https://doi.org/10.52763/PJSIR.PHYS.SCI.69.1.2026.22.28

Pak. j. sci. ind. res. Ser. A: phys. sci. 2026 **69A**(1) 22-28

Physico-Mechanical Investigation of Amphibolite and Fine Materials from Kaiigah Upper Kohistan, Khyber Pakhtunkhwa, Pakistan: Implications for Potential Aggregate Analysis

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(received May 22, 2024; revised March 6, 2025; accepted March 7, 2025)

Abstract. A study was carried out to evaluate the physical and mechanical properties of amphibolite located in the Kaiigah region of the upper Kohistan Dasu Dam area. The study aimed to explore its suitability as a source for aggregates and to evaluate its geotechnical performance. The region is mainly composed of amphibolite. The assessment included a comparison of physical properties against recognized standards to gauge their suitability for construction use. It was found that there is a strong direct correlation between water absorption rates and Los Angeles abrasion results. The analysis covered both fine and coarse aggregates, examining parameters such as specific gravity, Los Angeles abrasion, unit weight, sieve analysis, Proctor compaction, Atterberg limits and sand equivalent, in accordance with ASTM and British Standards. The findings were cross-referenced with ASTM and AASHTO standards to gauge aggregate quality. It was concluded that the amphibolites from Kaiigah meet the necessary criteria for specific gravity and Los Angeles abrasion, indicating their suitability for the local construction sector.

Keywords: amphibolite, geotechnical investigation, Kohistan, KP, Pakistan

Introduction

Geological materials have played a crucial role in construction for centuries. Natural aggregates are extensively used in various structures, such as buildings, civil engineering projects and infrastructure elements like roads, railways and runways. To determine the appropriateness of natural rocks for use as aggregates, their properties are evaluated against established national and international criteria (Koukis *et al*., 2007). Aggregates used in construction are generally classified into two main types: 1. Aggregates derived from hard rocks, such as those from igneous types like granite, dolerite and gabbro. 2. Aggregates obtained from sedimentary rocks, including sandstone and limestone, as well as metamorphic rocks such as gneiss and marble.

These materials are usually extracted through techniques like drilling, blasting and crushing in quarries. Sand and gravel aggregates come from loose sediments of river, lake or marine origins (Johnson and De Graff, 1988) and are collected using mechanical excavators. Both aggregate types undergo processes of washing and screening to comply with construction specifications. A comprehensive understanding of geology, extraction techniques and testing standards is essential to ensure the suitability of these materials for construction. Aggregates are categorized into quality grades such as poor, marginal or exceptional, based on the source material's properties, processing techniques and resulting engineering characteristics (Hartley, 1974). Exploring rock aggregates from the Kaiigah Chuchang region could address growing demands and reduce environmental impacts. This study aims to conduct a geotechnical evaluation of rocks in the Dasu Dam area to identify suitable coarse and fine aggregates for construction through geological assessments and standardized testing. The research focuses on evaluating the aggregates' quality by analyzing their physical and mechanical properties, identifying different rock types and determining their suitability through quality tests for both

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coarse and fine aggregates. Laboratory tests were performed to evaluate soil suitability for road aggregate material and additional testing provided data based on the physical properties of the rock and soil for designing effective earthworks. The primary objective is to assess the geological potential of the Kaiigah area and its appropriateness for the Dasu Dam project.

Materials and Methods

Rock samples of amphibolite and granulite were gathered from the Kaiigah region near the Dasu hydropower project. These samples were processed and evaluated following ASTM and British Standards. Physio-mechanical testing was conducted on the samples, with field density tests performed on finer materials directly at the site. The samples were sourced from well-exposed areas, representing a range of rock types found locally. After crushing, the materials underwent a series of tests. The sampling locations were chosen for their extensive exposure and were comprehensively examined, while amphibolites and granulites were the primary rocks studied, small quantities of diorite, gabbro and norite were also noted. The laboratory analysis was conducted at the CCECC (China Civil Engineering Construction Corporation) facility within the Dasu hydropower project, adhering to ASTM and AASHTO standard.

