MECHANICAL CHARACTERISTICS OF AGGREGATE RESOURCES FROM SWAT, KHYBER PAKHTUNKHWA, PAKISTAN

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DEPARTMENT OF EARTH AND ENVIRONMENTAL SCIENCES BAHRIA UNIVERSITY ISLAMABAD

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A thesis submitted in fulfilment of the requirement for the award of the degree of Master of Science (Geology)

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Certificate

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DEDICATION

This thesis is dedicated to my beloved parents and respectable teachers whose prayer and guidance has always been wheels for me that has always helped me to travel in this competitive era.

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ABSTRACT

Aggregate resources act as a backbone for the infrastructure and serve as an essential component in the concrete, asphalt and have multiple construction applications. Their availability and low cost make them crucial for economic growth and development. In this regard the research has been conducted on the Kashala formation, Kamila amphibolites, Marghazar formation and NakaniGhar formation that are exposed in Swat area and an attempt is made to evaluate their physio-mechanical properties that have great value in assessing the aggregate suitability for its application in any project. To assess the physio-mechanical properties, gradation analysis, The relevant ASTM and AASHTO standards were followed when conducting the Los Angeles abrasion test, crushing value test, impact value test, flakiness and elongation test, soundness test, specific gravity test, and water absorption test. Key findings showed that while abrasion resistance varied, all formations showed good resistance to weathering. The Kashala Formation had the maximum abrasion loss, while the Kamila amphibolite displayed the lowest. Kamila amphibolite exhibited the best flakiness and elongation, while Marghazar Formation displayed the least desirable values. Except for the Marghazar Formation, which showed a higher susceptibility to fracturing, impact resistance was generally good. Most of the particles in all the formations were fine, and their crushing resistance was moderate. The suitability of a formation for a given application will rely on the project requirements. For applications requiring high abrasion resistance and where flakiness and elongation are crucial, Kamila formation might be preferred. In such cases, Marghazar Formation may be less appropriate. To guarantee optimal performance, the predominance of fine particles in all formations must be considered while designing concrete or asphalt mixes. This thesis can help choose the right aggregates for building projects by offering insightful information about the characteristics of these rock formations.

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CHAPTER 1

INTRODUCTION

1.1 Background

Aggregate is onne of the materials that is widely used is naturally occurring aggregate (Luhar et al., 2019). Concrete and asphalt, which are composed of sized or crushed and sized rock resources, are used to build most roads, bridges, houses, and other engineering projects (Adeyi, et al., 2019). Aggregates are used in the production of a vast range of products for the home and business, from massive boulders (rip rap) used as fill in large construction projects to finely ground flour-sized particles used in paint, glass, plastic, medications, feed for agriculture, and soil conditioners (Deaton and Zaidi, 2002). Apart from their application in building aggregates, other environmentally beneficial products include those that regulate pollutants, manage soil erosion, and purify water (Brunner and Rechberger, 2015). More than 90% of asphalt pavement and 80% of concrete are composed of construction aggregate (Shi et al., 2018). A binder, like cement or asphalt, makes up the remaining ingredient (Shi et al., 2018). The aggregate is made up of around 52% of all constructing crushed stone, and the remaining 48% is made up of sand and gravel (Adeyi, 2019).

Studies have indicated that the mechanical characteristics of aggregates, including their size, shape, compressive strength, and surface texture, are significant factors that impact the durability and performance of building materials. For instance, Chen et al. (2019) emphasized the need for a thorough examination of aggregate properties by identifying the aggregate structure as a major component influencing the performance of road materials. Similar to this, Al-Attar (2003) emphasized the relevance of coarse particles in the development of concrete strength by pointing out the notable strength differential between mortar and concrete with the same cement/aggregate ratio. Locally produced aggregates can support sustainable building practices and provide financial advantages including lower labor and shipping expenses (Tam et al., 2018). Thus, it is crucial to comprehend and maximize the qualities of aggregates to guarantee the structural integrity, financial viability, and environmental sustainability of building projects.

