonite clay is an absorbent aluminium phyllosilicate clay with a fine, soft texture. Its high-water absorption and flexibility help to reduce water content, improve structural integrity, and reduce erosion concerns [63]. Due to its expansiveness, bentonite clay absorbs water thoroughly-and swells within the goldmine tailings, generating a gel. Bentonite reduces the water content of the tailings, enhancing stability and minimizing liquefaction risk [63], [64]. The tailings particles become more compact as the clay absorbs water and expands. This

increased cohesiveness makes the tailings stronger and more resistant to deformation and failure [65]. Bentonite stabilization reduces goldmine tailings erosion, while its swelling and cohesive qualities are used to protect tailings from wind and water erosion [65], [66]. Moreover, the plasticity makes bentonite clay easy to mix and spread in tailings. This enhances its application and assures clay distribution throughout the tailings. Its workability helps it integrate with tailings, enhancing stabilized material homogeneity and uniformity [64]. Tailings characteristics, water content, and stability goals determine bentonite grade and dosage [64].

### 6.5. Polymer

Polymers are chemical compounds or mixtures of compounds that are formed by the combination of monomers linked together by ionic or covalent bonds [67]. Goldmine tailings are stabilized with polymers, including emulsions and foams. These polymer-based compounds prevent tailings particles from dispersing and increase their cohesiveness and durability [68]. Polymer additives safeguard goldmine tailings particles by encapsulating them, thus preventing particles from splitting and spreading, reducing erosion and contamination hazards [69]. Furthermore, polymers reduce deformation and settling in goldmine tailings. The tailings matrix resists compression and shear pressures because of its polymer network [70]. Polymer-based additives can optimize stability with cement or lime while improving the binding and cohesiveness of classical stabilizers, increasing stabilized tailings performance synergistically [69].

### 6.6. Geosynthetics

Geotextiles are synthetic fiber fabrics that are porous and are typically used to strengthen tailings material [71]. Geotextiles and geomembranes are geosynthetic materials used to stabilize and confine goldmine tailings [71], [72], [73]. They avoid excessive settlement and deformation by strengthening and stabilizing tailings. Further to this, geosynthetics reinforce weak regions and distribute loads to strengthen the tailings' structure. Geotextiles protect against wind and water erosion when placed on or in tailings material. They reduce the velocity of surface runoff, promote filtration, and facilitate water drainage

[74]. This prevents surface erosion, preserves tailings containment, and reduces sediment and pollutant transfer. To limit pollutant migration, goldmine tailings management uses geomembranes, which is an impermeable synthetic liner that prevents dangerous compounds from seeping into the environment by separating tailings from soil or water [75]. Geomembranes preserve water supplies and reduce tailings management's ecological impact. Goldmine tailings stabilization systems are personalized and optimized due to design flexibility.

## 7. Alternative Stabilization Materials

### 7.1. Quarry dust as a stabilizing agent

Quarry dust is a concentrated by-product of the crushing of rocks used as fine aggregates in concrete production [76]. The quarry dust serves as a high-shear-strength additive, playing a pivotal role in soil stabilization [77]. Its fine particles, akin to cosmic dust in the atmosphere, fill voids and interact with nearby aggregates, enhancing the structural stability [78] of pavement materials. Research in the field of pavement construction extensively explores the advantages of using quarry dust as a stabilizing agent.

#### 7.1.1. Properties of quarry dust

Quarry dust's exceptional performance in pavement construction is attributed to its physical properties, with particle size enhancing compaction and stability [79], [80]. The angular shape of its particles promotes interlocking and cohesiveness, enhancing load transfer capacity and resistance to displacement [81]. Quarry dust has a higher specific gravity compared to natural soils or aggregates, making it stable and resistant to settlement or deformation under pressure [82]. Additionally, its chemical composition, including silica, feldspar, calcite, and clay, triggers chemical reactions with lime or cement, strengthening pavement materials.

Beyond quarry dust mechanical strength, its porosity and void ratio reduce water accumulation and pavement deterioration [81]. It is neutral to slight alkalinity fosters a stable and durable environment, ensuring long-lasting pavement construction [82]. However, the attributes of quarry dust depend on the geological source of the quarry,

extraction methods, and processing procedures. Therefore, it is essential to conduct laboratory examinations of quarry dust samples to determine their suitability for specific applications in construction. A summary of the physical and chemical properties of quarry dust is shown in Tables 3 and 4.

**Table 3.** Physical properties of Quarry dust [80], [81], [82], [83].

Properties	Values
Specific gravity	2.54 – 2.60
Absorption (%)	1.20 – 1.50
Bulk relative density ( $kg/m^3$ )	1720 – 1810
Fine particles less than 0.075mm (%)	12 – 15
Fineness modulus	3.315
Natural water content (%)	6.59

**Table 4.** Chemical properties of Quarry dust [82].

Properties	Values (%)
SiO <sub>2</sub>	62.48
Al <sub>2</sub> O <sub>3</sub>	18.72
Fe <sub>2</sub> O <sub>3</sub>	6.54
CaO	4.83
MgO	2.56
K <sub>2</sub> O	3.18
TiO <sub>2</sub>	1.21

#### 7.1.2. Performance in pavement construction

Quarry dust possesses remarkable potential in construction, particularly for innovative applications in pavement materials. It has been extensively studied and used in pavement construction. [84], [85], [86], [87], [88]. Its angular particles interlock with adjoining aggregates, enhancing load transfer and lowering traffic load displacement [89]. This interlocking mechanism strengthens the pavement structure by resisting deformation, rutting, and cracking. In addition, quarry dust stabilizes subgrades, while it increases subgrade load-bearing capacity and minimizes differential settling. This stabilization increases pavement performance and lifespan, especially in weak subgrade circumstances [90]. Furthermore, quarry dust is moisture-controlling, while its porosity and void ratio provide efficient drainage, eliminating water collection and pavement degradation from moisture [91].

Moreover, quarry dust may reduce pavement construction costs. Compared to traditional aggregates, quarrying by-products are cheaper. Its use as a stabilizing agent minimizes materials and optimizes pavement design, resulting in cost-effective solutions [92]. Numerous field applications and case studies have demonstrated the successful performance of quarry dust in pavement construction [93]. These real-world examples demonstrate its efficacy and reliability at different temperatures, traffic circumstances, and places.

### *7.1.3. Limitations and considerations in quarry dust applications*

Quarry dust has gained attention in the construction industry as a cost-effective stabilizing agent for innovative pavement solutions. However, its practical application presents challenges that must be carefully evaluated. Factors like particle size distribution, source heterogeneity, and compatibility with other construction materials can impact pavement stability, drainage, and load-bearing capability. To harness the potential of quarry dust, a thorough examination of these limitations is essential [94]. Quarry dust's chemical reactions with binders like lime or cement can affect the pavement's strength, resilience, and longevity. To avoid compatibility issues, ensure compatibility and conduct thorough laboratory testing. Additionally, environmental factors such as temperature and moisture fluctuations directly impact pavement durability and performance. While extreme temperatures can lead to rutting, cracking, and material aging, moisture causes stripping, pumping, and weakening of the subgrade. Applying proper design, material selection, and drainage solutions can improve pavement lifespan and lower maintenance costs. Health considerations also demand attention when working with quarry dust. Quarry dust handling, transportation, and placement can pollute the air and cause respiratory problems [94]. However, to ensure safety and regulatory compliance, quarry dust should be tested for asbestos and heavy metals. Another issue is durability and performance.

In short-term experiments, quarry dust performed well, but its long-term performance and resistance to weathering, aging, and mineral leaching need further examination. Predicting quarry dust's long-term stability and durability requires understanding its behavior over

time and in diverse environments. Overcoming these limitations of quarry dust requires quality control. Controlling moisture content, particle size distribution, and material quality to ensure consistency and reliability. Optimizing performance and minimizing restrictions requires tailoring mix design and construction to site conditions.

## **7.2. Coal as a stabilizing agent**

Coal ash, a byproduct of power plant coal combustion, is usually non-spherical and ranges from 0.5 to 100  $\mu\text{m}$  [95]. Its particles are primarily silicon dioxide ( $\text{SiO}_2$ ), aluminum oxide ( $\text{Al}_2\text{O}_3$ ), and iron oxide ( $\text{Fe}_2\text{O}_3$ ) [96]. Coal ash has shown promising potential as a stabilizing agent in pavement construction, offering opportunities for improved strength, durability, and environmental stewardship [97]. As the demand for sustainable and eco-friendly construction practices continues to rise, the utilization of coal ash presents a compelling solution. Coal ash, which encompasses both fly ash and bottom ash, possesses distinct engineering properties that contribute to its effectiveness as a stabilizing agent [97].

Fly ash consists of fine particles carried away by flue gases in the process of coal combustion. Its abundance and various advantages make it valuable when utilized appropriately. Bottom ash, on the other hand, comprises the larger, coarser particles that settle at the bottom of the combustion chamber. Each type of coal ash, fly, bottom, or ponded ash has its specific engineering qualities. The type of coal ash used as a stabilizing agent varies on project needs, availability, and performance goals. Engineers and researchers can use each type of coal ash in pavement building and other engineering projects by studying their qualities [98]. Fly ash particles are finer than cement particles and spherical, making them pozzolanic and consequently improving the engineering properties of pavement due to their pozzolanic capabilities [99].

Fly ash has been widely examined as a stabilizing agent in pavement construction and shown to improve strength, durability, and stability. The pozzolanic reaction with fly ash strengthens unstable materials while its silica and alumina content react with lime to form calcium silicate hydrates (CSH), which bind and strengthen its

stabilizing material, thereby improving pavement performance and lifetime.