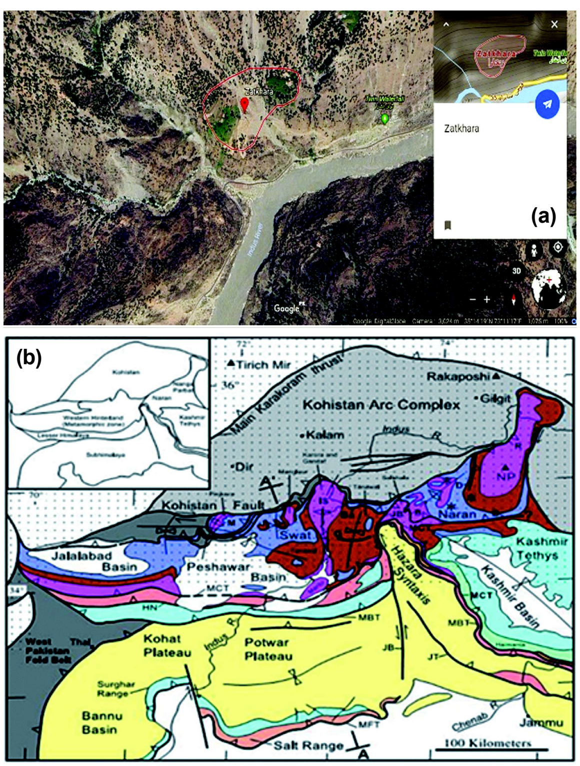

Fig. 1. **(a)** Showing the study area location where the Amphibolite's are exposed, **(b)** geological map of northern Pakistan showing different geological entities and study area (Modified after Anjum *et al*., 2018).

Geological context of the study area. The region under study is part of the Kohistan island arc located in northern Pakistan. This arc is bordered to the north by the Shyok suture, also known as the Main Karakorum Thrust (MKT) and to the south by the Indus suture or main mantle thrust (MMT). (Khan *et al*., 2007) describe the Kohistan sequence as a broad island arc system extending through both crustal and mantle layers. Kazmi and Rana (1982) further confirmed that this is an accreted island arc that underwent changes during the Himalayan orogeny. The MMT forms the southern and eastern boundaries of the Kohistan island arc, extending from the Shyok suture in the north to the Indus suture in the south (Fig. 1A). This arc extends eastward from Afghanistan through Swat to Babusar and northward from the Nanga Parbat-Haramosh massif to Ladakh, linking with the Indus suture zone (Jan and Howie, 1981).

The intra-oceanic crust of Kohistan consists of several geological units arranged from south to north: (i) the Jijal complex, (ii) the Kamila amphibolite, (iii) the Chilas complex with mafic to intermediate plutonic rocks, (iv) the Kohistan batholiths, (v) the Jaglott Group, (vi) the Chalt Volcan and (vii) the Yaseen Meta-sediment. The Kamila amphibolite, which traverses the southern arc from east to west, has been thoroughly examined in the Indus Valley (Treloar *et al*., 1996; Hanson 1989). This area features amphibolite-facies meta-plutonic and meta-volcanic rocks (Fig. 1B). Two types of amphibolite are present: fine- to medium-grained, either homogeneous or banded Eroðlu and Calik, (2023); Treloar *et al*. (1996). These amphibolites, originally formed from igneous processes, have undergone metamorphism resulting in mixed lithologies like gabbro and diorite in the Kaiigah area (Fig. 2). In this region, the Kamila amphibolites interact notably with the Chilas complex to the north, in contrast to the Jijal complex (Tahirkheli 1982). The region's varied lithology arises from metamorphic processes, including the presence of diorite and gabbro. The area is also marked by significant tectonic activity, including various faults, joints, cracks and shear zones. The Chilas complex mainly comprises gabbronorite and several ultramafic anorthosite bodies,

