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Assessment of Potential Alkali-Carbonate Reactivity and Petrographic Analysis of Limestone from Samana Suk Formation Dhamtaur Area, District Abbottabad, Pakistan to Use as Aggregate

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Abstract: A detailed Limestone from the Samana Suk Formation in Dhamtaur, Pakistan, was studied to assess its potential as a construction aggregate. The limestone contains variable amounts of dolomite, which can be harmful to concrete. Petrographic analysis and ACR tests showed that the dolomite content is low and the limestone has low alkali reactivity. Engineering laboratory tests confirmed that the limestone meets ASTM and AASHTO standards for aggregate properties. Therefore, the limestone from Dhamtaur can be used as an aggregate in concrete and asphalt works. The results of the engineering laboratory tests indicate that limestone from the Samana Suk Formation, located in the Dhamtaur area, exhibits specific gravity (2.84g/cm3), water absorption (0.0781%), Los Angeles abrasion value (20%), and sulfate soundness (2.23%). These findings strongly support the viability of utilizing these rocks as aggregate, aligning with the established standards of ASTM and AASHTO. A petrographic examination indicates the presence of dolomite in a minor proportion (2-15%) with a Porphyrotopic-S type texture. Analysis of ACR results demonstrates a slight expansion in the limestone (0-0.01%), implying low reactivity to alkali. Consequently, it is reasonable to propose the utilization of these rocks as a source of aggregate in concrete and asphalt projects.

Keywords: Alkali Carbonate Reactivity (ACR); limestone; dolomitic content; Porphyrotopic-S type texture.

Introduction

Aggregates, the fundamental constituents of construction materials, are composed of natural or crushed rock fragments. Derived from weathering or blasting of rocks, these aggregates possess varying mechanical, physical, and geological properties. Natural aggregates, formed by natural processes, and crushed aggregates, particularly limestone, are both extensively utilized in construction. Pakistan's vast road network, responsible for freight transportation, demands aggregates for construction and maintenance (Ahsan et al., 2009; Gondal et al., 2006). Low-cost natural aggregates, such as crushed rocks, stream, and terrace gravels are widely used in construction projects, including buildings, road bases, and asphalt concrete (Croney & Croney, 1998; Neville, 2011). Limestone, the prevalent aggregate choice for bridges, roads, and other engineering structures (Naeem et al., 2014) that is obtained through modern blasting or open excavation and transported to crushing plants for sizing (Khan et al., 2009). Durable aggregates, essential for long-term structural integrity, maintain their engineering properties without compromising the structure's strength (Lafrenz, 1997; A. Neville, 1981; Smith & Collis, 2001). Limestone is a common aggregate choice due to its strength, low porosity (<1%), and high density (Aquino et al., 2010; McNally, 1998; West, 1996). It also has minimal thermal expansion and bonds well with cement (Akman, 1984; French, 1991). However, low-quality aggregates can compromise the performance of structures, making aggregate behavior in construction a critical issue. Aggregates should be free of deleterious materials like reactive silica, dolomite, and sulfates (Tugrul & Yılmaz, 2012).

The limestone from Samana Suk Formation in the Hazara region is often used as an aggregate, but the presence of dolomite in the Dhamtaur area may limit its suitability for construction projects (Akhtar et al., 2019). While limestone from Sheikh Budin Hill has been recommended for aggregate use (Rehman et al., 2018). The properties of limestone from Dhamtaur remain unknown. To assess its potential as a construction aggregate, representative samples from Dhamtaur were collected for evaluation. The Dhamtaur area is located 3 km northeast of Abbottabad, Pakistan, features the exposure of the Samana Suk Formation along Abbottabad Murree road. The study area is situated at a latitude of 34º 08′ 48″ N and longitude 73º 17′ 28″ E. The samples were collected from a quarry site of the Samana Suk Formation which is easily accessible from Abbottabad Murree Road. (Fig. 1)

Fig. 1 Google Earth snapshot of the area showing the quarry site of the Samana Suk limestone along Abbottabad Muree Road.

Materials and Methods

Geology of Study Area

The study area (Hazara) was created by the convergence of the Eurasian and Indo-Pakistan plates in the late Cretaceous (Treloar & Izatt, 1993). The Indo-Pakistan plate was part of Gondwana in the early Cretaceous, and the Himalayas began to uplift after global plate tectonics transformed the region into the Himalayan Mountain. The Hazara basin contains a range of rocks, including metamorphic, meta-sedimentary, and sedimentary rocks belonging to Precambrian-Miocene periods (Latif, 1970). The Samana Suk Formation was deposited in the Hazara basin during the Early to Middle Jurassic as lagoons to open marine shelf carbonates (Ahsan, 2007; Nawaz Chaudhry et al., 1998; Shah, 1977).