A number of researchers have looked into the mechanical characteristics, chemical composition, and petrographic features of the formations that are the focuso f this study. The investigations on the Nikanai Formation Limestone, Kashala Formation, Marghazar Formation, and Kamila Amphibolite all highlight the necessity for additional investigation to validate their geological characteristics and determine whether or not they are suitable for mining exploration and development. While the mechanical and petrographic properties of these formations appear promising, more research is advised to fully comprehend their long-term performance and possible uses in a variety of engineering and industrial situations (Khan et al., 2012; Sajid et al., 2009; Shah et al., 2022). Natural sand and gravel aggregates have been thoroughly evaluated by Fookes (1991) and Přikryl (2017), highlighting the significance of in-depth research to guarantee the long-term viability and safety of constructed settings. Their research showed that insufficient investigation of rock resources could result in unfavorable consequences, such as decreased structural integrity and environmental risks. Furthermore, Müller et al. (2014) looked at the size, shape, and surface quality of coarse particles and how these affect the structural performance and durability of concrete. These results emphasize how important it is to use aggregates with the best qualities when creating building materials in order to get the desired results.

Furthermore, the problems with using angular and fissile rocks as aggregates—particularly with regard to workability and bond strength in concrete—were examined by Fabro et al. (2011) and Hacch et al. (2011). Their findings showed that, although angular pieces offered a robust interlock, they may cause issues with mixing and compaction, necessitating modifications to the ratios of sand, water, and cement. Smooth, spherical aggregates, on the other hand, were found to create mixes that were easier to deal with, however their bond strength may be compromised (French, 1991). Additionally, Abubaker (2018) investigated the crushing strength of several kinds of rock that are utilized as aggregates, offering information on material selection for applications requiring high-strength concrete. All of these research demonstrate how important aggregate characteristics are in influencing how well building materials work, especially when it comes to concrete and asphalt.

By concentrating on the particular mechanical characteristics of the formations under study, the current research expands on these earlier investigations. In order to support ongoing efforts to maximize aggregate selection for construction, this study intends to compare the results with previous literature, notably in terms of compressive strength, aggregate structure, and surface texture. This study aims to improve knowledge about the performance of these particular formations under different conditions by combining fresh data with the work of earlier authors. This will ultimately contribute to the sustainability, longevity, and safety of constructed environments.

Alpurai Group is divided into four formations: Marghazar, Kashala, Saidu, and Nikanai Formation. This article describes the metamorphic sequence in Lower Swat and its relationship to Pakistan's geology. The geologic sequence includes the Precambrian Cambrian Manglaur formation, which is unconformably overlain by the Alpurai group. The Alpurai group is further divided into the Carboniferous or younger Marghazar formation, and the Triassic or younger Kashala, Saidu, and Nikanai formations. The stratigraphic chain includes the Precambrian Cambrian Manglaur formation, which is unconformably superimposed by the Alpurai group. It is further divided into the Carboniferous or earlier Marghazar formation and the Triassic or earlier Kashala, Saidu, and Nikanai formations. The Jobra formation, which is uncertain in age, forms irregular lenses beneath the Alpurai group. Alpurai Group of Triassic age or younger as shelf deposits, representing the return of epicontinental shelf sedimentation in Lower Swot and Peshawar Basin. In northern Pakistan's Swot region, metasediments from the Mesozoic Alpurai Group, comprising the Saidu, Nikanai, Kashala, and Marghazar formations, as well as the Paleoproterozoic Manglaur Formation, are interrupted by the Permian Swat Granite. (DiPietro and Lawrence, 1991, DiPietro et al., 1993; Anczkiewicz et al., 2001, Hussain et al., 2020).

The Kamila Amphibolite, part of the Kohistan Arc in northern Pakistan, is a major metamorphosed mafic unit made mostly of hornblende and plagioclase with some pyroxene and garnet that formed under amphibolite facies conditions. This unit is related with the tectonic collision of the Kohistan Arc and the Indian Plate during the Himalayan orogeny. The amphibolite has extensive foliation and distortion, indicating ductile tectonic activity. Its mineralogical composition, which includes retrograde phases such as chlorite, indicates a complex metamorphic history involving both high-grade and subsequent lower-grade metamorphism. The Kamila Amphibolite gives critical insights into the subduction and magmatic processes of the Kohistan-Ladakh Arc (Petterson and

Windley,1985) and Jan & Howie, 1981).