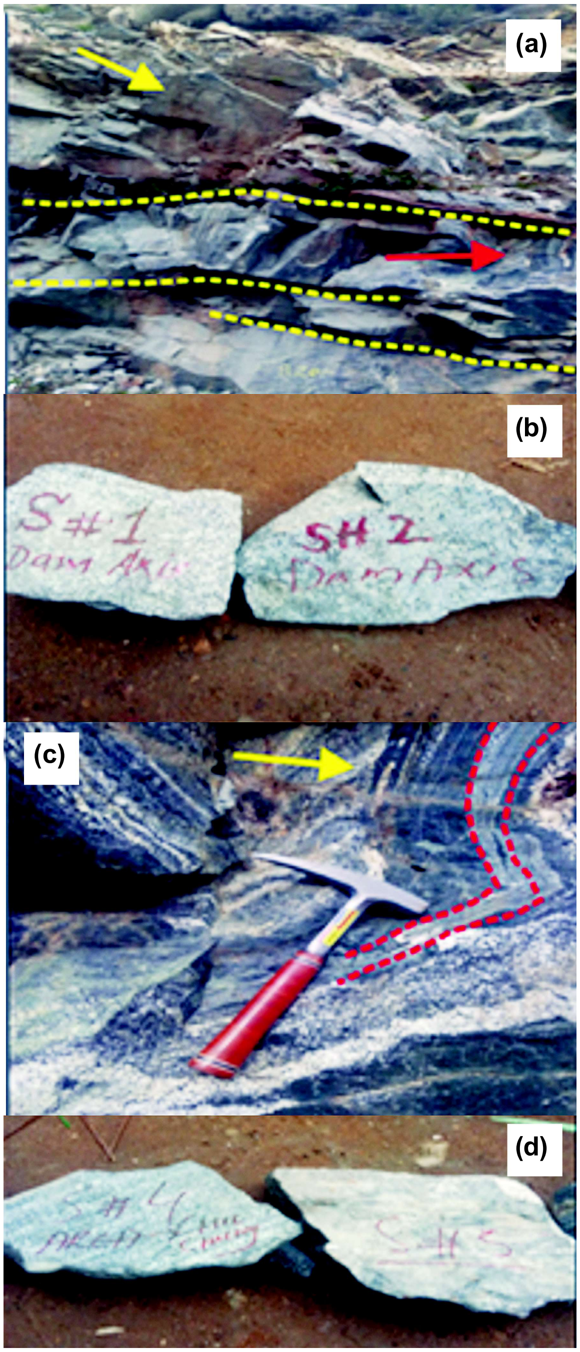

Fig. 2. Showing rocks sample (**b** and **d**) for different tests, (**a** and **c**) showing outcrop with weathering and fractures in Fig. **(a)** and micro folding in Fig. **(b)**.

with ultramafic rocks such as olivine-rich cumulates including dunite, wherlite and lherzolite and plagioclase being prevalent in the cumulate gabbro and gabbronorite.

Results and Discussion

Physical and mechanical analysis. To evaluate the suitability of construction aggregates for geotechnical projects, they are subjected to specific physio-mechanical tests. In this study, samples of both coarse and fine materials were selected for various tests. These tests were performed to determine the geotechnical feasibility of the aggregates. All testing procedures adhered to the standards specified in ASTM D-2419/AASHTO T-176 and ASTM C-535 (2003) (Malki *et al*., 2024).

Specific gravity and water absorption test. In physio-mechanical assessments of construction aggregates, specific gravity is crucial for evaluating the suitability of rock minerals. It is a key measure of their strength and quality, as noted by (Sajid *et al*., 2020; Smith and Collis, 2001). Specific gravity is determined by comparing the material's density to that of water, while water absorption indicates the amount of water the aggregates can retain. Typically, aggregates with lower specific gravity are considered weaker than those with higher values. Rocks with a specific gravity of 2.55 or higher are deemed suitable for heavy construction, suggesting that the rocks tested meet this standard and are fit for such projects Smith and Collis (2001). According to Table 1, the Kaiigah amphibolite's have a water absorption value of 0.3. The specific gravity of these rocks surpasses 2.55, affirming their suitability for heavy-duty applications. Furthermore, rocks with water absorption rates under 1% are highly resistant to weathering, showing minimal degradation from frost and chemical processes.

