

Research

## Petrography and geomechanical properties of some mine waste rocks from the Tarkwaian Group in Ghana: implications for their use as aggregates in general engineering works

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### Abstract

This research investigated some mine waste rocks from the southwestern part of the Tarkwaian Group in Ghana to check their suitability for general engineering works using petrography and geomechanical characteristics of the rocks. The rocks were subjected to a total of ten (10) tests, including Aggregate impact value (AIV), Aggregate crushing value (ACV), Loss Angeles abrasion (LAA), Specific gravity (SG), and Water absorption (WA), as well as flakiness and elongation index, slake durability (SD), chloride test (CT), sulphate test (ST), and ten percent fines (TPF). The tests were carried out per the American Society for Testing and Materials guidelines (ASTM). The following average test results were obtained: AIV (7.12%), ACV (15.60%), LAA (23.16%), TPF (269.7 kN), sulphate (0.0215%), chloride (0.00123%), flakiness (39.5%) and elongation (39.4%). The mine waste rocks are dominated by quartz and sericite, according to the petrographic examination and thus, can be classified as quartzites. Except for the flakiness and elongation index tests, all the results were consistent with the ASTM standards. The analysis carried out on the selected mine waste rocks from the southwestern part of the Tarkwaian Group could be catastrophic for heavy engineering works such as roads, bridges, and heavy buildings but can be used for pavements, lightweight buildings, monuments, and decoratives due to the percentage of quartz present to compensate for the weakness posed by the sericite.

**Keywords** Mine waste rocks · Quartzite · Petrography · Geomechanical properties · Aggregate · Tarkwaian group

## 1 Introduction

The Tarkwaian Group is located within the Kumasi and Cape Coast basins of Ghana. This system hosts some of the major gold-producing companies in the world due to its mineral resources and unique geological succession [45]. These companies have stimulated economic growth and spurred infrastructural development, which has elevated the demand for raw materials (aggregates and binders) [1]. Although the companies contribute massively to the country's GDP, the solid waste generated is more than what the land can accommodate [24].

Mine waste is one of the world's major waste streams, and it can contain considerable amounts of hazardous compounds resulting from the extraction and processing of mineral resources [47]. At the United Nations Earth Summit in 1992, one of the major difficulties in maintaining the quality of the Earth's ecosystem was highlighted as environmentally sound waste management. At the World Summit on Sustainable Development in 2002, governments underlined the

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necessity of solid waste management. They urged that waste prevention, reduction, reuse, and recycling be prioritized [28, 42].

According to Hammond [29], Ghana has 136 million tons of mine waste rocks covering 1090 km<sup>2</sup> that are chemically and mineralogically suitable for engineering work. Influences drawn from a yearly output of 20 000 million tons over 35 years may infer that Ghana today has 137 million tons of mine waste covering a total land area of 2199 km<sup>2</sup>. Several mitigation methods (waste prevention, minimization, reuse, and recycling) have been implemented. The benefits of reusing mine waste can be described as follows: reduced pollution, energy savings, and natural resource conservation. This reuse approach can reduce the volume of mine wastes disposed of on the surface, alleviate their associated environmental problems, reduce restoration costs, allow for the creation of economic benefits, reduce the level of damage to the natural landscape caused by quarries and sandpits, and facilitate the production of common raw materials [24, 34, 35, 51]. Mine wastes present certain oppressing challenges which inhibit their utilization, especially in the construction sector. These include mine waste transportation, haulage costs, and haulage distances [8, 29]. Other minor drawbacks include the variety of waste materials, as well as the likelihood of soluble compounds leaching into rivers and agricultural areas, contaminating water, and ruining fertile agricultural land [8, 30, 50]. Although they have several limitations, their benefit is outrageous, provided proper safety protocols and best waste management practices are observed. In order to utilize the rock wastes in the construction sector, they need to be broken down into smaller sizes (aggregate) and tested for both mineralogical and geotechnical properties [43]. Aggregates are rock fragments that can be utilized in building projects in their innate state or after mechanical processing such as sizing, crushing, and washing [43, 50, 53]. To make concrete, mortar, or asphalt, sand, gravel, and crushed stone aggregates are typically blended with a binding medium such as cement or bitumen [22, 33]. They also supply the foundation for paved roads (base and sub-base), railroad ballast, rip-rap, road covering materials including asphalt and macadam, as well as unpaved road surfaces and water treatment filtering material [33].

In all, there is enough affirmation that some mine waste rocks can be used in engineering projects. Therefore, the goal of this study is to evaluate the petrographic and geomechanical properties of mine waste rocks in the southwestern part of the Tarkwaian Group in Ghana, which will provide information on the suitability of the mine waste rocks for general engineering purposes. In this regard, petrographic results and geomechanical properties will be compared with the American standards for general engineering purposes.