Furthermore, fly ash reduces fine-grained soil plasticity and swelling [99]. It affects the plasticity index and swelling potential in expansive soils. This adjustment makes stabilized materials less susceptible to moisture-induced volume fluctuations, reducing soil swelling-related pavement distress [100]. In addition, fly ash stabilizes materials and increases load-bearing capability [100]. Cementitious chemicals and particle bonding promote stiffness and deformation resistance. Stabilization helps the pavement endure high traffic and prevents structural problems. Also, fly ash reduces stabilized material permeability. The stabilized matrix compacts and interconnects to reduce water flow across pavement layers. Reduction in permeability protects the pavement from water penetration and moisture-related deterioration such as frost heave and base erosion [99]. Pavement durability increases with fly ash stabilization. Fly ash protects stable materials from chemical, sulphate, and alkali-silica reactions.

### **7.3. Benefits of stabilization with quarry dust and coal ash**

Sustainable built environment for the future focuses on technological innovation, environmental conservation, and development. Therefore, the utilization of mining wastes/industrial wastes as raw materials for construction purposes has been reported as a sustainable and environmentally benign alternative [101].

Quarry dust is the residue from the mineral aggregate released in crushing mills. Generally, quarry dust is a small sand-sized particle utilized as construction aggregate. It has some merits compared to river sand, including good cementitious material strength support, lower cement consumption, good workability, and being environmentally friendly [102]. Quarry dust can be used to improve the durability of pavement from subgrade soil and eliminate potholes in highways during soil

stabilization, also enhances fatigue resistance by improving gradation, interlock, and stiffness, but excessive use can cause brittleness. [43]. The major demerit is the reduction of soil plasticity, but it reduces the cost of construction [43]. There has been an increasing interest in replacing sand with quarry dust in recent times. Considering the social perspective, it could be important to use low-cost quarry dust to reduce the cost of construction.

Fly ash is the waste generated from coal-based energy generation (coal combustion). The application of fly ash in construction has gained more attention recently because of its availability as a means of waste management and ground improvement [103], [104], [105]. The type of coal determines the quality of fly ash and the percentage of pozzolans that can enhance chemical reactions, which may improve soil strength for geotechnical applications. Studies on the influence of fly ash replacement for cement in recycled aggregate concrete showed a minor reduction and partial lesser yield strength but improved flowability, enhanced chloride resistance, and lesser plastic viscosity, making them a sustainable material for engineering applications [106]. Fly ash improves long-term durability and reduces cracking, but excessive fines can reduce flexibility and delay strength gain [103]. It has been observed that the application of fly ash as a construction material can heavily minimize environmental, social, and economic impacts [107]. Its usage has the potential to reduce the consumption of conventional calcium-based materials such as cement for soil stabilization [103]. Using quarry dust and fly ash to produce construction and building materials provides a solution to using available resources to solve environmental issues, build low-cost housing from wastes, and the supplementary as construction aggregate materials [106]. Table 5 below shows the influence of the particle size of goldmine tailings, quarry dust, and coal ash on the mechanical and durability properties of stabilized samples.

**Table 5.** Summary of the Influence of particle size distribution of GT, QD, and CA on the mechanical properties of the stabilized aggregate [43], [52], [102], [103], [106], [107].

Material	Particle size Distribution	Strength Contribution	Compaction	Durability	Binder Interaction
GT	Mostly fine (silt & clay)	Low (requires stabilization)	Poor (high water retention)	Poor (erosion-prone)	Needs additional stabilizers
QD	Well-graded (coarse to fine)	High (improves friction & interlock)	High (dense packing)	High (resists wear & erosion)	Enhances cement/lime reactions
CA	Ultra-fine (pozzolanic)	Medium (long-term strength gain)	Poor (difficult to compact alone)	High (low permeability)	Acts as a pozzolanic binder

## 8. Geotechnical Solution to Environmental Challenges in Mining Industries

In searching for a viable way to utilize goldmine tailings, some researchers [4], [50], [108], [109] have investigated the potential uses of these waste materials for different construction purposes. Most goldmine tailings require stabilization before they can be used for any application due to their chemical and geotechnical properties. Environmental sustainability is a critical factor in modern construction practices, driving the need for innovative solutions that minimize environmental impact while meeting infrastructure requirements. Pavement construction with stabilized gold mining tailings is a focus.

Due to their storage issues and ability to seep toxins into nearby ecosystems, goldmine tailings can cause environmental problems [110]. While a stabilizing method involving quarry dust and coal ash can turn these tailings into a sustainable pavement material, examining the environmental impacts of employing stabilized mining tailings for pavement construction is critical. This alternative material's practicality and environmental impact can be obtained by assessing its environmental advantages, dangers, mitigation methods, as well as waste reduction and resource conservation.

### 8.1. Conventional use of goldmine tailing in construction

Numerous studies have been done regarding the replacement of raw materials with tailings in various construction products [111], [112], [113], [114]. Most goldmine tailings consist of industrial sand (i.e., silica) and silica sand that can be suitably described as a granular

material consisting of mainly quartz and a small quantity of clay, coal, and other minerals [111]. Silica sand has been identified as an essential component in several engineering projects, including glass making, building products and abrasive, and hydraulic fracturing of oil wells [113], [114],[115], [116]. Silica is characterized by hardness, high melting point, and chemical inertness, which can be traced to the strength of the bonds within the atoms.

Fine aggregates used in brick production can be substituted with mine tailings, reducing the demand for sand from riverbeds. The utilization of goldmine tailings for brick making with different mixing ratios of goldmine tailing, water, and cement was investigated [117]. Produced bricks were cured in three environments: oven-dried at 360 °C, sun-dried, and in water for 24 hours. The bricks were examined for unconfined compressive strength, weight loss, and water absorption. The results show that goldmine tailings can potentially replace the natural material presently used in brick production [117]. The available minerals in goldmine tailings can be transformed from one phase to another under temperature, making them suitable for tiles and ceramic production. Goldmine tailings have been identified as an economical and eco-friendly alternative to clay and kaolinite in traditional ceramics and tiles. The application of mine tailings to replace fine aggregate in concrete and mortar has been investigated because of its specific gravity and particle size. Goldmine tailings were investigated as a substitute for sand in concrete; an optimum strength of 47 MPa was recorded with 30 % sand replacement [118]. It has been reported that it can assist in reducing the demand for limited quantities of fine aggregate globally [119]. Likewise, the replacement of coarse aggregate with mining tailings in concrete has been reported with

satisfactory performance concerning conductivity. This process was reported to enhance the conductivity by 50 % when a 15 % substitution was experimented. This makes it applicable in snow/de-icing melting concrete for pavements in cold regions, and usage when cathodic protection of reinforcement is needed [120].

Goldmine tailings can be used as cementitious binders for clinker, to replace cementitious materials, and as a direct cement substitution or as a precursor for alkali materials [118]. For this usage, physical and chemical modification of mine tailings by thermal treatment, alkali activation, and size reduction may be done to attain a desirable characteristic. 30 % cement replacement with goldmine tailings has been observed to produce the optimal result [118]. The use of goldmine tailings as aggregate in producing ultra-high-performance concrete (UHPC) has been examined. Quartz sand was replaced with goldmine tailings and was investigated using various percentages of goldmine tailings up to 100 %. Some mechanical characteristics, like compressive strength, splitting tensile strength, elastic modulus, and durability characteristics like carbonation resistance, water absorption, and initial water absorption rate, were determined. UHPCs with 80 % goldmine tailings produce compressive strength that can be compared to or slightly above the compressive strength of UHPC, which contains 100% quartz sand. More than 120 MPa strength was achieved when 100 % goldmine tailings were used for UHPC, which is higher than what was reported for iron ore and other quartz-based tailings. Due to their higher strength and sustainability with improved durability compared to normal-strength concrete, goldmine tailings can be utilized for slender construction and/or more durable structural members, and pavements than those constructed with normal-strength concrete [121].

The utilization of goldmine tailings for Portland cement preparation has been experimented with, and it was reported that its relatively high reaction can improve the burnability of the materials. In addition, it does not influence the hydration types and clinker mineralogical phases with well-performed macroscopic physical characteristics. It was reported that the initial and final setting time is like that of Portland cement and consistent [122]. Goldmine tailings can be used as an additive to Portland cement in construction activities. Adding about 5–15 % goldmine tailings to cement does not significantly affect the mechanical characteristics of the concrete [123].

## 9. Use of Stabilized Goldmine Tailings in Pavement

Pavement is produced from a composition of aggregates (stone and sand), binders, admixture, and water. It has been observed that pavement comprises about 65 – 80 % aggregates in the concrete volume [124]. This implies that a considerable amount of natural aggregate is required for pavers, and sourcing these materials from natural deposits and rocks alters the aesthetics of the environment. Therefore, replacing natural aggregates with goldmine tailings has been identified as a sustainable means of pavement production [16]. Partial replacement of aggregates with goldmine tailings in road pavement has been investigated, and it was observed as a compatible physical property [125] and, thereby, recommended as a bright replacement for aggregates in road pavements [126].

### 9.1. Performance of stabilized goldmine tailings

Different studies have investigated the performance of stabilized goldmine tailings application, and it was discovered that the performance varies depending on various factors such as mix design, hydration time, activated materials, the quantity of water used, particle size, by-product, etc. [41], [125], [126]. For instance, goldmine tailings were mixed with granulated blast furnace slag (GBFS) to produce a sustainable and green backfill material. The mixing ratios considered were 100, 10:90, 20:80, 30:70, 40:60, and 50:50 of GBFS: goldmine tailings. The performance of these combinations was evaluated through mineralogy, evolution of particle size distribution, elemental composition, and micrography of the stabilized specimen. It was observed that the combination of 80 % goldmine tailings and 20 % GBFS produced the optimum compressive strength of 0.9 MPa [41]. The major products noticed to be formed are calcium sulphate dihydrate and calcium magnesium carbonate. A significant alteration in the microstructure of the GBFS portion was noticed with an increase in the GBFS mixed with the goldmine tailings. Considering the volume distribution, it was noticed that the production of finer particles was visible upon stabilization with goldmine tailings. The particle size distribution significantly influenced the strength of the developed GBFS modified with goldmine tailings. All the specimens produced from the mixing ratios considered met the requirement for

backfill-bearing material with a strength of 0.3 – 0.7 MPa for conventional engineering design and less than 1 MPa for freestanding backfilling material. The environmental impact assessment of the specimen showed that the stabilized material contains an acceptable percentage of contaminants [41].