Proctor test. The Proctor test, developed by Ralph R. Proctor in 1933, assesses soil compaction properties, specifically identifying the optimal moisture content

Table 1. Showing results of the analyzed sample for specific gravity and water absorption

Description	Values
Size of material	Retain of 4 no sieve
Weight of oven dry sample in air (A)	2510.2 g
Weight of saturated surface dry sample in air (B)	2500.9 g
Saturated surface dry sample weight in water (C)	1600 g
Specific gravity bulk A/(B-C)	2.78
Specific gravity bulk SSD B/(B-C)	2.77
Specific gravity Apparent A/(A-C)	2.75
Absorption(B-A)A×100	0.39

needed to attain the maximum dry density of the soil. The main objectives of soil compaction include improving shear strength, decreasing compressibility, reducing permeability and controlling swelling and shrinkage (Rahn 1986). At the site, the compaction level assessed by comparing the actual dry density with the Proctor value as listed in (Table 2) and visualized this data through a plot moisture content *vs* maximum dry density in (Fig. 3).

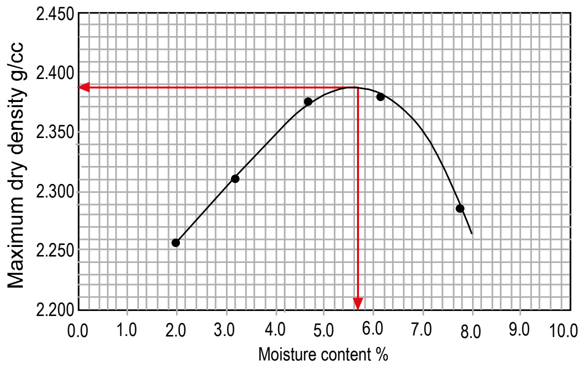

Fig. 3. Graph showing values for maximum dry density and optimum moisture content. Graph y-axis showing the values for dry density in which the maximum dry density point is 2.387 and the minimum point of dry density is 2.200 and x axis showing the values of of moisture content the optimum moisture content maximum point is 5.7.

Atterberg limits of fine aggregates. Atterberg limits are essential for assessing the moisture content in fine-grained soils. These tests are particularly significant for clay and silt, which experience volume changes with water absorption. The liquid limit represents the lowest moisture content at which the soil becomes liquid-like but resists flow minimally (Harrison, 1993). Conversely, the plastic limit is the moisture content, expressed as a percentage of the dry soil's weight, at which the soil begins to crumble when shaped into a thread as listed in Table 3 and clearly shown in Fig. 4.

Field density test of soil through the sand cone method. The sand cone method is a prevalent technique for measuring soil density in construction projects, especially highways. This test evaluates the dry density

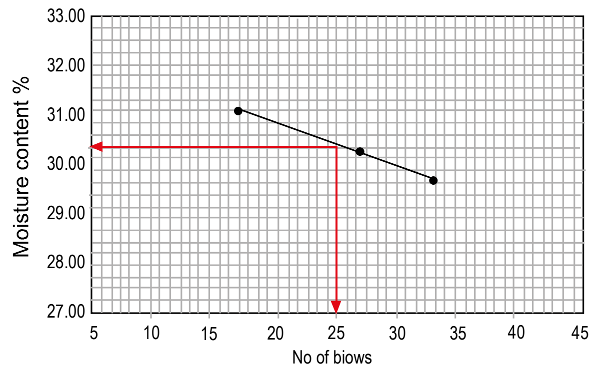

Fig. 4. Showing the overall results of liquid limit, plastic limit, plasticity index with number of blows.