1.2 Problem Statement

Aggregates play a crucial role in development projects, serving as essential building constituent for roads, buildings, and various construction materials. Their importance spans across multiple fields, including geology, civil engineering, construction materials science, and environmental science. Previous researchers have investigated some aspects of aggregate rocks from Swat area for accessing the quality of aggregates and studied geological formations and the distribution of aggregates resources.

Despite the existing research, there remains a need for comprehensive studies focused on the specific characteristics of local aggregates and their impact on construction projects. This study aims to fill this gap by investigating the quality and performance of local aggregate rocks, particularly their effect on the durability of roads and buildings in the study area. Additionally, the study will explore cost-effective and eco-friendly construction materials by promoting the use of local aggregates.

1.3 Objectives

(i). To determine the mechanical properties of selected formations from Swat area.

(ii). To identify the potential resources of aggregate from Swat area.

1.4 Study Area

The study area (Mingora and Kabal) is in the Swat region of Northern Pakistan, between latitude 30° 44’ and 34°50’ north and longitude 72°15’ to 72°18’ east. The present study area geologically lies on the northern tip of Indian plate where Precambrian to Mesozoic argillites, quartzite and limestone record a history of shelf deposition interrupted by numerous erosional unconformities (Dipietro, 1993). Alpurai group is divisible to four formations, the lower part of this group consists of pelites, psammites and amphibolites while the upper part contains marble, graphite and garnetiferous calc-pelite (Shah et al., 2022).