Some studies [127], [128], [129], [130], [131], have reported partially replacing natural river sand with goldmine tailings in concrete production but with different performances. Generally, for better performance, partial substitution with stabilized goldmine tailings varies between 5 and 30 % of the natural river sand because, above 30 % replacement, the compressive strength of the concrete begins to reduce. A study by Reddy et al. [127] reported that replacing natural river sand with 10, 20, and 30% goldmine tailings, it was observed that goldmine tailing above 20% reduced the concrete strength [127].

In contrast, a similar investigation showed that the optimum performance was recorded at 10 % replacement but inferior performance at 30 % replacement [128]. Replacement of fine aggregate with stabilized goldmine tailings at 25, 50, 75, and 100 % showed that the best performance was achieved at 25 %, and beyond that, the strength declined. It was also observed that additives could enhance the concrete strength, but above 50 % natural sand replacement had no significant influence on the concrete [129]. Rajendra et al. [130] replaced natural sand with goldmine tailings at 5, 10, 15, 20, and 25 %, and it was observed that the best performance was attained between 5 and 15 % replacement with goldmine tailings. Replacement of quartz sand with goldmine tailings in ultra-high performance concrete up to 80% of quartz retained or even improved the compressive strength than 100% quartz sand [121]. Optimal performance was recorded at 5 % substitution when stabilized goldmine tailings were utilized as an additive in mortar preparation [121]. The optimum performance from replacing natural materials with stabilized goldmine tailings depends on the characteristics of the replaced materials [121] and the replacement purpose [131].

## 9.2. New trends and developments in goldmine tailing stabilization

Several mine tailings, like gold, alumina, copper, zinc, tungsten, iron ore, vanadium, phosphate, lead, and

sulphuric, have been experimented with as soil-stabilizing materials [43]. Different studies have reported gold mines as soil stabilizers, and most included the addition of cementitious agents such as cement, lime, cement kiln dust, and lime kiln dust. The physicochemical characteristics of the gold mine tailings will determine the interactions with the aggregate or soil and enhance the soil's compressive and shearing strength [132]. The compressive strength of the soil stabilized with goldmine tailings of soil stabilized with gold mine tailings depends on the properties of the soil, goldmine tailings percentage, and moisture content at the time of compaction [133]. Several researchers have studied the utilization of goldmine tailings as soil stabilizers to facilitate its management and reduce its harmful effects by investigating the chemical composition and leaching properties of the tailings before application [22], [23], [25].

Research on tailings stabilization with environmentally benign materials like geopolymer has recently attracted interest from researchers and policymakers globally. Geopolymers are three-dimensional amorphous alumina-silicate binders. It is a chain structure produced from mostly aluminium (Al) and silicon (Si) ions and belongs to the inorganic polymer family [134]. Generally, amorphous materials that are rich in alumina ( $Al_2O_3$ ) and silica ( $SiO_2$ ) can be used to produce geopolymer. Geopolymerization is the reaction between alumina and silica-rich materials with a higher percentage of the alkaline solution to produce amorphous semi-crystalline alumina-silicate polymers with excellent chemical and physical characteristics [132].

Mine tailings alkali activation synthesis introduces a solution with high alkalinity into the mine tailings rich in silicon and aluminium to produce alkali-activated materials [43], [134]. The principal alkali-based chemicals utilized for this process are sodium hydroxide and sodium silicate. The end products of this process are materials with low shrinkage and low density, higher resistance to chemicals and fire, enhanced durability, and acceptable mechanical strength [44], [133], [134].

The application of goldmine tailings, some alkali-activated materials, and additional alumina-silicate components has recently been at the center of research. Goldmine tailings were combined with fly ash at different ratios for soil stabilization. All the ratios considered met

the minimum requirement for compressive strength, with values ranging from 74 to 828 MPa [22]. Goldmine tailings were experimented with using potassium aluminate, potassium hydroxide, and potassium silicate as activators. The optimum compressive strength of the geopolymer was observed with a potassium silicate/potassium hydroxide proportion of 50:50. Findings show that an increase in curing temperature from 65–100 °C improved the compressive strength of potassium aluminate and potassium hydroxide-activated goldmine tailing geopolymers [135]. It was also noticed that potassium hydroxide and potassium aluminate activators produced better stability than potassium hydroxide and potassium silicate activators, even when the curing temperature was increased to 100 °C [135].

Another study also reported that increasing the molarities of sodium hydroxide solution and slag concentration improved the compressive strength of goldmine tailings slag or metakaolin blended geopolymer [136]. Literature regarding the long-term durability of mine tailing geopolymer composites is scarce because of minimal research in this space. The geopolymer of goldmine tailings was experimented with sulphate and acid solution at high temperatures. It was noticed that the percentage loss of strength with corresponding time in nitric and sulphuric acids is comparable to a cementitious composite material used as a reference. Similar results were observed when sodium and magnesium sulphate solutions were also subjected to high temperatures [137].

The application of tailings as an alternative to natural aggregates (sand or gravel) in geopolymerization, partially or fully, could result in an upsurge in the porosity and water absorption of the concrete [138]. On the other hand, this can make the material more vulnerable to chemical attack, harming its durability. Due to the lack of understanding regarding these and other characteristics of the durability of goldmine tailings, more research in this field is needed for future applications.

The microstructural arrangement of geopolymerized materials, the structure, content, percentage of the amorphous produced, and crystalline stages; likewise, the available, distribution, and pore size are all important factors that determine the characteristics of mine tailing geopolymer concrete. It was reported that the increase in sodium silicate percentage in tailing polymer concrete to about 30 % densifies the microstructural arrangement of

the material. The investigation shows that nearly all the geopolymer was turned into fused rectangular prisms, and the sodium silicate percentage shows a total conversion to highly alkaline conditions [149]. Compared to ordinary Portland cement binders, mine geopolymers are known for higher thermal stability and the capacity to maintain strength even after exposure to high temperatures [112], [113]. This is due to the structure's unique properties, which are generated through branched  $\text{AlO}_4$  and  $\text{SiO}_4$  tetrahedral frameworks. In furtherance to the composition method and curing of the alkali-activated, the aggregate type or aluminosilicate precursor used in the preparation of goldmine tailing polymers plays a significant role in the advancement of the thermal properties of geopolymers. It should be considered that when goldmine tailings are used in geopolymers, a specific examination of these materials' physical evolution and performance under constant and cyclic temperatures is needed to ascertain the probability of their application in civil engineering constructions.

## 10. Challenges and Future Directions

The sustainability of the construction industry faces a threat from the escalating demand for primary resources. Addressing this challenge involves exploring alternative secondary sources, and one promising approach is substituting natural materials with goldmine tailings. However, utilizing goldmine tailings in construction is hindered by their toxicity, necessitating alkali activation methods like geopolymerization. This does not only address the toxicity issue but also reduces production costs, making it a significant process for stabilizing hazardous compounds when combined with goldmine tailings, eliminating leaching challenges while producing suitable structural and chemical materials [114], [122], [125], [140].

Geopolymerization seems to be a bright technique in terms of technical, environmental, and economic perspectives. Geopolymers have been identified as an alternative binder that has been widely experimented with; it has a broad range of origins and are sustainable. The mechanical and durability characteristics of fly ash-based geopolymers with nano silica under magnesium sulfate, sulphuric acid, and seawater were investigated. Nano-silica fly-ash-based geopolymer was observed to have better durability than Ordinary Portland Cement when subjected to chemical attacks [141]. When

comparing the mechanical properties, physical properties, and hydraulic performance of clay stabilized with lightweight slag-soil geopolymer to cement-stabilized soils, it was noticed that clay-stabilized soil performed better than cement-stabilized soil in terms of strength, water absorption, and permeability [142]. When mechanical and durability characteristics were considered when comparing the use of fly-ash and slag-based geopolymers as concrete materials, it was found that slag-based geopolymer concrete was stronger and more durable than fly-ash-based geopolymer. This is attributed to the stable polymerization arrangement of slag-based geopolymers. [143]. A mixture of natural materials, such as clay minerals, clinker, or gypsum, can be used to produce composite geopolymers. Additionally, residues from industrial activities such as blast furnace slag powder, quarry dust, scrubber sludge, fly ash, calcium carbide, industrial alkali, and red mud can be utilized for geopolymerization [50]. Nevertheless, despite several studies on this subject matter, its commercial application remains limited. Goldmine tailings contain latent pozzolanic reactivity [96], and thermal treatment can be applied to improve the pozzolanic reactivity.

Goldmine tailings produced during mining are huge at different sites, resulting in environmental challenges [144]. Using these residues as pavement materials in the construction industry is a major factor in conserving natural resources and minimizing environmental challenges for construction and mining [25]. Utilizing goldmine tailings in pavement production could provide competitive material and reduce production costs, resource consumption, and goldmine tailings discharge. In addition, green management of goldmine tailings and the production of pavements with low energy requirements could be achieved. It is required that more research on the implementation and improved optimized uses of goldmine tailings in construction companies should be encouraged.

To develop the commercial application of goldmine tailings in the construction industry, available data, information on secondary materials, and legislative frameworks from the national/regional governments are essential [145]. The review of the selected articles has shown different promising prospects for future research and development in applying goldmine tailings in the construction industries.