Table 2. Showing results of proctor test

Description	Layer 1	Layer 2	Layer 3	Layer 4	Layer 5
Weight of wet soil+ mould	9205 g	9380 g	9595	9680 g	9550 g
Weight of wet soil	5105 g	5280 g	5495 g	5580 g	5450 g
Wet density Wet soil/v of mould	2.39 g/cm cube	2.384	2.485	2.525	24.64
Dry density Wet density/(m.c+100)100	2.257	2.310	2.374	2.379	2.286
Container	1	2	3	4	5
Weight of container	64.2 g	64.2 g	60.7	63.4	64.8
Weight of con+ wet soil	448.0 g	468.0	402.0	442.0	502.0
Weight of con+ dry soil	440.0 g	455.3	386.9	420.2	470.5
Weight of dry soil	376.3 g	394.6 g	323.5 g	355.5 g	4.4.7 g
Weight of water	7.5 g	12.7	15.1	21.8	31.5
M.C% weight of water	2.0%	3.2	4.7	6.1	7.8

Table 3. Showing Liquid limit and plastic limit results

Liquid limit Description	Unit	AASHTO T-89			Plastic limit AASHTO T-90	
Trial #	g	1	2	3	1	2
No of blows	g	17	25	33		
Dish no	g	24	34	4	37	45
Weight of dish with wet soil	g	39.92	44.7	42.29	22.49	24.19
Weight of dish with dry soil	g	35.46	39.59	38.10	22.3	24.5
Weight of dish	g	21.11	22.7	23.99	21.01	23.12
Weight of water	g	4.46	5.11	4.19	0.19	0.14
Weight of dry soil	g	14.35	16.89	14.11	1.29	0.93
Moisture content %	g	31.08	30.25	29.70	14.73	15.05
Final result						
Liquid limit	30.38					
Plastic limit	14.89					
Plasticity index	15.49					

of soil to ensure proper compaction. It involves field procedures where soil samples are extracted, weighed, dried and re-weighed to assess their moisture content as shown in Fig. 4 (Harrison, 1993).

Sieve analysis. This test is mainly conducted to assess the grading of materials intended for use, as aggregate gradation is crucial for aggregates in cement and asphalt concrete mixes. The grading affects the workability of the aggregates (Ramsay *et al*., 1974). Sieve analyses are vital in aggregate testing. These laboratory tests use specific ranges and sizes of aggregates, with results based on the amount of material passing through or retained by the designated sieves (Table 5).

Table 4. Showing the values of field density test through cone method

Mass of weight soil from hole	7040	6519
Mass of sand with bottle and cone before test	9081	9081
Final mass of sand	3601	3556
Mass of sand in plate and cone	5480	5525
Mass of sand in hole	3727	3772
Volume of sand in hole	2617	2649
Bulk density of wet soil(gm/cc)	2.6	2.461
Container no.	D	E
Mass of wet soil + container(gm)	948	857
Mass of dry soil + container	9.2	821
Mass of container	157.5	157.3
Mass of water	46	36
Mass of dry soil	744.5	663.7
Moisture con	6.1	5.4
Bulk density of dry soil	2.407	2.335
Relative density	102.3	99.2
	Pass	Fail

Sand gradation. Coarse aggregates used in concrete production consist of particles of different sizes, a distribution known as gradation. The gradation is established by sequentially passing a sample through a set of sieves arranged in decreasing order of size, with the largest sieve positioned at the top (Irfan, 1994). The results of the gradation analysis for the samples can be found in Table 6.

Loss angle abrasion test. To assess the toughness and longevity of crushed aggregates, the Los Angeles

Table 5. Showing the values of sieve analyses of samples

Sieve no.	Accumulative retain gm		Percent retain	Percent passing
12.5 mm	½ inch	0gm	0%	0.00%
9.5 mm	3/8inch	5.6 gm	0.3%	99.7
4.75 mm	No#4	1454	78.8%	21.2
2.36 mm	No#8	1816 g	98.5	1.5
2.0 mm	No#10	1816.7 g	98.6	1.4
1.18 mm	No#16	1820 g	98.7	1.3
0.60 mm	No#30	1822.9 g	98.8	1.2%
0.425 mm	No#40	1824.0	98.9	1.1%
0.30 mm	No#50	1825.5 g	99.0	1.0%
0.15 mm	No#100	1829 g	99.2%	0.8%
PAN	No#200	1841 g		