Table 1.General Stratigraphy of rock units exposed in southeastern Hazara, Pakistan (Shah 1977)

ERA	PERIOD	EPOCH	FORMATION	LITHOLOGY
Cenozoic	Neogene	Miocene	Kamlial Formation Murree Formation	Sandstone
	Paleogene		Unconformity	
		Eocene	Kuldana Formation	shale
			Chorgali Formation	limestone
			Margala Hill limestone	Limestone
		Paleocene	Patala Formation	shale
			Lockhart Formation	Limestone
			Hangu Formation	Sandstone
			Unconformity	
Mesozoic	Cretaceous		Kawagarh Formation	Limestone, Shale
			Lumshiwal Formation	Sandstone
			Chichali Formation	Shale
			Unconformity	
	Jurassic		Samana Suk Formation	Limestone
Paleozoic			Datta Formation	Limestone
			Unconformity	
	Cambrian		Hazira Formation	Shale
			Abbottabad Formation	Shale, Dolomite
			Unconformity	
Proterozoic	Precambrian		Tanawal Formation Hazara Formation	Slates, Shale, siltstone

The Precambrian Hazara Formation slates are the oldest exposed rocks in the Dhamtaur area. The Jurassic Samana Suk Formation, composed mostly of limestone, unconformably overlies the Hazara Formation. The Cretaceous sequence includes the Chichali, Lumshiwal, and Kawagarh formations. The Paleocene sequence is exposed as the Hangu and Lockhart formations. The Eocene sequence includes the Nammal and Sakessar formations (Akhtar et al., 2019).

The Samana Suk Formation of Middle Jurassic, is well-developed limestone formation which is well exposed and found in the northwestern Himalayan region of Pakistan, which includes the Hazara area, Samana Range, Salt Range, Kohat area, Kalachitta Range and Trans-Indus Ranges f; Latif, 1970; Shah, 2009). Studies are underway to investigate the use of the Samana Suk Formation from the Hazara area as aggregate.

The Samana Suk limestone is gray to dark gray on fresh surfaces but becomes light gray to yellowish gray on weathered surfaces. The beds are 12-20 centimeters thick and are cut by thin calcite veins, joints, and fractures. The Samana Suk Formation conformably overlies the Datta Formation and unconformably overlies the Chichali Formation (Akhtar et al., 2019).

Sampling and Analysis

Fieldwork was conducted to collect 200 representative limestone samples from the Samana Suk Formation in Dhamtaur village, including quarry, outcrop, and crushing plant locations. The large block samples were crushed following the ASTM D-7512 standard, as feasible. Tests on geotechnical engineering were conducted employing procedures from the American Standards of Testing Materials (ASTM), developed by the American Association of State Highway and Transportation Officials (AASHTO).

Physiochemical Tests included Specific Gravity (ASTM C- 127), Water Absorption Test (AASHTO T

Table 2.Calculations and Results of Potential Reactivity for limestone of Samana Suk Formation Dhamtaur area, (Rock Cylinder Method) (AASHTO T 303)

Sr.No	Sample Name	Initial Value before	Final Value after 30 days	Change in length	% Change in length
1	S.1	36.26	36.28	0.02	0.055 %
2	S.2	35.70	35.74	0.04	0.011 %
3	S.3	33.73	33.74	0.01	0.029%
4	S.4	34.65	34.65	0.00	0.000
5	S.5	35.44	35.46	0.02	0.056%
6	S.6	36.33	36.35	0.02	0.055%
7	S.7	34.55	34.56	0.01	0.02%
8	S.8	35.23	35.24	0.01	0.02%
9	S.9	33.47	33.50	0.03	0.089%
10	S.10	33.15	33.19	0.04	0.012%
11	S.11	35.45	35.50	0.05	0.014%

Table 3. Microscopic features obtained from point counting method in thin section of limestone from Samana Suk Formation, Dhamtaur village area, eastern Hazara, Abbottabad district, KPK, Pakistan