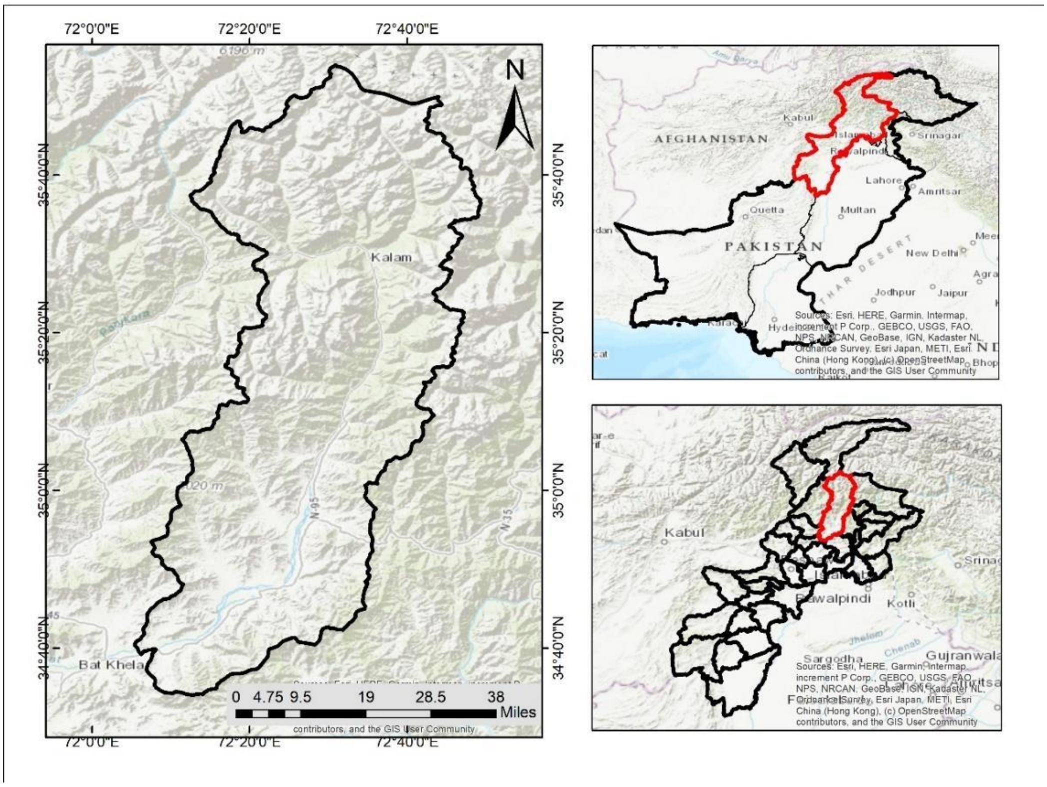


Figure 1.1 Map of study area

CHAPTER 2

GENERAL GEOLOGY AND TECTONICS

2.1 Tectonic and Geologic Settings

Several hundred meters of unfossiliferous siliceous schist, calcareous quartz-mica-garnet schist, marble, and para-amphibolite are unconformably layered over the Swat Granite Gneiss northeast of Nowshera in the Swat area (Ahmad, 1999). According to Kazmi et al. (1984), the rocks in this series, known as the Alpurai Schists, could have formed at any time during the Paleozoic and Mesozoic eras. According to Treloar et al. (1989), this tectonostratigraphic unit forms part of the Swat nappe and the cover of the Precambrian Manglaur Schist. There is a vast area covered by the Alpurai Schists (Ahmad et al. 1987, Lawrence et al. 1989). After connecting a few more lithostratigraphic units to the Alpurai Schists, DiPietro (1990) named the Alpurai group. The Marghazar, Kashala, Saidu, and Nikanai Formations are part of this Alpurai Group.

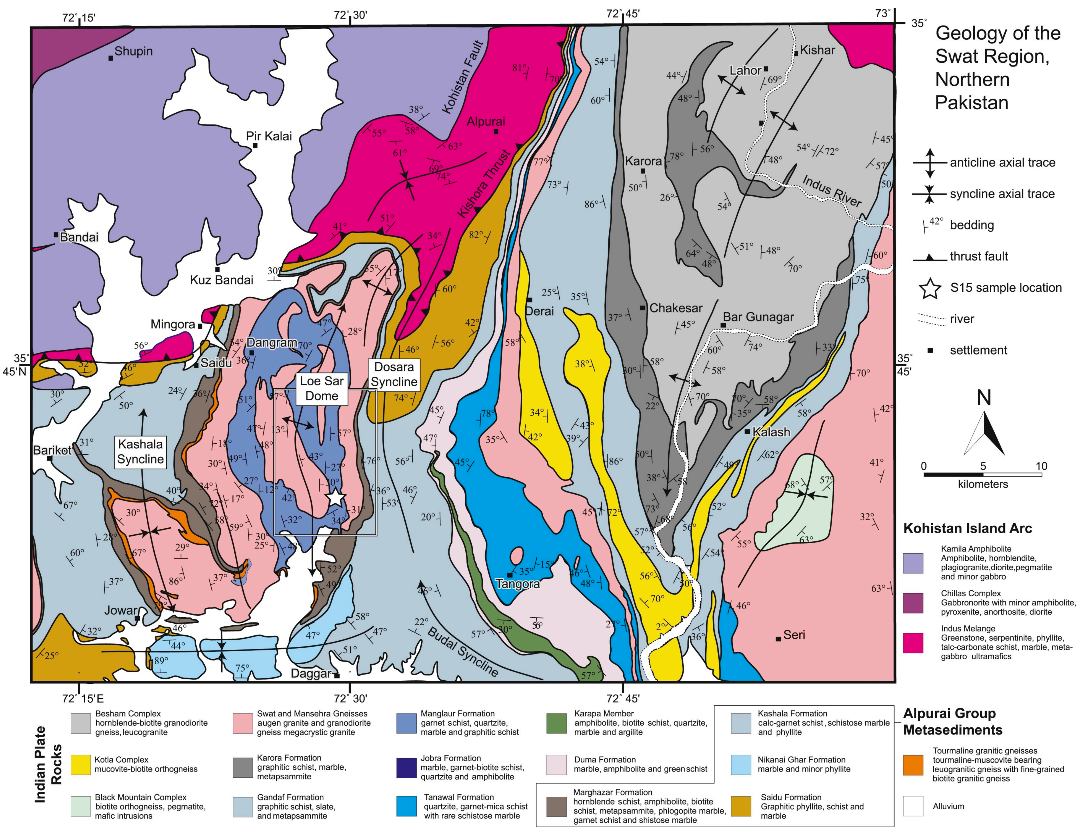


Figure 2.1 Geological map of swat (DiPietro et al., 1999)