## 11. Research Limitations

The process of achieving a circular economy in the construction industry related to the management of goldmine tailings is constrained by several factors. A significant limitation lies in the lack of awareness within the mining and construction industries regarding the potential of goldmine tailings as viable and sustainable construction materials. The prevailing linear economic model—characterized by a take-make-use-dispose approach—still dominates in many countries, impeding the adoption of waste-derived materials. For the successful commercialization and widespread adoption of goldmine tailings in construction, there is a critical need for comprehensive data on secondary raw materials, including their chemical and physical properties, suitable binders, activators/hardeners, and supportive legislative frameworks at national and regional levels. The performance of goldmine tailings in construction applications is governed by multiple interrelated factors such as elemental composition, mineralogy, solidification behavior, and pozzolanic activity. Understanding these synergistic interactions is essential for optimizing their use.

## 12. Conclusion

Literature has shown goldmine tailings, quarry dust, and coal ash as an attractive and bright means of resource recovery, producing sustainable construction and building materials, backfilling, and stabilizing materials for toxic element immobilization. Adding goldmine tailings to construction materials will reduce the pressure on the primary resources in this sector and improve the final product characteristics at a reasonable cost. This process reduces the carbon footprint related to the typical cementitious materials and eliminates substantial ecological challenges produced by goldmine tailings accumulation. Since the properties of goldmine tailings show that they can substitute natural river sand, they can be a secondary source of sand, and their utilization in paver production can assist in improving paths and roads. Further research is necessary to explore, implement, and improve the application of goldmine tailings in pavement construction, with emphasis on enhancing mechanical properties, optimizing stabilization techniques, and improving durability, while ensuring long-term performance and environmental sustainability.

### Competing Interest Statement

The authors declare no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

### Data Availability Statement

No datasets were generated or analysed to support the findings of this research.

### Acknowledgments

The Durban University of Technology (DUT), Durban, South Africa, is acknowledged for the financial support offered in the preparation of this manuscript.

### Funding Statement

This research was funded by the Durban University of Technology, South Africa, Research Scholarship and Future Professor program [GOOT], and the APC was funded by the Future Professor program [GOOT-02S8GT019].

### Author Contribution Roles

**Aderinto G.E.:** Conceptualization, methodology, investigation and review of related literature, data curation and analysis, and writing of original draft.

**Ikotun J.O.:** Conceptualization, supervision, research administration, methodological guidance, writing (review and editing), and validation.

**Katte V.Y.:** Conceptualization, supervision, methodological guidance, writing (review and editing), and validation.

**Babafemi J.A.:** Methodological guidance, writing (review and editing), and validation.

### References

- [1] L. Nakaona, K. K. Maseka, E. M. Hamilton, and M. J. Watts, "Using human hair and nails as biomarkers to assess exposure of potentially harmful elements to populations living near mine waste dumps," *Environmental Geochemistry and Health*, vol. 42, no. 4, pp. 1197-1209, 2020, <https://doi.org/10.1007/s10653-019-00376-6>.
- [2] R. Stewart, H. Dayal, L. Langer, and C. Van Rooyen, "The evidence ecosystem in South Africa: growing resilience and institutionalisation of evidence use," *Palgrave Communications*, vol. 5, no.1, 2019, <https://doi.org/10.1057/s41599-019-0303-0>.
- [3] D. A. Vallero, and G. Blight, "Mine waste: A brief overview of origins, quantities, and methods of storage," *Waste*, Academic Press, pp. 129-151, 2019, <https://doi.org/10.1016/B978-0-12-815060-3.00006-2>.
- [4] U. Okereafor, M. Makhatha, L. Mekuto, and V. Mavumengwana, "Gold Mine Tailings: A Potential Source of Silica Sand for Glass Making," *Minerals*, vol. 10, no. 5, pp.448, 2020, <https://doi.org/10.3390/min10050448>.
- [5] L. Nyamasve, "Potential of typha capensis in phytoremediation of selected heavy metals and sulphates in water: a case study of Freda Rebecca Gold Mine tailing stream," Doctoral dissertation, Civil Engineering, Bindura University of Science Education, Bindura, Zimbabwe, 2017.
- [6] M. N. Khan, M. I. Khan, J.H. Khan, S. Ahmad, and R. W. Azfar, "Exploring waste marble dust as an additive in cementitious grouts for semi-flexible pavement applications: Analysis and optimization using RSM," *Construction and Building Materials*, vol. 411, pp. 134554, 2024, <https://doi.org/10.1016/j.conbuildmat.2023.134554>.
- [7] A. Solouki, G. Viscomi, R. Lamperti, and P. Tataranni, "Quarry waste as precursors in geopolymers for civil engineering applications: A decade in review," *Materials*, vol. 13, pp. 14, 3146, 2020, <https://doi.org/10.3390/ma13143146>
- [8] C. Qi, A. Fourie, "Cemented paste backfill for mineral tailings management: Review and future perspectives," *Minerals Engineering*, vol. 144, pp. 106025, 2019, <https://doi.org/10.1016/j.mineng.2019.106025>
- [9] M. Ryan, A. Kney, T. Carley, "A study of selective precipitation techniques used to recover refined iron oxide pigments for the production of paint from a synthetic acid mine drainage solution," *Applied Geochemistry*, vol. 79, pp. 27-35, 2017, <https://doi.org/10.1016/j.apgeochem.2017.01.019>.
- [10] S. Cesare, T. Piergiorgio, L. Claudio, M. Francesco, "Application of Mining Waste Powder as filler in Hot Mix Asphalt," *MATEC Web Conferences*, vol. 274, pp.

- 04002,  
<https://doi.org/10.1051/mateconf/201927404002>.
- [11] F. Giustozzi, K. Mansour, F. Patti, M. Pannirselvam, F. Fiori, "Shear rheology and microstructure of mining material-bitumen composites as filler replacement in asphalt mastics," *Construction and Building Materials*, vol. 171, pp. 726–735, 2018, <https://doi.org/10.1051/mateconf/201927404002>.
- [12] A. L. Murmu, N. Dhole, and A. Patel, "Stabilisation of black cotton soil for subgrade application using fly ash geopolymer," *Road Materials and Pavement Design*, vol. 21, no. 3, pp. 867–885, 2020, <https://doi.org/10.1080/14680629.2018.1530131>.
- [13] T. Mashifana, and N. Sithole, "Leaching kinetics of gold mine tailings: the removal of manganese and iron by sodium carbonate," *In E3S Web of Conferences*, vol. 96, pp. 02005, 2019, <https://doi.org/10.1051/e3sconf/20199602005>.
- [14] M. Edraki, T. Baumgartl, E. Manlapig, D. Bradshaw, D.M. Franks, C.J. Moran, "Designing mine tailings for better environmental, social and economic outcomes: a review of alternative approaches," *Journal of Cleaner Production*, vol. 84, pp. 411–420, 2014, <https://doi.org/10.1016/j.jclepro.2014.04.079>
- [15] D. Kossoff, W.E. Dubbin, M. Alfredsson, S.J. Edwards, M.G. Macklin, K.A. Hudson-Edwards, "Mine tailings dams: Characteristics, failure, environmental impacts, and remediation," *Applied Geochemistry*, vol. 51, pp. 229–245, 2014, <https://doi.org/10.1016/J.APGEOCHEM.2014.09.010>.
- [16] J. Ikotun, R. Adeyeye, M. Otieno, "Application of mine tailings sand as construction material – a review," *MATEC Web of Conferences*, vol. 364, pp. 05008, 2022, <https://doi.org/10.1051/MATECCONF/202236405008>.
- [17] J.K. Lee, J.Q. Shang, S. Jeong, "Thermo-mechanical properties and microfabric of fly ash-stabilized gold tailings," *Journal of Hazardous Materials*, vol. 276, pp. 323–331, 2014, <https://doi.org/10.1016/J.JHAZMAT.2014.04.060>.
- [18] W. Zhang, X. Gu, J. Qiu, J. Liu, Y. Zhao, X. Li, "Effects of iron ore tailings on the compressive strength and permeability of ultra-high performance concrete," *Construction and Building Materials*, vol. 260 pp. 119917, 2020, <https://doi.org/10.1016/J.CONBUILDMAT.2020.119917>.
- [19] B.A. Wills, J.A. Finch, Chapter 16 - Tailings Disposal, in: B.A. Wills, J.A. Finch (Eds.), *Wills' Mineral Processing Technology* (Eighth Edition), Butterworth-Heinemann, Boston, 2016: pp. 439–448. <https://doi.org/https://doi.org/10.1016/B978-0-08-097053-0.00016-9>.
- [20] T. Mashifana, N. Sithole, E. Mkhonto, "Stabilization of gold mine tailings: The effect of hydrated lime on the unconfined compressive strength," *In IOP Conference Series: Materials Science and Engineering*, vol. 652, No. 1, pp. 012045, <https://doi.org/10.1088/1757-899X/652/1/012045>, (accessed July 13, 2023).
- [21] M.W. Gitari, S.A. Akinyemi, R. Thobakgale, P.C. Ngoejana, L. Ramugondo, M. Matidza, S.E. Mhlongo, F.A. Dacosta, N. Nemapate, "Physicochemical and mineralogical characterization of Musina mine copper and New Union gold mine tailings: Implications for fabrication of beneficial geopolymeric construction materials," *Journal of African Earth Sciences*, vol. 137, pp. 218–228, 2018, <https://doi.org/10.1016/J.JAFREARSCI.2017.10.016>.
- [22] R.M. Rachman, A.S. Bahri, Y. Trihadiningrum, "Stabilization and solidification of tailings from a traditional gold mine using Portland cement," *Environmental Engineering Research*, vol. 23, pp. 189–194, 2018, <https://doi.org/10.4491/EER.2017.104>.
- [23] J.S. Ogola, W. V. Mitullah, M.A. Omulo, "Impact of gold mining on the environment and human health: A case study in the Migori Gold Belt, Kenya," *Environmental Geochemistry and Health*, vol. 24, pp. 141–157, 2002, <https://doi.org/10.1023/A:1014207832471/METRICS>.
- [24] D.W. Dixon-Hardy, J.M. Engels, "Guidelines and Recommendations for the Safe Operation of Tailings Management Facilities," *Environ Eng Sci*, vol. 24, pp. 625–637, 2007, <https://doi.org/10.1089/ees.2006.0133>
- [25] R.P. Mapinduzi, P. Bujulu, W. Mwegoha, "Potential for reuse of gold mine tailings as secondary construction materials and Phytoremediation," *International Journal on Environmental Sciences*, vol. 7, no. 1, pp. 49-61, 2016.
- [26] O. Novhe, B. Yibas, R. Netshitungulwana, R. Lusunzi, "Geochemical and Minerological Characterization of Mine Residue Deposits in the Komati/Crocodile Catchment, South Africa: an Assessment for Acid/Alkaline Mine Drainage: An interdisciplinary response to mine water challenges," China University of Mining and Technology Press, Xuzhou, ISBN, 978-7, 2014.
- [27] B. Vriens, B. Plante, N. Seigneur, H. Jamieson, "Mine Waste Rock: Insights for Sustainable Hydrogeochemical Management," *Minerals*, vol. 10, pp. 728, 2020, <https://doi.org/10.3390/MIN10090728>.
- [28] P. Kinnunen, R. Obenaus-Emler, J. Raatikainen, S. Guignot, J. Guimerà, A. Ciroth, K. Heiskanen, "Review of closed water loops with ore sorting and tailings valorization for a more sustainable mining industry," *Journal of Cleaner Production*, vol. 278, pp. 123237, 2021, <https://doi.org/https://doi.org/10.1016/j.jclepro.2020.123237>.
- [29] A. Muir, J. Mitchell, S.R. Flatman, C. Sabbagha, "A practical guide to re-treatment of gold processing residues," *Minerals Engineering*, vol. 18, pp. 811–824, 2005,