## 2 Study area

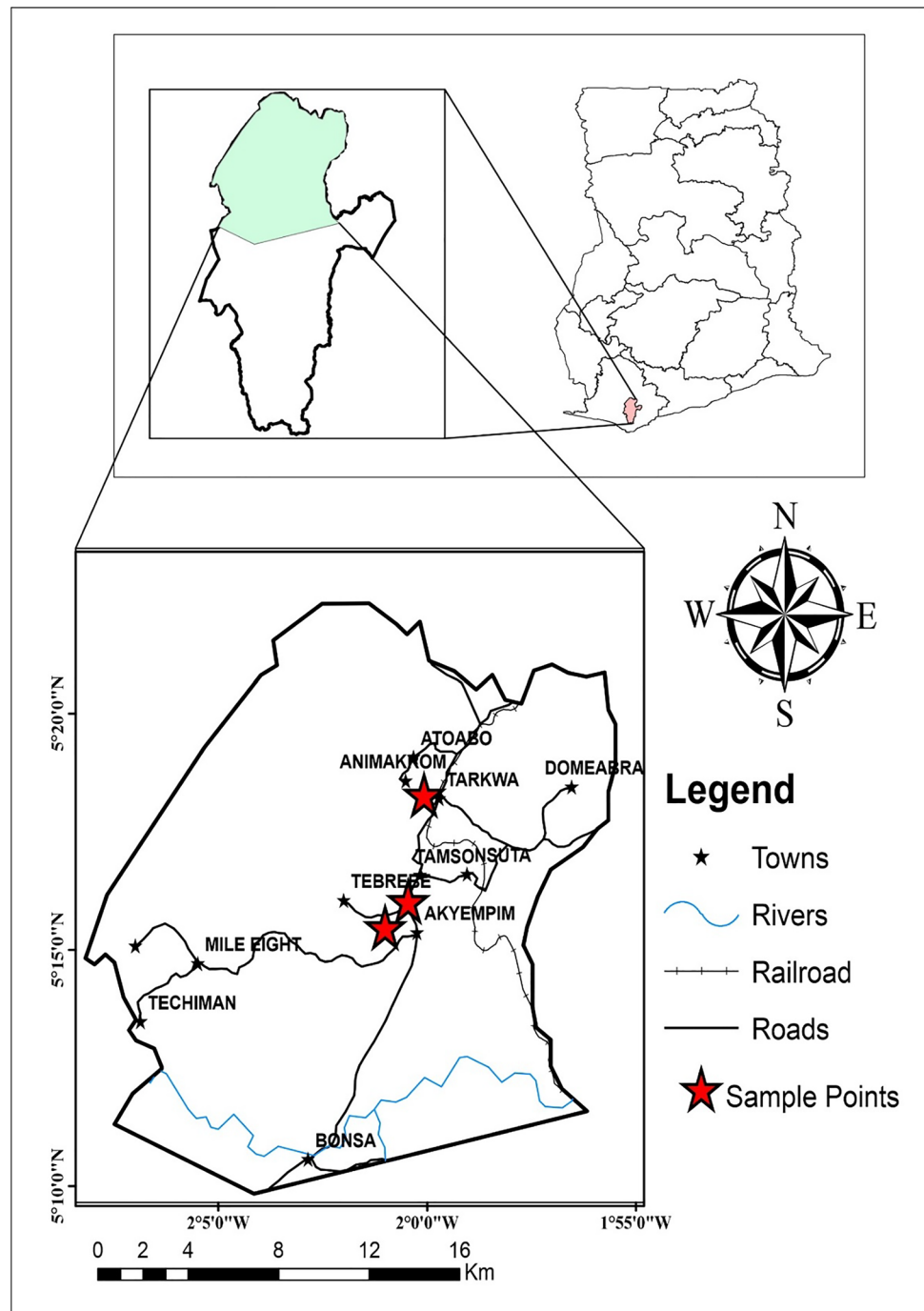
### 2.1 Location and topography

The study area is located in the Tarkwa-Nsuaem Municipality in southwestern Ghana (Fig. 1), some 310 km away from Accra by car. It is located on latitude 5°18'23" N and longitude 1°59'5" W [4]. It is roughly 70 km north of Takoradi's coastal metropolis and 10 km southwest of the Gold Fields Tarkwa Mine [4]. To the north, it is bordered by Prestea Huni-Valley, to the south, Ahanta West; to the west, Nzema East; and to the east, Mpohor Wassa. Tarkwa is the capital of the municipality, which has a total population of 34,941 people and a total land area of 905.2 km<sup>2</sup> [4]. Precambrian rocks of the Birimian and Tarkwaian formations underpin the forest dissected plateau [6, 32]. The ground rises from 240 to 300 m above sea level. The terrain is mostly undulating, with a few scarps rising between 150 and 300 m above sea level [4]. It has a consistent temperature, ranging between 26 and 32 °C between August and March, respectively [3, 40, 41]. The average annual precipitation of the area is extremely high as compared to other parts of the country and is between 400 and 1680 mm [41]. The stature of trees in the area ranges from 15 to 40 m high, they are characterized by wide crowns, climbers, and lianas, which can venture into the upper tree layer [4].

### 2.2 Geological setting

The Tarkwaian Group is made up of meta-dolerite and clastic metasediments from the Proterozoic Era [32]. They are mostly found in the Tarkwa area of Ghana's southwestern region, where they form a NE-SW trending belt [25]. The belt stretches around 250 km from Axim to the edge of the Volta Basin near Agogo [32]. It is around 16 km wide. A stretch of the Bui Syncline corresponding to the Côte d'Ivoire borders at 8° N [32]. The other belt, which stretches from near Beposo in the Brong-Ahafo Region to Banda-Nkwanta in the Northern Region, is about 140 km long and 0.8 km wide [32]. The bottom strata of the Tarkwaian Group are made up of a thick succession of argillaceous and arenaceous

**Fig. 1** Location map of the study area



sediments (preponderantly arenaceous) [31]. The Tarkwaian Group is a shallow-water mainland system that is thought to have originated from the Birimian and cognate granites [31]. The rocks are thought to have originated in intracratonic basins that were flanked by granite-greenstone belts from the Birimian Supergroup [31]. The waste was deposited in a steep-sided basin full of freshwater by high-energy alluvial fans [32]. They constitute poorly sorted, coarse, young sediments with low roundness, which are typical of a braided stream. The Tarkwaian is posited to lay unconformably on the Birimian (Fig. 2), however, in certain spots, the metasedimentary Birimian and the Tarkwaian are inter-folded due to the post-Tarkwaian orogenic action [32]. Low-grade metamorphism has occurred in the Tarkwaian sediments, for example, middle greenschists to middle almandine-amphibolite facies [32]. Higher grades are uncommon and frequently occur in intrusive rocks. According to [7, 37], five phases of deformation, associated with thrust faults and dolerite sills, have occurred in the greenschist facies. The dominant minerals are chloritoid, sericite, calcite, limonite quartz chlorite, and