The Marghazar Formation is made up of phlogopite marble, amphibolite, hornblende schist, garnetiferous schist, and psammitic schist. It is layered unevenly on top of the Swat Granite Gneiss and Manglaur Formation. Mahmood and Malkani (2017). The Marghazar Formation is covered in layers by the calcareous schists of the Kashala Formation, Saidu Schist, and Nikanai Formations. The Kashala Formation contains rocks from the Late Triassic (Carnian) period. (Pogue and others, 1992) The Himalayan thrust belt in the Swat-Mardan region exposes the Triassic Kashala and Nikanai Formations, which are a part of the Alpurai Group (Ullah, 2015). To the east of this region, in the Hazara area, there is no Triassic sequence and the Jurassic rocks do not conform with each other. encompass the Paleozoic period. The Zait limestone can be found in the Mastuj yalley in the Chitral region of the Karakoram's (Malkani and Mahmood, 2017).

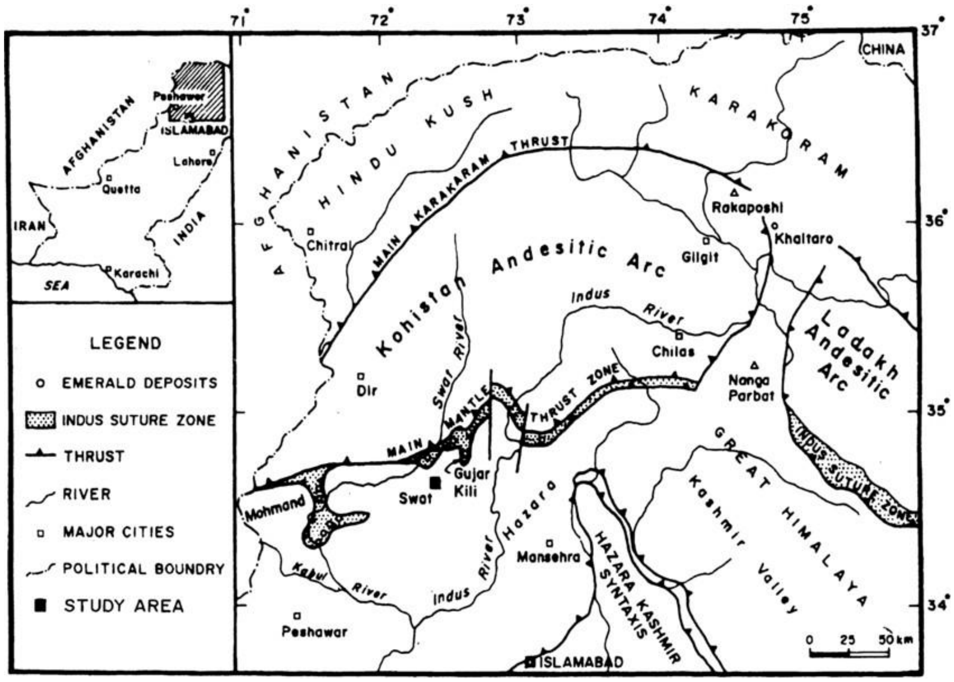


Figure 2.2 Tectonic map of the study area (Akram et al., 2004)

The basement sequence in this area is composed of the Precambrian Manglaur Formation, which is intruded by Swat Granite Gneiss (Kazmi et al, 1984). The Manglaur Formation contains amphibolite, calcsilicate, graphitic schist, quartz-feldspar schist, and quartz-mica-garnet schist. The Manglaur schists include garnet porphyroblasts from two generations, indicating at least two metamorphic phases separated by a retrograde episode. The Manglaur Formation and Swat Granite Gneiss are unconformably covered by the Late Paleozoic Alpurai group. (DiPietro 1993, Pogue et al. 1992, Kazmi et al. 1984). While calcschists and marbles make up the upper portion, gynet-quartz-mica schists, quartzofeldspathic gneisses, metapelites, and amphibolites predominate in the lower portion.