- <https://doi.org/https://doi.org/10.1016/j.mineng.2005.01.027>.
- [30] L. Xie, D. van Zyl, "Distinguishing reclamation, revegetation and phytoremediation, and the importance of geochemical processes in the reclamation of sulfidic mine tailings: A review," *Chemosphere*, vol. 252, pp. 126446, 2020, <https://doi.org/https://doi.org/10.1016/j.chemosphere.2020.126446>.
- [31] S.S. Sarathchandra, Z. Rengel, Z.M. Solaiman, "A Review on Remediation of Iron Ore Mine Tailings via Organic Amendments Coupled with Phytoremediation," *Plants*, vol. 12, no. 9, pp. 1871, 2023, <https://doi.org/10.3390/plants12091871>.
- [32] M.O. Mendez, R.M. Maier, "Phyto-stabilization of Mine Tailings in Arid and Semiarid Environments—An Emerging Remediation Technology," *Environmental Health Perspective*, vol. 116, pp. 278–283, 2008, <https://doi.org/10.1289/ehp.10608>.
- [33] C. Lv, R. Bi, X. Guo, D. Chen, Y. Guo, Z. Xu, "Erosion characteristics of different reclaimed substrates on iron tailings slopes under simulated rainfall," *Scientific Report*, vol. 10, pp. 4275, 2020, <https://doi.org/10.1038/s41598-020-61121-z>.
- [34] R.G. Gopez, "Utilizing mine tailings as substitute construction material: the use of waste materials in roller compacted concrete," *Open Access Library Journal*, vol. 2, no. 12, pp. 1-9, <https://doi.org/10.4236/oalib.1102199>.
- [35] C. Balegamire, B. Nkuba, P. Dable, "Production of gold mine tailings-based concrete pavers by substitution of natural river sand in Misisi, Eastern Congo," *Cleaner Engineering and Technology*, vol. 7, pp. 100427, 2022, <https://doi.org/https://doi.org/10.1016/j.clet.2022.100427>.
- [36] B.M. Ramalinga Reddy, K.S. Satyanarayanan, J. Reddy, N. Parthasarathi, "Production of gold mine tailings-based concrete pavers by substitution of natural river sand in Misisi, Eastern Congo," *Cleaner Engineering and Technology*, vol. 7, pp. 100427, 2022.
- [37] G. B. Lottermoser, "Recycling, reuse and rehabilitation of mine wastes," *Elements*, vol. 7, no. 6, pp. 405-410, 2011.
- [38] N. Garcia-Troncoso, H. Baykara, M.H. Cornejo, A. Riofrio, M. Tinoco-Hidalgo, J. Flores-Rada, "Comparative mechanical properties of conventional concrete mixture and concrete incorporating mining tailings sands," *Case Studies in Construction Materials*, vol. 16, pp. 01031, 2022, <https://doi.org/https://doi.org/10.1016/j.cscm.2022.e01031>.
- [39] I. Susanto, S. Fransisco, Y. Firdaus, Y. Ronny, "Utilization of tailing waste as aggregate for road pavement," *IOP Conference Series: Earth and Environmental Science*, vol. 802, pp. 012020, 2021, <https://doi.org/10.1088/1755-1315/802/1/012020>.
- [40] A.N. Ally, M.M. Blanche, U.J.P. Nana, M.M. Grâce, N. François, C. Pettang, "Recovery of Mining Wastes in Building Materials: A Review," *Open Journal of Civil Engineering*, vol. 11, pp. 379–397, 2021, <https://doi.org/10.4236/ojce.2021.114022>.
- [41] T. Mashifana, T. Sithole, "Clean production of sustainable backfill material from waste gold tailings and slag," *Journal of Cleaner Production*, vol. 308, pp. 127357, 2021, <https://doi.org/https://doi.org/10.1016/j.jclepro.2021.127357>.
- [42] M. Tarnawczyk, Ł. Uzarowicz, K. Perkowska-Pióro, A. Pędziwiatr, W. Kwasowski, "Effect of Land Reclamation on Soil Properties, Mineralogy, and Trace-Element Distribution and Availability: The Example of Technosols Developed on the Tailing Disposal Site of an Abandoned Zn and Pb Mine," *Minerals*, vol. 11, 2021, <https://doi.org/10.3390/min11060559>.
- [43] A.O. Igbadamhe, A.A. Amadi, M. Alhassan, "Preliminary Assessment of Iron Ore Tailings Stabilized with Quarry Fines and Cement for Pavement Subbase." Proceedings of the 1st International Civil Engineering Conference, Department of Civil Engineering, Federal University of Technology, Minna, Nigeria, 2018. (accessed July 15, 2023).
- [44] S. Ramanathan, P. Perumal, M. Illikainen, P. Suraneni, "Mechanically activated mine tailings for use as supplementary cementitious materials," *RILEM Technical Letters*, vol. 6, pp. 61–69, 2021, <https://doi.org/10.21809/RILEMTECHLETT.2021.143>.
- [45] H. A. Sultan, "Stabilized copper mill tailings for highway construction," *Transportation research record*, no. 734, pp. 1–7, 1979, [Online]. Available: <http://worldcat.org/issn/03611981>.
- [46] R. K. Swami, N. K. S. Pundhir, and S. Mathur, "Kimberlite tailings: A road construction material," *Transportation research record*, vol. 2, no. 1989, pp. 131–134, 2007, doi: 10.3141/1989-56.
- [47] G. Qian, T. Huang, and S. Bai, "Use of Cement-Stabilized Granite Mill Tailings as Pavement Subbase," *Journal of Materials in Civil Engineering*, vol. 23, no. 11, pp. 1575–1578, 2011, doi: 10.1061/(asce)mt.1943-5533.0000276.
- [48] J.K. Lee, J.Q. Shang, S. Jeong, "Thermo-mechanical properties and microfabric of fly ash-stabilized gold tailings," *Journal of Hazardous Materials*, vol. 276, pp. 323–331, 2014, <https://doi.org/https://doi.org/10.1016/j.jhazmat.2014.04.060>.
- [49] G.A. Miller, S. Azad, "Influence of soil type on stabilization with cement kiln dust," *Construction and Building Materials*, vol. 14, pp. 89–97, 2000, [https://doi.org/https://doi.org/10.1016/S0950-0618\(00\)00007-6](https://doi.org/https://doi.org/10.1016/S0950-0618(00)00007-6).
- [50] J. Kiventerä, K. Piekkari, V. Isteri, K. Ohenoja, P. Tanskanen, M. Illikainen, "Solidification/stabilization of gold mine tailings using calcium sulfoaluminate-belite cement," *Journal of Cleaner Production*, vol. 239, pp. 118008, 2019,