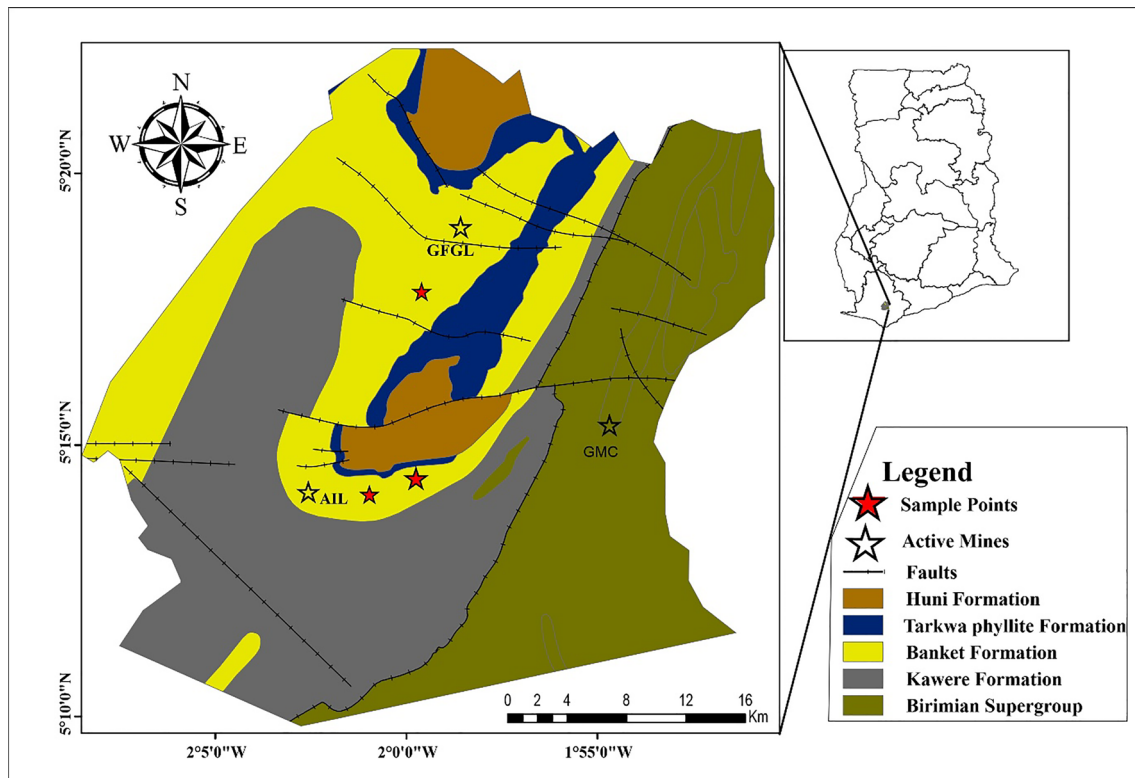


Fig. 2 Geological map of the study area

zoisite. From oldest to youngest, the Tarkwaian Group is divided into four strata: Kawere, Banket, Tarkwa phyllites, and Huni sandstone (Fig. 2 [31, 37]). The Tarkwaian Group represents a fluvatile series with a thickness varying between 120 and 600 m. Ankobra, Bonsa, and Huni streams and their various tributaries including Anoni, Sumin, Buri, and Ayiasu drain the area portraying a dendritic pattern [4, 37].

### 3 Methodology

#### 3.1 Sample collection

The reconnaissance survey was carried out in the rock waste dump, and a total of 100 kg of representative samples were collected. The samples were carefully packed in sample bags with their unique identification numbers and conveyed to the Petrological and Geotechnical Laboratories of the University of Mines and Technology, Tarkwa, Ghana for testing.

#### 3.2 Hand specimen description and thin sections

To establish the modal percentages of minerals, representative samples were collected and evaluated with the hand lens. Following the ASTM: C294-98 requirements, thin section and hand specimen descriptions were employed to understand the mineralogical composition of the aggregates. Under a microscope, rock slides were examined to identify the characteristics of the minerals that made up the rocks. In most cases, a chemical analysis of a mineral is not required to determine its identity [39]. For some minerals, certain qualities are diagnostic. The petrographic study was then performed on two thin sections. To determine the constituent rock-forming minerals, a petrographic investigation of the two thin sections was performed using the Leica DM 2700 Research Microscope's transmitted light operations. Minerals were discovered using the microscope's crossed Nicol and plane-polarized light modes to determine their optical characteristics such as crystal shape, habit, cleavage, hardness, luster, color, streak, specific gravity (density), pleochroism, extinction (angle), birefringence, interference color, and twinning. Mineral modal abundances were calculated using standardized charts [2].

### 3.3 Geotechnical laboratory tests

In this study, a total of four test work samples were used for all the geotechnical laboratory tests. The four samples have similar mineralogy based on the petrographic studies. It is worth mentioning that four samples were used because of the unified lithology in the mine waste rocks in the study area.

#### 3.3.1 Aggregate impact value test (AIV)

The American Society for Testing and Materials (ASTM) D5874-16 was used to conduct the AIV test [18]. A total mass of 1 kg of dry aggregate was employed, which passed through a 14 mm BS sieve and was retained on a 10 mm BS sieve. Three equal layers of aggregate were stuffed into a cylindrical cup, and each layer was tamped 25 strokes with the rounded end of the tamping rod, and the surplus aggregate was struck off with the tamping rod as a straight edge. To the nearest gram, the total weight of aggregate in the cylindrical steel cup was calculated ( $M_0$ ). The cup was firmly mounted at the bottom of the machine. A continual process of elevating the hammer until its lower face was 380 mm above the cup and allowing it to fall freely on the sample, a total of 15 blows were delivered. The crushed aggregate was taken out of the cup and sieved using a 2.36 mm BS sieve for one minute until no more substantial amounts passed. The fraction of the sample that passed through the sieve was weighed to a precision of 0.1 g ( $M_1$ ). Using the same approach, the test was repeated on a second sample. Using equation one, the average of the two values was recorded as the total impact value of the tested substance.

$$AIV = \frac{M_1}{M_0} \times 100 \quad (1)$$

where,  $M_0$  = mass measured aggregates.