The Swat Granite gives rise to a few unique inliers, the majority of which are antiforms. These antiforms are separated by synclinal troughs filled with cover sediment. North of Nikanai Formation, the Hum Granite is made up of a nappe zone that verges to the south. Ophiolitic melanges, which form southwest-verging klippe and nappes, are the result of extensive (kilometer-long) ophiolite slabs and The Indus Suture in the Malakand-Mohmand region. The Mohmand-Swat sequence, which, according to Baig et al. (1989) and DiPietro et al. (1993), is an oblique, high angle, left lateral shear zone, is truncated eastward by the north-south trending Puran Fault. But according to Treloar et al. (1989 c,d), this fault is known as the Alpurai Thrust, and it has been folded into a south vergent thrust by the Besham antiform. The MMT, Thakot, Balakot, Oghi, Alpurai, and Bata1 shear zones were affected by this event (D1), which resulted in simple shear zones with thrust-related folds and ductile blastomylonites.

The three main lithologic varieties are quartz-feldspar schist, quartz, mica-kyanite schist, and quartz-mica-garnet schist. Thinly layered, paraamphibolite is a hornblende and graphitic schist. in the Swat Manglaur Formation now. (Kazmi et al., 1984). The Manglaur Schist has an unconformably thick layer of the Alpurai Group on top of it. The age of the Manglaur Schist is uncertain. The Manglaur Schist has been tentatively dated to the Precambrian by Kazmi et al., (1984) and later researchers (Lawrence et al., 1989, Treloar 1989c, Williams, 1989) based on the Mansehra Granite's correlation with the Swat Granite Gneiss and its resemblance to the Tanawal Formation. These schists have been referred to as Manglaur Formation by DiPietro (1990). The bulk of the Besham Nappe is composed of Precambrian Besham Group sequences, and it is structurally overlain by the westward-moving Swat Nappe near Alpurai (Fletcher et a1., 1986; Treloar et al., 1989).

The discontinuous lenses of calcsilic granite-bearing marble that are located on the Swat Granite Gneiss in the Swat region, about 5 km southeast of Ham, are unconformably covered by the Alpurai Group. DiPietro (1990) named this marble unit the Jobra Formation; its age is unknown at this time. Because of its superposition between the Alpuari Group and the Swat Granite Gneiss, its Paleozoic age can be inferred. DiPietro (1990) links it to the Nowshera Formation based on its stratigraphic position and calc-silicate mineralogy.

2.2 Stratigraphy of the Study Area

The much older Swat Granite Gneiss lies atop a thick sequence of unfossiliferous rocks, including schist, marble, and amphibolite, in the Swat area northeast of Nowshera (Ahmad, 1999). According to Kazmi et al., (1984), these rocks, formerly known as Alpurai Schists, could have formed at any point during the Paleozoic to Mesozoic Era. They form part of the Swat nappe, a massive tectonic structure that shields the even older Manglaur Schist. These rocks, along with the Marghazar, Kashala, Saidu, and Nikanai Formations, have been grouped into the Alpurai Group by DiPietro's recent work. In Pakistan's Lower Swat area, the Alpurai Group has an intriguing geological composition. Its lower part consists of pelites, psammites, and amphibolite's, while the upper section features marble, graphite, and garnetiferous calc-pelite (Kazmi et al., 1984).

2.2.1 Marghazar Formation

The Marghazar Formation is a group of different types of rock that bears the name of a village in the Swat region. The Marghazar Formation is a stratified rock unit that is situated to the north and south of Marghazar village. It is a top older rock known as the Manglaur Formation and Swat Granite Gneiss (Dipietro, 1990). It consists of silica-rich schist with garnet crystals and mica, dark marble that weathers to a grey hue, schist containing amphibole minerals, schist containing epidote and biotite, and pure marble. It is composed of various rock types, such as marble, amphibole schist, and schist with garnet (Dipietro, 1990). This formation is similar to the bottom layer of a historical sandwich; on top of it is the Kashala Formation, which is dated to the Triassic period by fossils. Based on this layering, scientists believe the Marghazar Formation itself is probably older, possibly from the Carboniferous period (DiPietro, 1990; Kazmi, 1997).