Sample Number.	Calcite %	Dolomite %	Clays %	Silica %	Allochems	Petrographic Features	Rock Name
S.1	95	3	1	1	Abundant ooids	Fine to medium grains	Oosparite
S.2	96	2	0	1	No fossils	Medium grain size	Boundstone
S.3	98	1	0	1	No fossils	Medium to fine grain	Calcitic limestone
S.4	85	12	1	2	No fossils	Fine grains	Dolomitic Limestone
S.5	95	3	2	0	Abundant ooids	Fine to medium grains	Oosparite
S.6	96	2	1	1	Abundant peloids and less ooids, fossils	Coarse to medium grains	Biosparite
S.7	94	4	2	0	Abundant ooids	Fine to medium grains. Calcitic veins	Oosparite
S.8	90	6	1	3	No fossil	Medium grains.	Calcitic limestone
S.9	94	2	3	1	Abundant ooids	Medium grains	Oosparite
S.10	95	3	1	1	Abundant peloids and less ooids	Coarse grains.	Pelsparite
S.11	84	14	1	1	Ooids and peloids are present.	Coarse to medium grains.	Dolomitic limestone

84-77), Los Angeles Abrasion Value (AASHTO T 96-77), Sulfate Soundness (AASHTO T-104), Alkali Carbonate Reaction (ACR) (AASHTO T-303) and Petrography (ASTM C-295)

Results and Discussion

Specific Gravity (ASTM C- 127) and Water Absorption Test (AASHTO T 84-77)

Specific gravity is the key factor to assess strength and quality of aggregates (Khan, 2008). Published literature suggests aggregates higher specific gravity values generally better. Average specific gravity of all samples was found 2.84 g/cm³, with average water absorption value 0.0781%, within AASHTO T 84-77 limit 2%. (ASTM C-127).

Average specific gravity (Sp) = bulk sample density / water density

Average water absorption is: [(A - B) / B] * 100%, where:

- A represents the sample weight before drying.
- B represents the sample weight after drying.

Los Angeles Abrasion Index (AASHTO T 96)

Los Angeles Abrasion test measures toughness, durability crushed aggregates. Aggregates degrade significantly over time, so it is important test of resistance to crushing, disintegration, degradation. Average Los Angeles Abrasion value study 20%, within AASHTO T 96-77 limit 35%. The formula for percentage loss is: [(initial weight - final weight) / initial weight] * 100%

Sulfate Soundness (AASHTO T-104)

The sulfate soundness test measures the durability of aggregates under intense weathering conditions. The average value, obtained after completing 5 cycles of immersion in a sodium sulfate solution followed by drying, was 2.23%. This value is within the specified limit of 12% (AASHTO T-104).

Average sulfate soundness = [(final weight - initial weight) / initial weight] * 100%

Alkali Carbonate Reaction (ACR) (AASHTO T-303)

Rock cylinder (ASSHTO T-303) measures carbonate rock expansion. ACR method chemically determines rock's potential to react with alkali carbonates as aggregate in construction. Eleven rock samples with smooth surfaces were prepared. Length measured before NaOH solution immersion at 25°C for 30 days. After immersion, length measured again with digital gauge. Difference in length calculated to evaluate carbonate rock expansion (Table 2).

Petrography (ASTM C-295)

Petrographic study of aggregates was conducted following ASTM C 295 (Tremblay et al., 2007) to identify rock types, chemical instability, volumetric instability, alkali-silica reactivity, and alkali-carbonate reactivity. It also identifies deleterious contaminants like magnesium oxide, glass, gypsum, coal ash cinders, soil, hydrocarbons, clinker, calcium oxide, and chemicals that can affect hardening or characteristics of concrete. Additionally, micro plants, animal excrement, and other contaminants can harm concrete performance (Neville, 2011). Petrographic study showed Samana Suk limestone from Dhamtaur constituting mainly calcite (>95%), minor dolomite, silica and clay (Fig.2) Calcite consists of matrix (micrite, sparite). Skeletal grains (shell, miliolid) and non-skeletal grains (oolite, peloid) are also observed. Porphyrotopic-S dolomite is less reactive to alkalis (Guangren et al., 2002). Limestone is non deleterious. No other reactive components were found. There is no possibility of alkali reaction with ordinary Portland cement/high alkali cements and asphalt concrete (Table 3).

The test results for Samana Suk limestone as an aggregate were compared with ASTM standards developed by AASHTO and the Highway Division of Punjab Manual. The recommendations for use of Samana Suk limestone as road aggregate are based entirely on these analyzed values.