$M_1$  = mass of aggregate passing through the BS 2.36 mm sieve.

#### 3.3.2 Aggregate crushing value test (ACV)

The ASTM C131M-20 [13] was used as the standard by which the ACV test was done. A 3 kg of dry aggregate passed a 14 mm BS sieve and was retained on a 10 mm BS sieve. A cylindrical steel cup was stuffed in 3 equal layers of aggregate and each layer was tamped 25 strokes by the rounded end of the tamping rod and the surplus aggregate detached, using the tamping rod. The net weight of aggregate in the cylindrical steel cup was recorded to the nearest gram ( $M_0$ ). The surface was leveled and the plunger was inserted so that it rested horizontally on the surface. The entire assembly was then placed between the testing machine's platens and loaded at a consistent rate to achieve a load of 400 kN in ten minutes. The load was then released, and all aggregate was removed from the cup and sieved through a 2.36 mm BS sieve for one minute until no more substantial amounts passed. The proportion that passed through the sieve was weighed to an accuracy of 0.1 g ( $M_1$ ). Using the same approach, the test was repeated on a second sample. The average of the two results was recorded as the aggregate crushing value of the tested material, using Eq. (2).

$$ACV = \frac{M_1}{M_0} \times 100 \quad (2)$$

where  $M_0$  = mass measured aggregates.

$M_1$  = mass of aggregate passing through the BS 2.36 mm sieve.

#### 3.3.3 Loss Angeles abrasion test (LAA)

The ASTM C 131 [19] was the reference in undertaking the LAA test. A 5000 g ( $M_0$ ) of washed and oven-dried aggregate was passed through a 14 mm BS sieve and was retained on a 10 mm BS sieve. The samples were poured into a large rotating drum of the Los Angeles machine and 12 steel balls were added to it. The drum was subjected to the rotation for 500 revolutions at a constant speed of 30–33 rpm. Upon the test, the entire aggregate dust was discharged and sieved on a 1.70 mm BS sieve. The material retained on the 1.70 mm BS sieve was washed, oven-dried at 105–110 °C to substantially constant mass, weighed to the nearest gram, and denoted  $M_1$ .

The test was repeated for a second sample and the mean was taken as the LAA value. LAA is calculated by using Eq. (3).

$$\text{LAA} = \frac{M_1}{M_o} \times 100 \quad (3)$$

where  $M_o$  = total mass of measured aggregates.

$M_1$  = mass of aggregate passing through the BS 1.70 mm sieve.

### 3.3.4 Specific gravity and water absorption (SG and WA)

This test was carried out in compliance with ASTM C 127-15 [11]. The samples were quartered and coned before being placed in a container. After that, the containers containing the samples were filled halfway with distilled water and left to soak for 24 h. The containers were then filled to the brim after 24 h, and the mass of the container(s), sample, and water was taken and labeled 'B'. The aggregates were collected and cleaned with a dry clean cloth, and the mass of the saturated dry sample was taken and marked 'A'. The saturated dry sample was oven-dried for four hours, and the empty container(s) were refilled to the brim with distilled water, with the mass denoted 'C'. The samples were removed from the oven after four hours, and the mass was measured and labeled 'D'. Specific gravity and water absorption were calculated with Eqs. (4 and 5).

$$\text{SG} = \frac{D}{A - (B - C)} \times 100 \quad (4)$$

$$\text{WA} = \frac{A - D}{D} \times 100 \quad (5)$$

### 3.3.5 Chloride and sulphate tests (CT and ST)

The chloride and sulphate tests were conducted in harmony with the ASTM C1152 [12] and C1580 [14], following the same procedure. A total of 300 g undersize representative sample was collected after passing it through 4.75 mm. It was then pulverized to pass the 425  $\mu\text{m}$  sieve. The pulverized material was oven-dried and cooled in a desiccator to a temperature of  $60 \pm 5$   $^{\circ}\text{C}$  and  $25 \pm 3$   $^{\circ}\text{C}$  respectively. A total of 30 g of the pulverized sample was transferred into a clean 400 mL beaker. Then 300 mL of deionized water was added, stirred, and covered with a watch glass. The sample was heated to  $(66 \pm 11)$   $^{\circ}\text{C}$  using a hot plate and stirred regularly. The leaching volume was maintained at 300 mL by adding deionized water. The sample was removed from the hot plate after 16 h. The sample was filtered through a filter paper by the decantation process. The solution was allowed to cool to  $(25 \pm 1)$   $^{\circ}\text{C}$  after which the solution was filled to the mark with deionized water. A sample of the solution obtained was sent to an external laboratory for chloride and sulphate ion chromatography analysis.

### 3.3.6 Ten percent fines test (TPV)

The Ten Percent Fines (TPF) test is a modification of the ACV test [15]. The TPF value represents the load required to produce a 10% loss in weight of the initial sample. The test was conducted with the same apparatus used for the ACV test, but with a maximum load that produced a percentage of sieves between 7.5 and 12.5%. Two trials were required and the load which gave 10% fines was calculated and reported. The load required to give 10% fines (F) is given by Eq. (6).

$$F = \frac{(14 \times f)}{(m + 4)} \times 100 \quad (6)$$

where;  $f$  = maximum load applied.

$m$  = actual percentage of fines.

### 3.3.7 Slake durability test (SDT)

The chain of custody forms was filled out, sample fragments were placed in the drum, and the test was weighed according to ASTM D4644 [16]. The drum, together with the sample fragments, was dried in the oven for 16 h before being weighed

after cooling for 20 min at room temperature. The natural water content of the trough was determined, and the drum was put in the trough and connected to the motor. The trough was filled to 20 mm (0.8 inches) below the drum axis with distilled water at room temperature and revolved at 20 rpm for 10 min. The water temperature was measured before and after the run. After the rotation period was completed, the drum was withdrawn from the trough and the lid was taken from the drum. The drum and sample were dried in the oven for 16 h at 105 °C. The drum and sample were weighed after cooling to obtain the oven-dried mass for the second cycle. To determine the mass of the drum, it was brushed, cleaned and weighed. The natural moisture content and the slake durability index was calculated using Eqs. (7) and (8), respectively.

$$W = \frac{(A - B)}{(B - C)} * 100 \quad (7)$$

where;

w = percentage of water content.