- <https://doi.org/https://doi.org/10.1016/j.jclepro.2019.118008>.
- [51] N. Degirmenci, A. Okucu, A. Turabi, "Application of phosphogypsum in soil stabilization," *Build Environment*, vol. 42, pp. 3393–3398, 2007, <https://doi.org/https://doi.org/10.1016/j.buildenv.2006.08.010>.
- [52] R.M. Rachman, A.S. Bahri, Y. Trihadiningrum, "Stabilization and solidification of tailings from a traditional gold mine using Portland cement," *Environmental Engineering Research*, vol. 23, pp. 189–194, 2018, <https://doi.org/10.4491/eer.2017.104>.
- [53] R.M. Rachman, A.S. Bahri, Y. Trihadiningrum, "Stabilization/solidification of tailings on traditional gold mining in Kulon Progo using fly ash," *Journal of Ecological Engineering*, vol. 19, pp. 178–184, 2018, <https://doi.org/10.12911/22998993/86145>.
- [54] G. Longarini, N. Nicola, P.G. Crespi, M. Zucca, N. Giordano, and G. Silvestro. "The advantages of fly ash use in concrete structures," *Inżynieria Mineralna*, vol. 15, no. 2, pp. 141-145, 2014.
- [55] I.Nawaz, "Disposal and utilization of fly ash to protect the environment," *International journal of innovative research in science, engineering and technology*, vol. 2, no.10, pp. 5259-5266.
- [56] Z. Pan, S. Hu, C. Zhang, T. Zhou, G. Hua, Y. Li, X. Lv, "Mechanical and Hydration Characteristics of Stabilized Gold Mine Tailings Using a Sustainable Industrial Waste-Based Binder," *Materials*, vol. 16, 2023, <https://doi.org/10.3390/ma16020634>.
- [57] M. Ondova, N. Stevulova, L. Meciarova, "The Potential of Higher Share of Fly Ash as Cement Replacement in the Concrete Pavement," *Procedia Engineering*, vol. 65, pp. 45–50, 2013, <https://doi.org/https://doi.org/10.1016/j.proeng.2013.09.009>.
- [58] C. Pereira dos Santos, G.J. Bruschi, J.R.G. Mattos, N.C. Consoli, "Stabilization of gold mining tailings with alkali-activated carbide lime and sugarcane bagasse ash," *Transportation Geotechnics*, vol. 32, 2022, <https://doi.org/10.1016/j.trgeo.2021.100704>.
- [59] M. Tebogo, N.T. Sithole, "Evaluation of Chemically Treated and Lime Stabilized Gold Mine Tailings: Effect on Unconfined Compressive Strength," *Key Engineering Materials*, vol. 803, pp. 366–370, 2019, <https://doi.org/10.4028/www.scientific.net/KEM.803.366>.
- [60] S.T. Ferrazzo, M.T. de Araújo, G.J. Bruschi, H.M. Chaves, E.P. Korf, N.C. Consoli, "Mechanical and environmental behavior of waste foundry sand stabilized with alkali-activated sugar cane bagasse ash-eggshell lime binder," *Construction and Building Materials*, vol. 383, pp. 131313, 2023, <https://doi.org/https://doi.org/10.1016/j.conbuildmat.2023.131313>.
- [61] C.A. du Plessis, H. Lambert, R.S. Gärtner, K. Ingram, W. Slabbert, J.J. Eksteen, "Lime use in gold processing – A review," *Minerals Engineering*, vol. 174, pp. 107231, 2021, <https://doi.org/https://doi.org/10.1016/j.mineng.2021.107231>.
- [62] T. Mashifana, N. Sithole, E. Mkhonto, "Stabilization of gold mine tailings: The effect of hydrated lime on the unconfined compressive strength," *IOP Conference Series: Materials, Science and Engineering*, vol. 652, pp. 012045, 2019, <https://doi.org/10.1088/1757-899X/652/1/012045>.
- [63] M. Bani Baker, R. Abendeh, A. Sharo, A. Hanna, "Stabilization of Sandy Soils by Bentonite Clay Slurry at Laboratory Bench and Pilot Scales," *Coatings*, vol. 12, 2022, <https://doi.org/10.3390/coatings12121922>.
- [64] A. Raj1, V. Toshniwal2, "Characteristic Properties of Bentonite Clay and use of Nanomaterials in Stabilizing its Expansive Behavior," *International Journal of Science and Research*, 2018, <https://doi.org/10.21275/ART2020380>.
- [65] D.M. Barbieri, B. Lou, R.J. Dyke, H. Chen, P. Zhao, S.A. Memon, I. Hoff, "Calcium bentonite and sodium bentonite as stabilizers for roads unbound," *Cleaner Engineering Technology*, vol. 6, pp. 100372, 2022, <https://doi.org/https://doi.org/10.1016/j.clet.2021.100372>.
- [66] Q. Chen, K. Luo, Y. Wang, X. Li, Q. Zhang, Y. Liu, "In-situ stabilization/solidification of lead/zinc mine tailings by cemented paste backfill modified with low-carbon bentonite alternative," *Journal of Materials Research and Technology*, vol. 17, pp. 1200–1210, 2022, <https://doi.org/https://doi.org/10.1016/j.jmrt.2022.01.099>.
- [67] S. Barati, P. Tabatabaie Shourijeh, N. Samani, S. Asadi, "Stabilization of iron ore tailings with cement and bentonite: a case study on Golgohar mine," *Bulletin of Engineering Geology and the Environment*, vol. 79, pp. 4151–4166, 2020, <https://doi.org/10.1007/s10064-020-01843-6>.
- [[68] Z. Pan, C. Zhang, Y. Li, C. Yang, "Solidification/stabilization of gold ore tailings powder using sustainable waste-based composite geopolymer," *Engineering Geology*, vol. 309, pp. 106793, 2022, <https://doi.org/https://doi.org/10.1016/j.enggeo.2022.106793>.
- [69] G.M. Alelvan, J.W. dos S. Ferreira, M.D.T. Casagrande, N.C. Consoli, "Proposal of New Construction Material: Polymer-Stabilized Gold Ore Tailings Composite," *Sustainability*, vol. 14, 2022, <https://doi.org/10.3390/su142013648>.
- [70] G.M. Alelvan, M.D.T. Casagrande, N.C. Consoli, "Mechanical behavior analysis of polymer-stabilized gold ore tailings," *Soils and Rocks*, vol. 45, 2022, <https://doi.org/10.28927/SR.2022.075421>.
- [71] S. Kumar, and S.K. Singh, "Subgrade soil stabilization using geosynthetics: A critical review," *Materials Today Proceedings*, vol. 4, pp.266, 2023,

- <https://doi.org/https://doi.org/10.1016/j.matpr.2023.04.266>.
- [72] E. Pakostova, A.J. Schmall, S.P. Holland, H. White, C.J. Ptacek, D.W. Blowes, "Performance of a Geosynthetic-Clay-Liner Cover System at a Cu/Zn Mine Tailings Impoundment," *Applied and Environmental Microbiology*, vol. 86, no. 8, pp. e02846-19, 2020, <https://doi.org/10.1128/AEM.02846-19>.
- [73] P.K. Nsiah, W. Schaaf, "The potentials of biological geotextiles in erosion and sediment control during gold mine reclamation in Ghana," *Journal of Soils Sediments*, vol. 19, pp. 1995–2006, 2019, <https://doi.org/10.1007/s11368-018-2217-7>.
- [74] B.O. Oyegbile, B.A. Oyegbile, "Applications of geosynthetic membranes in soil stabilization and coastal defence structures," *International Journal of Sustainable Built Environment*, vol. 6, pp. 636–662, <https://doi.org/https://doi.org/10.1016/j.ijse.2017.04.001>.
- [75] K. Maheshwari, C. H. and Solanki, "Behaviour of fiber reinforced soil," *Australian Geomechanics*, vol. 44, no. 4, pp.65, 2009.
- [76] M. Manickam, S. Dhivya Bharathi, D. Gowri, P. Indhra, J. Prabha, "Experimental investigations on soil stabilization by using quarry dust and waste plastic fibre as a subgrade in flexible pavement," *International Journal of Advanced Research and Innovation*, vol. 6, no. 4, pp. 1-7, 2019.
- [77] R. Kufre Etim, D. Ufot Ekpo, I. Christopher Attah, K. Chibuzor Onyelowe, "Effect of micro-sized quarry dust particle on the compaction and strength properties of cement stabilized lateritic soil," *Cleaner Materials*, vol. 2, pp. 100023, 2021, <https://doi.org/https://doi.org/10.1016/j.clema.2021.100023>.
- [78] P. Kumar, and N. V. Kumar. "Soil stabilization using lime and quarry dust," *International Journal of Innovation and Research Studies*, vol. 8, no. 1, pp. 103-111, 2018.
- [79] Y. Zhang, L.K. Korkiala-Tanttu, M. Borén, "Assessment for sustainable use of quarry fines as pavement construction materials: part II-stabilization and characterization of quarry fine materials." *Materials*, vol. 12, no. 15, pp. 2450, 2019, <https://doi.org/10.3390/ma12152450>.
- [80] G.K. Febin, A. Abhirami, A.K. Vineetha, V. Manisha, R. Ramkrishnan, D. Sathyan, K.M. Mini, "Strength and durability properties of quarry dust powder incorporated concrete blocks," *Construction and Building Materials*, vol. 228, pp. 116793, 2019, <https://doi.org/https://doi.org/10.1016/j.conbuildmat.2019.116793>.
- [81] H.A.F. Dehwah, "Mechanical properties of self-compacting concrete incorporating quarry dust powder, silica fume or fly ash," *Construction and Building Materials*, vol. 26, pp. 547–551, 2021, <https://doi.org/https://doi.org/10.1016/j.conbuildmat.2011.06.056>.
- [82] B. Bahoria, D.K. Parbat, P.B. Nagarnaik, U.P. Waghe, "Effect of replacement of natural sand by quarry dust and waste plastic on compressive & split tensile strength of M20 concrete," 2013, [www.sciencedirect.com](http://www.sciencedirect.com)
- [83] S. Ponnada, V.R. Sankar Cheela, S.S.S.V. Gopala Raju, "Investigation on mechanical properties of composite concrete containing untreated sea sand and quarry dust for 100% replacement of fine aggregate," in: *Materials Today Proceedings, Elsevier Ltd*, pp. 989–996, 2020, <https://doi.org/10.1016/j.matpr.2020.06.203>.
- [84] R. Kufre Etim, D. Ufot Ekpo, I. Christopher Attah, K. Chibuzor Onyelowe, "Effect of micro-sized quarry dust particle on the compaction and strength properties of cement stabilized lateritic soil," *Cleaner Materials*, vol. 2, pp. 100023, 2021, <https://doi.org/https://doi.org/10.1016/j.clema.2021.100023>.
- [85] K. Shyam Prakash, Ch.H. Rao, "Study on Compressive Strength of Quarry Dust as Fine Aggregate in Concrete," *Advances in Civil Engineering*, pp. 1742769, 2016, <https://doi.org/10.1155/2016/1742769>.
- [86] S. Sudhakar, E. Duraisekaran, G. Dilli Vignesh, G.D. Kanna, "Performance Evaluation of Quarry Dust Treated Expansive Clay for Road Foundations," *Iranian Journal of Science and Technology - Transactions of Civil Engineering*, vol. 45 pp. 2637–2649, 2021, <https://doi.org/10.1007/s40996-021-00645-4>.
- [87] A.K. Pathe, P. Kumar Kushwaha, J.M. Thomas, "Review on performance of quarry dust as fine aggregate in concrete." *International Research Journal of Engineering Technology*, vol. 7, pp. 517-521, 2020.
- [88] L.R. de Rezende, J.C. de Carvalho, "The use of quarry waste in pavement construction," *Resource Conservation and Recycling*, vol. 39, pp. 91–105, 2003, [https://doi.org/https://doi.org/10.1016/S0921-3449\(02\)00123-4](https://doi.org/https://doi.org/10.1016/S0921-3449(02)00123-4).
- [89] N. Liza Rahim, R. Che Amat, N. Mohamad Ibrahim, N. Aini Syafiqah Abd Rahim, N. Hamzah, N. Aina Misnon, "Sustainable Utilisation of Quarry Dust Waste in Concrete: Strength Performance," *IOP Conference Service of Earth Environmental Science*, vol. 616, pp. 012052, 2020, <https://doi.org/10.1088/1755-1315/616/1/012052>.
- [90] J. Valentin, J. Trejbal, V. Nežerka, T. Valentová, M. Faltus, "Characterization of quarry dusts and industrial by-products as potential substitutes for traditional fillers and their impact on water susceptibility of asphalt concrete," *Construction and Building Materials*, vol. 301, pp. 124294, 2021, <https://doi.org/https://doi.org/10.1016/j.conbuildmat.2021.124294>.
- [91] H.A. Omar, N.I.Md. Yusoff, M. Mubarak, H. Ceylan, "Effects of moisture damage on asphalt mixtures," *Journal of Traffic and Transportation Engineering (English Edition)*, vol. 7, pp. 600–628,