abrasion test was performed. This test quantifies the number of fines generated due to impact and abrasion (Lindqvist *et al*., 2007). The resulting abrasion value reflects the aggregates' ability to withstand wear during concrete mixing and traffic exposure. According to ASTM C-535 (2003), acceptable abrasion values range from 0% to 30% for highway use and from 30% to 50% for road applications. Table 7 displays the results of the Los Angeles test, which indicate an abrasion value of 20%. This value is within the ASTM standard range of 0% to 50%, implying that Kaiigah amphibolites are suitable for highway construction. The abrasion is determined using the formula: Abrasion = (Initial weight – Final weight) × 100.

Table 6. Showing values of the sample after sand gradation test

Sieve size	Acc retain (%)	Retain (%)	Passing (%)	Specification limit
3/8inch	4.2	0.3	99.7	100
NO#4	62.8	4.7	95.3	95-100
NO#8	213.9	16.1	83.9	
NO#16	532.4	40.2	89.8	40-80
NO#30	931.1	70.3	29.7	-----
NO#50	1187.3	89.6	10.4	10---30
NO#100	1235.6	94.8	5.2	2-10
NO#200	1286.5	98.1	8.9	0-3
PAN	1297.8			

Table 7. Showing the results of the loss angles abrasion test

2	Revolution (30-33 RPM)	500
3	Steel balls	8
A	Total weight of sample	5000 gm
B	Weight of tested sample retain on#12 sieve	3996.0 gm
C	Abrasion % (A-B)/A×100	20.0%
Standards limit		0 to 50%

Table 8. Showing results of unit weight test

1	Weight of measure fill with aggregate	17720 g
2	Weight of measure	3231 g
3	Net weight of aggregate	14489 g
4	Volume of measure	9298 cm cube
5	Unit weight of aggregate	1.558 g/cm³

Table 9. Shows the sand equivalent values

Test no.	1	2	3
Sand reading	3.9	3.7	3.7
Clay reading	4.6	4.3	4.2
Sand equivalent	84.8	86.0	88.1

Unit weight test of very fine coarse aggregate. Unit weight or bulk density is the measurement of the weight of a material per unit volume, whether the material is permeable or impermeable, assessed in air to determine its density (Lindqvist *et al*., 2007). For the 19 mm road aggregate, the rodded density was recorded as 1.748 g/cm³, while the unrodded density was 1.558 g/cm³. These measurements are listed in Table 8.

Sand equivalent test. This test aimed to measure the relative amounts of clay and dust in fine aggregates that pass through a No.4 sieve under standardized conditions (Irfan, 1994) (Table 9). The calculation for sand equivalent is given by the formula:

Sand reading ÷ clay reading × 100

For asphalt mixtures, the minimum acceptable sand equivalent value is 45, while for concrete, the value should be 70 or higher.

Compressive strength. Compressive strength tests conducted on concrete cubes or cores provide insights into the overall characteristics of the concrete. These tests assess whether a material or structure can support a load on its surface without experiencing cracks or deformation.

Conclusion

The analysis of the construction materials from the Dasu hydropower project area, indicates that they conform to NHA standards. The mechanical and physical characteristics of both coarse and fine aggregates are appropriate for use in concrete and road subbases. Testing followed international protocols, and all findings adhered to ASTM and BS specifications. The specific gravity of the materials is within the expected range and the water absorption rate is 0.3%, consistent with the typical 0.1% to 2.0% range for aggregates used in road surfaces. With such suitable materials readily available, the Dasu project can be efficiently completed using these assessed resources.

Acknowledgements

Mr. Muhammad Yaseen, thanks the chairperson (HoD) Department of Geology AWKUM for providing field work facilities to the study area. The authors are principally grateful to Mr. Muhammad Ismail, Material Engineer, Dasu Hydropower Project, Kohistan for helping during fieldwork and interpretation of the research data.

Conflict of Interest. The authors declare that they have no conflict of interest.

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