A = mass of drum plus sample at natural moisture content (g).

B = mass of drum plus oven-dried sample before the first cycle (g).

C = mass of drum (g)

$$I_d(2) = \frac{WF - C}{B - C} * 100 \quad (8)$$

where;

$I_d(2)$  = slake durability index (second cycle).

B = mass of drum plus oven-dried sample before the first cycle, (g).

$W_F$  = mass of drum plus oven-dried sample retained after the second cycle, (g).

C = mass of drum, (g).

### 3.3.8 Flakiness and elongation test (FI and EI)

This test was performed following ASTM D-4791 [17]. The order of arrangement of the BS sieves was, (63–50) mm, (50–37.5) mm, (37.5–28) mm, (28–20) mm, (20–14) mm, (14–10) mm, and (10–6.30) mm. A sample of unknown mass was obtained, quartered, and sieved through the sieves to obtain a representative sample. After sieving, the mass retained on each sieve size was passed through the corresponding slots on the elongation gauge. The samples used for the elongation gauge were passed through the flakiness gauge and the particles retained and those passing put together and their corresponding masses taken. These tests were repeated and the average was taken to be the flakiness index (FI) and elongation index (EI) using Eqs. (9) and (10), respectively.

$$FI = \frac{\sum \text{masses passing through individual slots}}{\text{total sample}} * 100 \quad (9)$$

$$EI = \frac{\sum \text{masses retained on each slot}}{\text{total sample}} * 100 \quad (10)$$

## 4 Results and discussion

### 4.1 Petrography

The optical and macroscopic studies were performed on the aggregates to show the relationship between the petrographic and the geomechanical properties. Table 1 shows the results obtained from the petrographic studies. The primary mineral in the samples is quartz and the secondary minerals were sericite and ore minerals. Some reasonable percentages of sericite and quartz were observed under plane-polarized light (PPL) and crossed polarized light (XPL) with values ranging from 15 to 50% and 50 to 80%, respectively (Table 1; Fig. 3a–f). The analysis shows no significant chloride and sulphate content. Based on the mineralogical composition, the rock type for the mine waste rocks is feldspathic quartzite.

Metasedimentary rocks are typically formed by a complex mixture of minerals and it is uncommon to find them have a homogeneous mineralogical composition [48]. It is even more complex when the rock undergoes varying degrees of alteration due to the everchanging geological processes of the earth [48]. This might be the reason for the heterogenous mineralogical composition of the studied mine waste rocks, which show alteration of the primary feldspars to sericite.

Hydrothermal alteration affected the mine waste rocks and it appears that quartz was present before the incursion of the hydrothermal fluid, which transformed the feldspars into sericite. The low water absorption ability is explained by the lack of microfractures [21, 46], and a large amount of sericite led to the high flakiness and elongation test results in the section of the geomechanical properties of the rocks. The AIV, ACV, LAA, SG, slake durability test, ten percent fines, and soundness values were influenced by the proportion of quartz in the samples.

## 4.2 Aggregate impact value test

In comparison to the ASTM D5874-16 Standard, the average aggregate impact value for the rock sample was 7.12%, which is lower than the maximum allowable limit value (12%). This shows that the rock is resistant to impact load making it a good aggregate for road and other heavy engineering works (Table 2). Quartz and opaque minerals have high strength compared to micas. The low AIV value thus indicates the presence of hard minerals like quartz and with its influence, the resistance of the aggregate to impose load was within the acceptable standards.

## 4.3 Aggregate crushing value test

The ACV is a strength parameter performed on aggregates to measure the percentage of fines generated when subjected to a uniformly increasing force to achieve a maximum value of 400 kn in 10 min. The maximum permissible limit value for the ACV test is 30% as documented in the ASTM C131M-20 Standard. The average ACV value obtained from the rock samples falls within the standard with an average value of 15.60% (Table 3). Since the value is less than 20%, this indicates that the samples have high resistance to crushing under gradually applied compressive load. If the ACV is greater than 35%, the aggregate is too weak for most building applications [44]. For highway pavements, materials with low aggregate crushing values are often preferred to be used in highway pavements [36]. Aggregates with a value less than 10% are considered very strong, values between 10 and 20% are considered strong and values between 20 and 30% are just good enough for roadstone [36]. The results are consistent with the petrographic studies as quartz dominates most of the samples.