- <https://doi.org/https://doi.org/10.1016/j.jtte.2020.07.001>.
- [92] K. Shyam Prakash, Ch.H. Rao, "Study on compressive strength of quarry dust as fine aggregate in concrete." *Advances in Civil Engineering*, no. 1, pp. 1742769, <https://doi.org/10.1155/2016/1742769>.
- [93] K. Hussain, F. Butt, M. Alwetaishi, R.M. Waqas, F. Aslam, M. Ibraheem, Z. Xulong, N. Ahmad, R.F. Tufail, M.A. Musarat, E.E. Hussein, "Effect of Quarry Rock Dust as a Binder on the Properties of Fly Ash and Slag-Based Geopolymer Concrete Exposed to Ambient and Elevated Temperatures," *Applied Sciences*, vol. 11, 2021, <https://doi.org/10.3390/app11199192>.
- [94] C. A. Ezaegu, M.S. Agusi, "Effects of The Total and Partial Replacement of Sharp Sand with Quarry Dust on Concrete," 2018.
- [95] W. Song, U. Schulz, H. Guo, D.B. Dingwell, "Volcanic ash hazards to aviation safety," In *Thermal Barrier Coatings*, Woodhead Publishing, pp. 293-324, 2023, <https://doi.org/https://doi.org/10.1016/B978-0-12-819027-2.00009-2>.
- [96] A. Cwirzen, "10 - Properties of SCC with industrial by-products as aggregates, in: R. Siddique (Ed.), *Self-Compacting Concrete: Materials, Properties and Applications*," Woodhead Publishing, pp. 249–281, 2020, <https://doi.org/https://doi.org/10.1016/B978-0-12-817369-5.00010-6>.
- [97] D.Y. Wiranata, S.-H. Yang, C.M. Akgul, H.Y. Hsien, M.Z.P. Nugraha, "Use of coal ash cement stabilized material as pavement base material: Laboratory characterization and field evaluation," *Construction and Building Materials*, vol. 344, pp. 128055, 2022, <https://doi.org/https://doi.org/10.1016/j.conbuildmat.2022.128055>.
- [98] C. Rajakumar, T. Meenambal, "Effect of coal ash in the stabilization of expansive soil for the pavement," pp. 170-177, 2015.
- [99] A. Bhatt, S. Priyadarshini, A. Acharath-Mohanakrishnan, A. Abri, M. Sattler, S. Techapaphawit, "Physical, chemical, and geotechnical properties of coal fly ash: A global review," *Case Studies in Construction Materials*, vol. 11, p. 00263, 2019, <https://doi.org/https://doi.org/10.1016/j.cscm.2019.e00263>.
- [100] S.S. Alterary, N.H. Marei, "Fly ash properties, characterization, and applications: A review," *Journal of King Saud University of Science*, vol. 33, pp. 101536, 2021, <https://doi.org/https://doi.org/10.1016/j.jksus.2021.101536>.
- [101] S. Maruthupandian, N.A. Chaliasou, A. Kanellopoulos, "Recycling mine tailings for a sustainable future built environment." In *Energy and Sustainable Futures: Proceedings of 2nd ICESF 2020*, pp. 163-169. Cham: Springer International Publishing, 2021, [https://doi.org/10.1007/978-3-030-63916-7\\_21](https://doi.org/10.1007/978-3-030-63916-7_21).
- [102] K. Sundaralingam, A. Peiris, A. Anburuvel, N. Sathiparan, "Quarry dust as river sand replacement in cement masonry blocks: Effect on mechanical and durability characteristics," *Materialia (Oxf)*, vol. 21, pp. 101324, 2022, <https://doi.org/10.1016/J.MTLA.2022.101324>.
- [103] R. Renjith, D. Robert, S. Setunge, S. Costa, A. Mohajerani, "Optimization of fly ash based soil stabilization using secondary admixtures for sustainable road construction," *Journal of Cleaner Production*, vol. 294, pp. 126264, 2021, <https://doi.org/10.1016/J.JCLEPRO.2021.126264>.
- [104] I. Phummiphan, S. Horpibulsuk, R. Rachan, A. Arulrajah, S.L. Shen, P. Chindaprasirt, "High calcium fly ash geopolymer stabilized lateritic soil and granulated blast furnace slag blends as a pavement base material," *Journal of Hazardous Materials*, vol. 341, pp. 257–267, 2018, <https://doi.org/10.1016/J.JHAZMAT.2017.07.067>.
- [105] A. Zanoletti, S. Federici, L. Borgese, P. Bergese, M. Ferroni, L.E. Depero, E. Bontempi, "Embodied energy as key parameter for sustainable materials selection: The case of reusing coal fly ash for removing anionic surfactants," *Journal of Cleaner Production*, vol. 141, pp. 230–236, 2017, <https://doi.org/10.1016/J.JCLEPRO.2016.09.070>.
- [106] K. Kim, M. Shin, S. Cha, "Combined effects of recycled aggregate and fly ash towards concrete sustainability," *Construction and Building Materials*, vol. 48, pp. 499–507, 2013, <https://doi.org/10.1016/J.CONBUILDMAT.2013.07.014>.
- [107] J.J. Wang, Y.F. Wang, Y.W. Sun, D.D. Tingley, Y.R. Zhang, "Life cycle sustainability assessment of fly ash concrete structures," *Renewable and Sustainable Energy Reviews*, vol. 80, pp. 1162–1174, 2017, <https://doi.org/10.1016/J.RSER.2017.05.232>.
- [108] G.J. Bruschi, C.P. dos Santos, M. Tonini de Araújo, S.T. Ferrazzo, S.F.V. Marques, and N.C. Consoli, "Green Stabilization of Bauxite Tailings: Mechanical Study on Alkali-Activated Materials," *Journal of Materials in Civil Engineering*, vol. 33, no. 11, p.06021007, 2021.
- [109] O.O. Ojuri, A.A. Adavi, and O.E. Oluwatuyi, "Geotechnical and environmental evaluation of lime-cement stabilized soil-mine tailing mixtures for highway construction," *Transportation Geotechnics*, 10, pp.1-12, 2017.
- [110] C. Cacciuttolo, D. Cano, M. Custodio, "Socio-Environmental Risks Linked with Mine Tailings Chemical Composition: Promoting Responsible and Safe Mine Tailings Management Considering Copper and Gold Mining Experiences from Chile and Peru," *Toxics*, vol. 11, 2023, <https://doi.org/10.3390/toxics11050462>.
- [111] J. Beño, K. Adamusová, V. Merta, T. Bajer, "Influence of silica sand on surface casting quality." *Archives of Foundry Engineering*, 2019, <https://doi.org/10.24425/afe.2019.127107>.
- [112] H.Y. Zhang, G.H. Qiu, V. Kodur, Z.S. Yuan, "Spalling behavior of metakaolin-fly ash based geopolymer