2.2.2 Kashala Formation

Rocks from the Triassic period can be found in two layers in the mountainous bend of the Himalayas in Mardan and Swat: the Kashala Formation and the Nikanai Formation. These layers are part of the larger Alpurai Group (DiPietro et al., 2021). The Kashala Formation is approximately 4,000 meters thick and composed of schist (flaky rock) that can be calcareous (containing calcium carbonate), contain garnet and actinolite minerals, or be marble (a rock formed from limestone) (Ishfaq and Mool, 2001). Interestingly, this formation includes some massive white to grey marble layers. The Kashala

Formation is located on top of a layer of amphibolite rock (rock rich in amphibole minerals) from the Marghazar Formation.but the contact between these two layers is very distinct and abrupt (DiPietro, 1990).

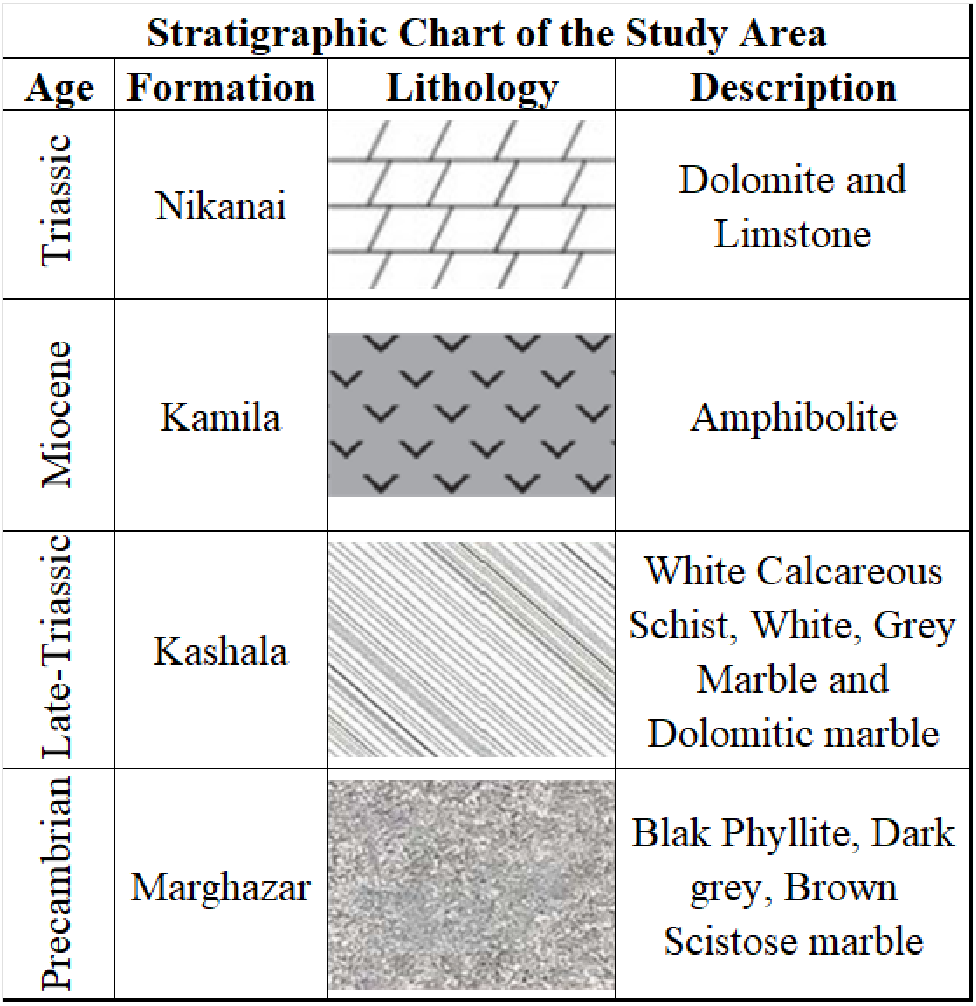
The Kashala Formation is a thick layer of rock (more than 100 meters) that sits on top of the Marghazar Formation (Ahmad et al., 1993). Unlike the name implies, it lacks true amphibolite (a specific rock type) (Ahmad et al., 1993). There is some confusion about how the Kashala Formation first meets the Marghazar Formation beneath it. It could be a smooth transition (conformable), a sharp break caused by faulting, or a highly deformed and mixed-up zone (greatly sheared unconformity) where the Kashala Formation meets much older Chakdara granite (Ahmad et al., 1993). The most common rock type is brown-weathering dolomitic marble, which is essentially marble with dolomite mixed in. The entire formation dates from the Late Triassic period. The Kashala Formation's top transitions smoothly (gradationally) into the Saidu Formation, which is known for its graphite-rich schist layers. (Kazmi and Jan, 1997).