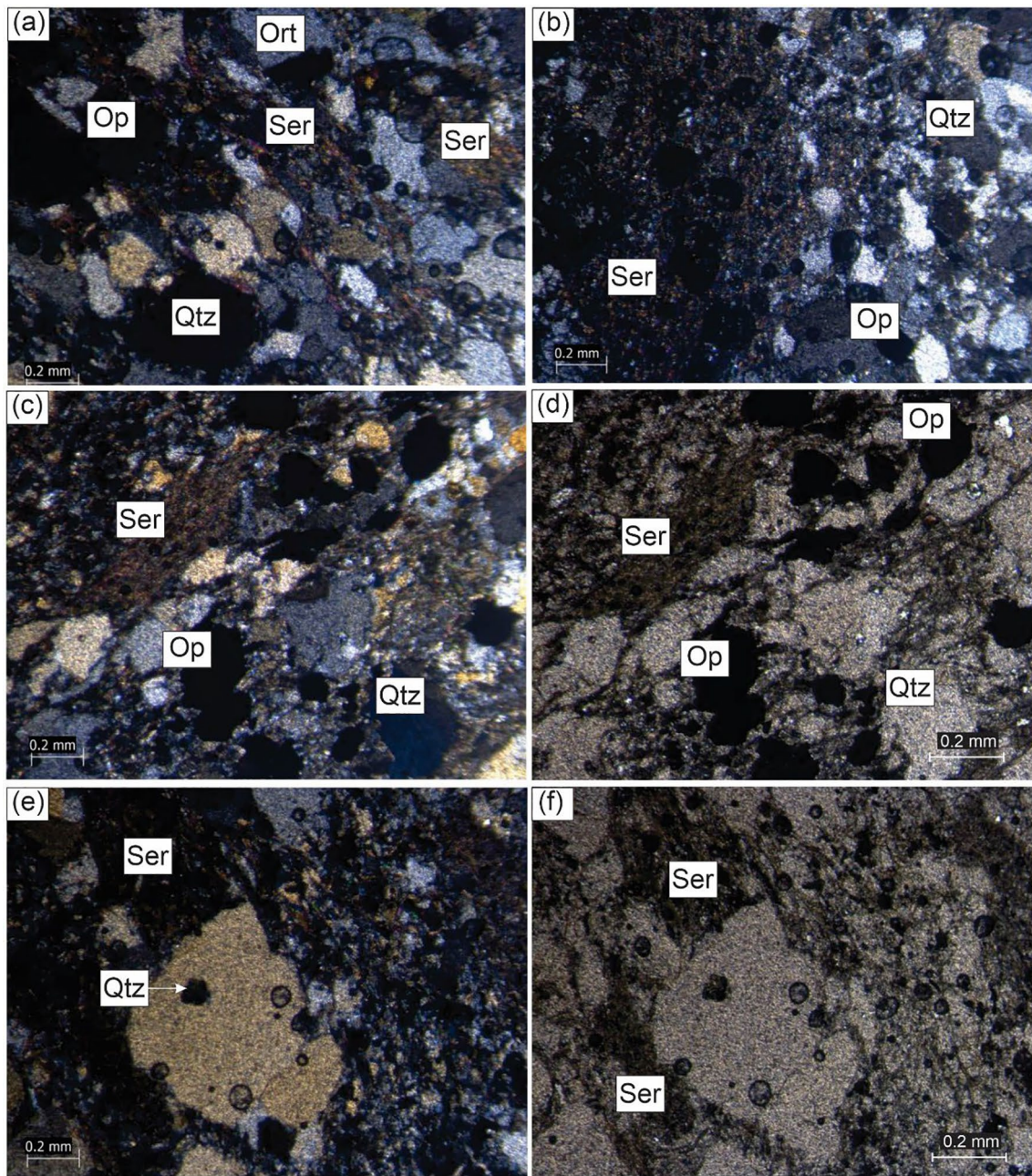
## 4.4 Specific gravity and water absorption test

Table 4 shows that the specific gravity and water absorption test results for the rock samples were 2.79 and 0.18%, respectively. The ASTM C127-15 Standard specifies that aggregate for engineering work must have specific gravity values ranging from 2.5 to 3.0 and a water absorption value of not exceeding 2.50%. The higher the SG value, the tougher the aggregates, and their resistance to abrasion and alteration, as well as their ability to withstand the effects of seasonal weathering [2]. On the other hand, the low water absorption value indicates that the pore spaces between them are very small and less susceptible to weathering showing how authentic the aggregate will be for engineering works [23, 47, 52]. Like the petrographic studies, minimal fractures were recorded on the microscopic level, which correlates with the low water absorption values in the analyzed samples.

**Table 1** Petrographic analysis of individual analyte points in thin sections

Item	Analyte points	Constituent minerals (Modal %)			
		Quartz	Sericite	Opaque	Total
A	MS 1-001	73	20	8	100
B	MS 1-002	80	18	2	100
C	MS 1-003	75	25	–	100
D	MS 1-004	68	25	12	100
F	MS 2-005	50	50	–	100
G	MS 2-006	60	35	5	100
H	MS 2-007	60	40	–	100





**Fig. 3** Photomicrograph images showing the abundance of sericite, quartz and opaque minerals in **a-c** under crossed polars and in **d-f** in XPL and PPL (Qtz Quartz, Ort Orthoclase, Ser Sericite, Op Opaque)

**Table 2** Summary of aggregate impact value (AIV) results

Number of tests	The initial mass of sample (g)	Final mass of sample	Mass passing (g)	Percentage loss in the sample (%)
1	679.50	630.50	49.0	7.21
2	678.70	632.90	45.80	7.24
3	658.80	612.00	46.0	6.99
4	669.00	622.0	47.0	7.03
Average AIV				7.12

**Table 3** Summary aggregate crushing value (ACV) results

Number of tests	The initial mass of sample (g)	Final mass of sample	Mass passing (g)	Percentage loss in the sample (%)
1	2732.5	2326.0	406.5	14.90
2	2813.0	2366.0	447.0	15.89
3	3000	2528.0	476.0	15.87
4	3000	2524	472.0	15.73
Average ACV				15.60

#### 4.5 Chloride and sulphate test

The chloride and sulphate content determination yields values of 0.00123 and 0.0215%, respectively (Table 5). According to the ASTM C1152, aggregates to be used for engineering works shall not contain chloride salt of more than 0.04%. Chloride salt in the presence of moisture can cause rapid corrosion of the reinforcement bars within the concrete, leading to expansive rusting of the reinforcement steel and subsequent deterioration of the concrete [9, 26]. The effect of sulfate above the stipulated value is synonymous with chloride [35]. The average value obtained for sulphate is less than 0.80% (Table 5), making the samples suitable for engineering works [10, 26]. The petrographic results reveal that there was no chloride- and sulphate-bearing minerals, which might be attributed to the very low chloride and sulphate values.

#### 4.6 Ten percent fines test

The ten percent fine test was performed on representative portions of dry rock aggregates. This test was performed following the ASTM C131M-20 Standard. At the end of the test, the force required to produce a ten percent fine of the total mass used was 269.7 kN. The minimum force required by the ASTM C131M-20 Standard is 110 kN. The results from Table 6 prove that the samples require a substantial force to produce 10% fines aggregate. The petrographic studies have similar mineral assemblage (quartz, sericite, and opaque) with different ratios. However, the difference in ratios had little to no influence on the results considering the correlation among the four trials.