- concrete under elevated temperature exposure," *Cem Concr. Compos*, vol. 106, pp. 103483, 2020, <https://doi.org/10.1016/J.CEMCONCOMP.2019.103483>.
- [113] R. Kumar, P. Das, B. Matcha, H.R. Arjun, G. Ignatius, "Utilization of Iron Ore Tailings for the Production of Fly Ash - GGBS-Based Geopolymer Bricks," *Journal of Advanced Manufacturing Systems*, vol. 16, pp. 275–290, 2017, <https://doi.org/10.1142/S0219686717500172>.
- [114] M.A. Adajar, H. Beltran, C. Calicdan, T.R. Duran, C. Ramos, J. Galupino, "Assessment of gold mine tailings as based geopolymer binder in concrete." In *Proceedings of the DLSU Research Congress*. 2021.
- [115] S.P. Malu, "Chemical Characterization of Silica Sand Deposit from River Katsina-Ala, North Central Region of Nigeria," *Global Journal of Pure and Applied Physics*, vol. 3, pp. 26–37, 2015, [www.eajournals.org](http://www.eajournals.org) (accessed August 1, 2023).
- [116] M. Hasanuzzaman, A. Rafferty, M. Sajjia, A. Olabi, "Properties of glass materials," *Reference Module in Materials Science and Materials Engineering*, pp. 647-657, 2016, <https://doi.org/10.1016/B978-0-12-803581-8.03998-9>.
- [117] M. Malatse, S. Ndlovu, "The viability of using the Witwatersrand gold mine tailings for brickmaking." *Journal of the Southern African Institute of Mining and Metallurgy* vol. 115, no. 4, pp. 321-327, 2015.
- [118] C. Ince, "Reusing gold-mine tailings in cement mortars: Mechanical properties and socio-economic developments for the Lefke-Xeros area of Cyprus," *Journal of Cleaner Production*, vol. 238, pp. 117871, 2019, <https://doi.org/10.1016/J.JCLEPRO.2019.117871>.
- [119] S.K. Kirthika, S.K. Singh, A. Chourasia, "Alternative fine aggregates in production of sustainable concrete- A review," *Journal of Cleaner Production*, vol. 268, pp. 122089, 2020, <https://doi.org/10.1016/J.JCLEPRO.2020.122089>.
- [120] H. Liu, B. Li, J. Xue, J. Hu, J. Zhang, "Mechanical and electroconductivity properties of graphite tailings concrete." *Advances in Materials Science and Engineering* 2020, no. 1, pp. 9385097, 2020, <https://doi.org/10.1155/2020/9385097>.
- [121] T. Ahmed, M. Elchalakani, H. Basarir, A. Karrech, E. Sadrossadat, B. Yang, "Development of ECO-UHPC utilizing gold mine tailings as quartz sand alternative," *Clean Engineering and Technology*, vol. 4, pp. 100176, 2021, <https://doi.org/10.1016/J.CLET.2021.100176>.
- [122] P. Maheshwari, and P. K. Basudhar, "Visco-elastic response of combined footings on earth beds with geocell-geomembrane inclusions." *Arabian Journal of Geosciences*, vol. 13, no. 21, pp. 1110, 2020.
- [123] S. Roy, G.R. Adhikari, R.N. Gupta, "Use of gold mill tailings in making bricks: a feasibility study," *Waste Management & Research*, vol. 25, pp. 475–482, 2007, <https://doi.org/10.1177/0734242X07076944>.
- [124] F. Colangelo, A. Forcina, I. Farina, A. Petrillo, "Life Cycle Assessment (LCA) of Different Kinds of Concrete Containing Waste for Sustainable Construction," *Buildings*, vol. 8, Page 70, 2018, <https://doi.org/10.3390/BUILDINGS8050070>.
- [125] J. Almeida, A.B. Ribeiro, A.S. Silva, P. Faria, "Overview of mining residues incorporation in construction materials and barriers for full-scale application," *Journal of Building Engineering*, vol. 29, pp. 101215, 2020, <https://doi.org/10.1016/J.JOBE.2020.101215>.
- [126] M. Amrani, Y. Taha, A. Kchikach, M. Benzaazoua, R. Hakkou, "Valorization of Phosphate Mine Waste Rocks as Materials for Road Construction," *Minerals*, vol. 9, no. 9, Page 237, 2019, <https://doi.org/10.3390/MIN9040237>.
- [127] B. R. Reddy, K. S. Satyanarayanan, H. Jagannatha, and N. Parthasarathi. "Use of gold mine tailings in production of Concrete-A feasibility study," *BDL*, vol. 9, pp. 197-202, 2016, (accessed August 19, 2023).
- [128] N. Parthasarathi, B.M.R. Reddy, K.S. Satyanarayanan, "Effect on workability of concrete due to partial replacement of natural sand with gold mine tailings," *Indian Journal of Science and Technology*, vol. 9, no. 35, pp. 1-4, 2016, <https://doi.org/10.17485/ijst/2016/v9i35/99052>.
- [129] L. Widodojoko, H. Hardjasaputra, S. Susilowati, "Study of Gold Mine Tailings Utilization as Fine Aggregate Material for Producing Shotcrete Based on Concept of Green Technology," *3rd International Conference on Engineering and Technology Development*, 2014, p.171172, <https://www.neliti.com/publications/171172/> (accessed August 19, 2023).
- [130] A. V. Preethi, S. Rajendra, P.L. K. Navneeth, "Studies on gold ore tailings as partial replacement of fine aggregates in concrete." *International Journal of Latest Technology, Engineering Management and Applied Science*, vol. 6, no. 4, pp. 30-33, 2017.
- [131] K. Kunt, M. Yıldırım, F. Dur, E.M. Derun, S. Pişkin, "Utilization of Bergama Gold Tailings as an Additive in the Mortar," *Celal Bayar University Journal of Science*, vol. 11, 2015, <https://doi.org/10.18466/CBUJOS.89776>.
- [132] B.A. Akinyemi, P.A. Alaba, A. Rashedi, "Selected performance of alkali-activated mine tailings as cementitious composites: A review," *Journal of Building Engineering*, vol. 50, pp. 104154, 2022, <https://doi.org/10.1016/J.JOBE.2022.104154>.
- [133] J.O. Ikotun, G.E. Aderinto, M.M. Madirisha, and V.Y. Katte, 2024. "Geopolymer cement in pavement applications: bridging sustainability and performance," *Sustainability*, vol. 16, no. 13, p.5417.
- [134] T. Falayi, "Effect of potassium silicate and aluminate on the stabilization of acidic gold mine tailings," *Proceedings of the Institution of Civil Engineers - Waste*

- and Resource Management, vol. 172, pp. 1–27, 2019, <https://doi.org/10.1680/jwarm.18.00015>.
- [135] J. Kiventerä, J. Yliniemi, L. Golek, J. Deja, V. Ferreira, M. Illikainen, "Utilization of sulphidic mine tailings in alkali-activated materials," *MATEC Web of Conferences*, vol. 274, pp. 01001, 2019, <https://doi.org/10.1051/MATECCONF/201927401001>.
- [136] E. Caballero, W. Sánchez, C.A. Ríos, "Synthesis of geopolymers from alkaline activation of gold mining wastes." *Ingeniería y competitividad*, vol. 16, no. 1, pp. 317-330, 2014, [http://www.scielo.org.co/scielo.php?script=sci\\_S0123-30332014000100028](http://www.scielo.org.co/scielo.php?script=sci_S0123-30332014000100028) (accessed July 22, 2023).
- [137] P.H.R. Borges, F.C.R. Ramos, T.R. Caetano, T.H. Panzerra, H. Santos, "Reuse of iron ore tailings in the production of geopolymer mortars," *REM - International Engineering Journal*, vol. 72, pp. 581–587, 2019, <https://doi.org/10.1590/0370-44672017720169>.
- [138] M. Falah, R. Obenaus-Emler, P. Kinnunen, M. Illikainen, "Effects of Activator Properties and Curing Conditions on Alkali-Activation of Low-Alumina Mine Tailings," *Waste Biomass Valorization*, vol. 11, pp. 5027–5039., 2020, <https://doi.org/10.1007/S12649-019-00781-Z/FIGURES/10>.
- [139] L.R. de Rezende, J.C. de Carvalho, "The use of quarry waste in pavement construction," *Resources Conservation and Recycling*, vol. 39, pp. 91–105, 2003, [https://doi.org/https://doi.org/10.1016/S0921-3449\(02\)00123-4](https://doi.org/https://doi.org/10.1016/S0921-3449(02)00123-4).
- [140] J. Kiventerä, I. Lancellotti, M. Catauro, F.D. Poggetto, C. Leonelli, M. Illikainen, "Alkali activation as a new option for gold mine tailings inertization," *Journal of Clean Production*, vol. 187, pp. 76–84, 2018, <https://doi.org/10.1016/J.JCLEPRO.2018.03.182>.
- [141] J. Valentin, J. Trejbal, V. Nežerka, T. Valentová, M. Faltus, "Characterization of quarry dusts and industrial by-products as potential substitutes for traditional fillers and their impact on water susceptibility of asphalt concrete," *Construction and Building Materials*, vol. 301, pp. 124294, 2021, <https://doi.org/https://doi.org/10.1016/j.conbuildmat.2021.124294>.
- [142] Y. Jun Du, B. Wei Yu, K. Liu, N. Jun Jiang, M.D. Liu, "Physical, hydraulic, and mechanical properties of clayey soil stabilized by lightweight alkali-activated slag geopolymer," *Journal of Materials in Civil Engineering*, vol. 29, no. 2, pp. 0401621, 2017, <https://ro.uow.edu.au/eispapers1/2010> (accessed August 23, 2023).
- [143] A. Çevik, R. Alzebaree, G. Humur, A. Niş, M.E. Gülşan, "Effect of nano-silica on the chemical durability and mechanical performance of fly ash based geopolymer concrete," *Ceramic International*, vol. 44, pp. 12253–12264, 2018, <https://doi.org/10.1016/J.CERAMINT.2018.04.009>.
- [144] C. Balegamire, B. Nkuba, P. Dable, "Production of gold mine tailings-based concrete pavers by substitution of natural river sand in Misisi, Eastern Congo," *Clean Engineering Technology*, vol. 7, pp. 100427, 2022, <https://doi.org/10.1016/J.CLET.2022.100427>.
- [145] A.E. Kurtoglu, R. Alzebaree, O. Aljumaili, A. Nis, M.E. Gulsan, G. Humur, A. Cevik, A.E. Kurtoglu, R. Alzebaree, O. Aljumaili, A. Nis, M.E. Gulsan, G. Humur, "Mechanical and durability properties of fly ash and slag-based geopolymer concrete." *Advances in concrete construction*, vol. 6, no. 4, pp. 345, 2018, <https://doi.org/10.12989/ACC.2018.6.4.345>.