Specific gravity is a measure of aggregate strength, and aggregates with high specific gravity are considered stronger. The analyzed samples have a specific gravity of 2.84%, which is within the standard recommendation range of 2.65% to 2.9%. Therefore, these samples are classified as good aggregates based on their comparison to standard values.

Petrography

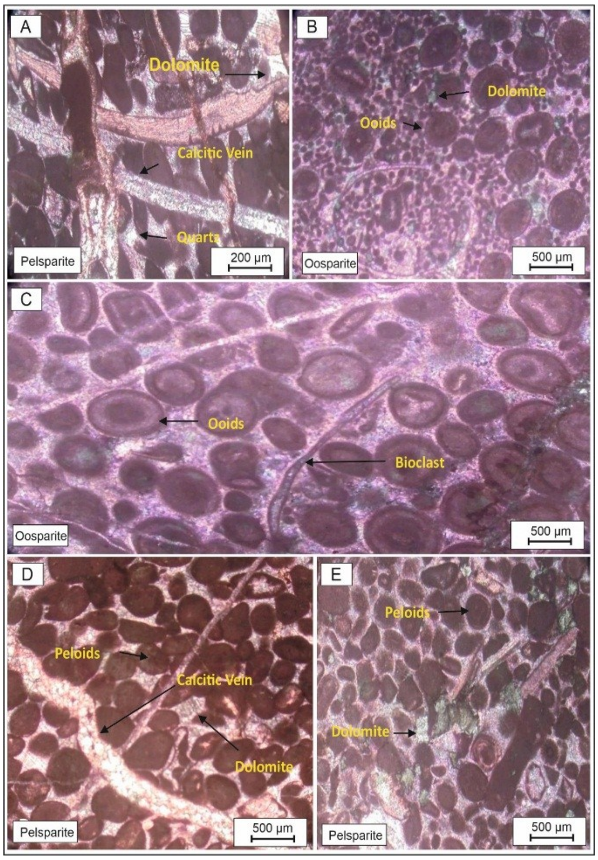

Fig. 2. Micrographs: (A) (Pelsparite) is showing medium to coarse grains texture, dolomite, Calcitic viens, Quartz (B) (Oosparite) is showing fine to medium grains texture, dolomite and Ooids (C) (Oosparite) is showing medium to coarse grain texture, Ooids and bioclast (D) (Pelsparite) is showing medium grain texture, Peloids and Calcitic veins and dolomite (E) (Pelsparite) is showing medium grain Peloids and dolomite grains.

Table 4. Geotechnical Test Results 0btained from Samples of Samana Suk Limestone, Dhamtaur

Laboratory Tests	Analyzed values	Standard Values
Average Specific gravity (AASHTO T 84-77)	2.84 %	≥2.6 % - ≤2.9 %
Average Water absorption (ASHTO T85-88)	0.0781 %	< 2%
Average Los angles abrasion value (AASHTO T 96-77)	20 %	<_50 %
Alkali carbonate reactivity test (AASHTO T-303)	0 to 0.01 %	<_1 %
Petrographic examination report (Dolomitic content)	0 to 15 %	<_25 %
Sulphate soundness (AASHTO T-104)	2.23 %	<_12 %

The standard value for water absorption is <2%, and the analyzed value is 0.0781%, which also classifies the samples as good aggregates. The average Los Angeles abrasion value was analyzed to be 20% (Table 4), while the standard values for subbase, base course, concrete, and surface course are 50%, 40%, 35%, and 30%, respectively. All the examined samples of Samana Suk limestone are suitable for use in subbase, base course, surface course, as well as concrete. However, they are best suited for base course and surface course due to their low Los Angeles abrasion value (<20%) and their hardness. The standard value for the alkali-carbonate reactivity test is <1%, and the analyzed values range from 0 to 0.01%, indicating negligible expansion in the aggregate. Therefore, Samana Suk limestone is strongly recommended for use as an aggregate.

Conclusion

Samana Suk limestone aggregates meet ASTM/AASHTO standards for specific gravity, sulfate soundness, Los Angeles abrasion, and water absorption. They have porphyrotopic-S texture (less reactive to alkalis) and minor dolomite (negligible expansion). Thus, Samana Suk limestone aggregates are suitable for subbase, base, and cement concrete. Medium to thick bedding suggests use in embankments, dimension stone, and rip-rap. Easily accessible outcrops allow open pit mining and transport. This durable aggregate source would benefit civil construction works in Abbottabad District and Hazara region, Pakistan.

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