**Table 4** Summary of specific gravity (SG) and water absorption (WA) results

Number of trials	1	2	3	4
Mass of vessel (g)	45.00	45.00	45.00	44.5
Mass of vessel + sample + water (S)	802.0	797.0	1015	885.0
Mass of vessel + water only (T)	614.0	614.0	618.0	622.5
Mass of saturated dry sample (V)	292.5	284.5	419.0	409.0
Mass of oven dry sample (Q)	292.0	284	418.2	408.3
Specific gravity $Q/[V-(S-T)]$	2.79	2.80	2.79	2.79
Water absorption $(V-Q)/Q*100$	0.17	0.18	0.19	0.17

\*The average SG and WA is 2.79 and 0.18%, respectively

**Table 5** Summary of chloride and sulphate contents

Number of tests	Chloride content (%)	Sulfate content (%)
1	0.00125	0.0215
2	0.00120	0.0213
3	0.00122	0.0216
4	0.00124	0.0215
Average	0.00123	0.0215

**Table 6** Summary 10% fines value results

Number of test	Applied force (kN)	Initial mass of sample (g)	Final mass of sample(g)	Mass passing (g)	ACV (%)	10% Fine value
1	290.311	2710.5	2410	300.5	11.1	269.163
2	290.311	2713.0	2415	298	11.0	269.009
3	290.311	2744	2545	304	11.1	269.5
4	290.420	2719.0	2420	299	11.0	271.02
Average						269.7

**Table 7** Summary of slake durability (SDT) results

Moisture content determination			
Sample trials		1	2
Mass of drum	g	1787	1782
Mass of drum + sample at natural moisture content	g	2191	2365.5
Mass of drum + oven-dried sample before the first cycle	g	2190.5	2365
Moisture content	%	0.124	0.086
Average moisture content	%	0.105	
Slake durability index			
Mass of drum + oven-dried sample before the first cycle	g	2201.5	2376.5
Mass of drum + oven-dried sample retained after the second cycle	g	2190	2363.5
Slake durability index	%	97.2	97.8
Average Slake durability index	%	97.5	

#### 4.7 Slake durability test

Table 7 shows the results of the slake durability test. The moisture content was also assessed throughout the test. Extremely high slake durability indexes range from 95 to 100 percent [27]. The aggregates have a slake durability value of 97.5%, indicating that they are extremely durable and can tolerate disintegration and weathering. The strength and durability of rock fragments are linked to the intensity of alteration and frictional resistance of the materials [20]. It could also be attributed to the abundance of quartz as observed in the photomicrographs since quartz is very resistant to weathering. Slake durability, a simulated form of physical weathering will depend on the constituents of the rock analyzed. Stable minerals like quartz have high resistance to atmospheric conditions hence, the reason for the 97.5% slake durability value for the studied samples. Although sericite was detected in the photomicrographs, its effect was limited to the resistance by the quartz and the opaque minerals making the rocks competent enough to withstand the action of abrasion in the presence of water.

#### 4.8 Los Angeles abrasion test

A representative portion of dry aggregates was subjected to the Los Angeles Abrasion Test. This test was carried out per ASTM C 131 on only the dry sample. The LAA measures the resistance of the aggregate to abrasion and attrition owing to wear and tear from friction between the tyres and aggregates and among the aggregates themselves. The average abrasion value is 23.19%, according to Table 8. Although the readings are within the ASTM C 131, threshold of 30%, they indicate that the aggregates have moderate resistance to crushing and traffic wear over time and are thus good for engineering works. This might be due to the percentage of quartz in the rocks as seen in the petrographic results. However, caution must be exercised on how to redress the possible effect of sericite due to its platy characteristics and weak strength.

## 4.9 Flakiness and elongation

The geometrical properties of the mine waste rocks were determined using the flakiness and elongation index. The average flakiness and elongation index obtained from the aggregates were 39.5 and 39.4%, respectively. According to the ASTM D-4791, it is stated that aggregates to be used for engineering works should not have flakiness and elongation value exceeding 25% of the entire mass used. The results obtained from Tables 9 and 10 indicate that the samples were flaky and elongated. This makes them more susceptible to breakage and their degree of perfect packing will be limited and cannot be used for heavy engineering works. Micaceous minerals with group name, phyllosilicates are flaky in nature. The presence of sericite in the feldspathic quartzite demonstrates the occurrence of sericitic alteration. The other test works above have limited influence of sericite, however this test rather confirms the presence of platy minerals in the petrographic studies. In essence, the values obtained from the flakiness and elongation tests were higher than the stipulated threshold values.

## 4.10 Suitability of the mine waste rocks for general engineering works

From all the test works conducted, it can be concluded the the mine waste rocks in the Tarkwaian Group of Ghana are gerrally suitable for engineering works (Table 11), but the high sericite content, which is as a result of alteration of feldspars in the rocks make them unsuitable for heavy engineering works. This resulted in high flakiness and elogation index values (Table 11).

Therefore, the overall, assessment of the samples selected from the mine waste rock dump in the Tarkwaian Group showed that they are weak to be used in massive works like heavy buildings, bridges, and roads but can be used for lightweight buildings, pavements, decorative, monuments due to the high percentage of quartz present to compensate for the weakness posed by the sericite. The samples can be mixed with laterites to form a stabilized material for base or sub-base depending on the intended use of the road.

**Table 8** Summary of Los Angeles abrasion (LAA) results

Number of tests	The initial mass of sample (g)	Final mass of Sample	Mass passing (g)	Percentage loss in the sample (%)
1	5000	3846.0	1154.0	23.08
2	5000	3840.0	1160.0	23.20
3	4989	3829.0	1160	23.25
4	5000	3839.0	1161.0	23.22
Average LAA				23.19

**Table 9** Summary of flakiness index (FI) results

Number of test	Sum of aggregate passing individual slot (M1) (g)	Sum of aggregate retain on individual slot (g)	Total sample used (M2)	Flakiness Index $FI = (M1/M2) * 100$
1	431.0	648.0	1079	39.9
2	417.5	646.5	1064	39.2
3	462.0	705.0	1167	39.6
4	397.5	620.5	1018	39.0
Average				<b>39.5</b>

**Table 10** Summary of elongation index (EI) results

Number of test	Sum of Aggregate passing individual slot (M1) (g)	Sum of aggregate retain on individual slot (g)	Total sample used (M2)	Elongation index $EI = (M1/M2) * 100$
1	406.0	622	1028	39.5
2	418.0	636	1054	39.7
3	418.0	649	1067	39.2
4	431.0	667	1098	39.3
Average				39.4

**Table 11** Comparison of the geomechanical test works on the mine waste rocks with their standards indicating the rock suitability/unsuitability for general engineering works

Test	ASTM standard value	Reference	Average Value (This Study)	Interpretation
Aggregate impact value (AIV)	10%	ASTM D5874-16 [18]	7.12%	Suitable
Aggregate crushing value (ACV)	30%	ASTM C131M-20 [13]	15.6%	Suitable
Specific gravity (SG)	2.5–3.0	ASTM C127-15 (2015)	2.79	Suitable
Water absorption (WA)	≤ 2.5%	ASTM C127-15 (2015)	0.18%	Suitable
Chloride (CT)	0.04%	ASTM C1152 [12]	0.00123%	Suitable
Sulphate (ST)	≤ 0.80%	ASTM C1580 [14]	0.0215%	Suitable
Ten percent fines (TPV)	≥ 110.0 kN	ASTM D1586-11 [15]	269.7 kN	Suitable
Slake durability index (SD)	95–100%	ASTM D4644 [16]	97.5%	Suitable
Los Angeles abrasion (LAA)	30%	ASTM C131M-20 [13]	23.16%	Suitable
Flakiness index (FI)	≤ 25%	ASTM D4791-05 (2005)	39.5%	Not suitable
Elongation index (EI)	≤ 25%	ASTM D4791-05 (2005)	39.4%	Not suitable

Moreover, the studied mine waste rocks can be used for surface dressing. Surface dressing is a type of surface treatment where single-sized rock aggregates, also known as "chippings," are layered over a thin layer of bitumen binder that has been sprayed onto the surface of crushed rock or gravel that has previously been prepared [5]. The four characteristics that determine aggregate acceptability for "chippings" are typically hardness, soundness, form, and cleanliness. As per the guidelines set forth by the Ministry of Transportation [38], "chippings" must be made of crushed rock that is shaped like a cube and devoid of any visible stone dust or dangerous materials like salt, clay, organic matter, or other items that could cause harm. Using the TFV and LAA tests, the aggregate strength (hardness and soundness) was determined in this investigation. Based on a review of Table 11, the TFV value is 269.7 kN. This value is higher than the minimal requirements specified by the MoT for surface treatment in Chipping Class 1, which is 210 kN but within the ASTM standard value (Table 11). The average LAA (23.16 %) satisfies surface dressing criteria. Therefore, the aggregates should be able to meet the requirements for "chippings" for surface dressing provided they are processed to obtain the necessary aggregate sizes.

## 5 Conclusions

The following conclusions were made from the results obtained from all the test works:

- i. The minerals observed under the petrographic microscope were stable minerals, which are good for engineering works. The opaque minerals in the aggregates are in minute concentrations, which means they have little to no impact when used for engineering works.
- ii. Chloride and sulphate test values were 0.00123 and 0.0215%, respectively, which were substantiated by the petrographic analysis. It was shown that no chloride and sulphate percentages were recorded, this indicates that the concrete will not deteriorate when used for civil engineering works.
- iii. The water absorption test performed gave a value of 0.18% and a specific gravity value of 2.79, respectively this shows that the sample is within the permissible limit, hence, is good for construction. The specific gravity (SG) and water absorption (WA) were also confirmed from the thin sections. According to Wesley and Egirani [49] the specific gravity of feldspathic quartzite ranges from 2.4 to 2.80 and water absorption ranges from 0.14 to 0.73%.
- iv. The ACV, AIV, LAA, and SD tests gave values of 15.60, 7.12, 23.16, and 97.5%. These values mean that the aggregates can withstand the gradual and impact load, have moderate strength, and can withstand abrasion, as well as withstand disintegration due to thawing and freezing.
- v. The 10% fines gave a load of approximately 269.7 kN. The value depicts that the aggregates require an appreciable force to reduce the total rock by ten percent and they are very strong.
- vi. Apart from the flakiness and elongation tests which had values (39.5 and 39.4%, respectively) greater than the maximum limit proposed by the ASTM, all other tests showed suitability of the mine waste rocks for general engi-

neering works. The higher flakiness and elongation index values were as a result of the higher percentage of sericite in the aggregate. The permissible value for general engineering works ranges from 20 to 30% depending on the conditions of the terrain in question. Therefore, the sericite which had a value of 15–50% could be the reason for the higher values obtained for the flakiness and elongation.

- vii. The overall, assessment of the samples selected from the mine waste rock dump in the Tarkwaian Group showed that they are weak to be used in massive works like heavy buildings, bridges, and roads but can be used for light-weight buildings, pavements, decorative, monuments due to the high percentage of quartz present to compensate for the weakness posed by the sericite. The samples can be mixed with laterites to form a stabilized material for base or sub-base depending on the intended use of the road.

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**Data availability** All data used in the study will be readily available to the public upon request to the corresponding author.

**Code availability** All software applications used in this study were the licensed software applications used by the University of Mines and Technology, Tarkwa, Ghana.

## Declarations

**Ethics approval and consent to participate** The authors declare that the submitted manuscript is original. Authors also acknowledge that the current research has been conducted ethically and all authors have agreed to the final shape of the research. Authors declare that this manuscript does not involve researching about humans or animals. The authors consent to participate in this research study.

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