2.2.3 Nikanai Formation

The name was given by Palmer-Rosenberg (1985). Marble dominates the Nikanai Formation, which includes both fine and coarse-grained varieties. The marble's colors range from white to dark grey, and it can be thickly layered or stacked into massive blocks. While marble takes center stage, other rock types such as schistose marble (marble with a layered structure), regular calcareous schist (calcareous rock), and even some calcareous quartzite (calcareous quartzite with calcium carbonate) are present in trace amounts (Shah et al., 2022).

2.2.4 Kamila Amphibolite

Kamila amphibolite is found in northern Pakistan and expands in Swat Dir along the north side, also known as the Kamila amphibolite belt (Jan 1977). The Kamila Amphibolite Belt is a jumbled collection of rocks in the southern Kohistan arc (Virdi, 1986). It is mostly amphibolite, but there are some hornblendites and gneisses mixed in. There is also some diorite, granite, and pegmatite scattered around. The amphibolites themselves come in two varieties: finely banded and chunky. Geologists believe the banded ones originated as volcanic rock, whereas the chunky ones were likely clumps of magma that hardened underground (Jan, 1977). To bolster this theory, they even discovered fragments of gabbro and some ancient lava formations. Regretfully, there has been a lot of folding, shoving, and squishing of the entire area. This caused such disarray that it is difficult to determine the precise original relationship between the volcanic and subterranean rocks. Many of the rocks were also bent and crushed by shearing forces, causing them to become banded. (Bard et al.,1980; Treloar et al., 1990; Jan 1979a, 1988, 1990; Khan et al., 1993)



Stratigraphic Chart of the Study Area			
Age	**Formation**	**Lithology**	**Description**
Triassic	Nikanai		Dolomite and Limstone
Miocene	Kamila		Amphibolite
Late-Triassic	Kashala		White Calcareous Schist, White, Grey Marble and Dolomitic marble
Precambrian	Marghazar		Blak Phyllite, Dark grey, Brown Scistose marble

Figure 2.3 Stratigraphic chart of the study area

CHAPTER 3

MATERIALS AND METHODS

3.1 Field Work

Field studies have great importance in aggregate characterization as they allow better understand to access the suitable rock properties, including lithology, mineralogy, thickness, and texture, and they make it easier to properly sample the required materials. The first step in aggregate quarry demarcation is choosing a suitable and representative location for field sampling (Fookes et al., 1988; Ahsan et al., 2009). The current investigation consists of both field and lab work. The field data was recorded using a digital camera, a geological hammer, and a GPS unit. Sampling from the Alpurai group (Kashala, Nikanai, Marghazar, and Saudi Formations) in the swat and bunner area, as well as from Kamilia Amphibolite belt in Swat, was collected during fieldwork February 2023.

3.2 Sampling

Approximately 20kg crushed aggregates were collected from Alpuari group and Kamila amphibolite for mechanical test which include the following test.

Figure 3.1 Sampling sites

i. Sieves analysis
ii. Specific gravity and water absorption
iii. Los Angeles Abrasion (LLA)
iv. Soundness test
v. Flakiness and elongation test
vi. Aggregate crushing value
vii. Aggregate impact value.

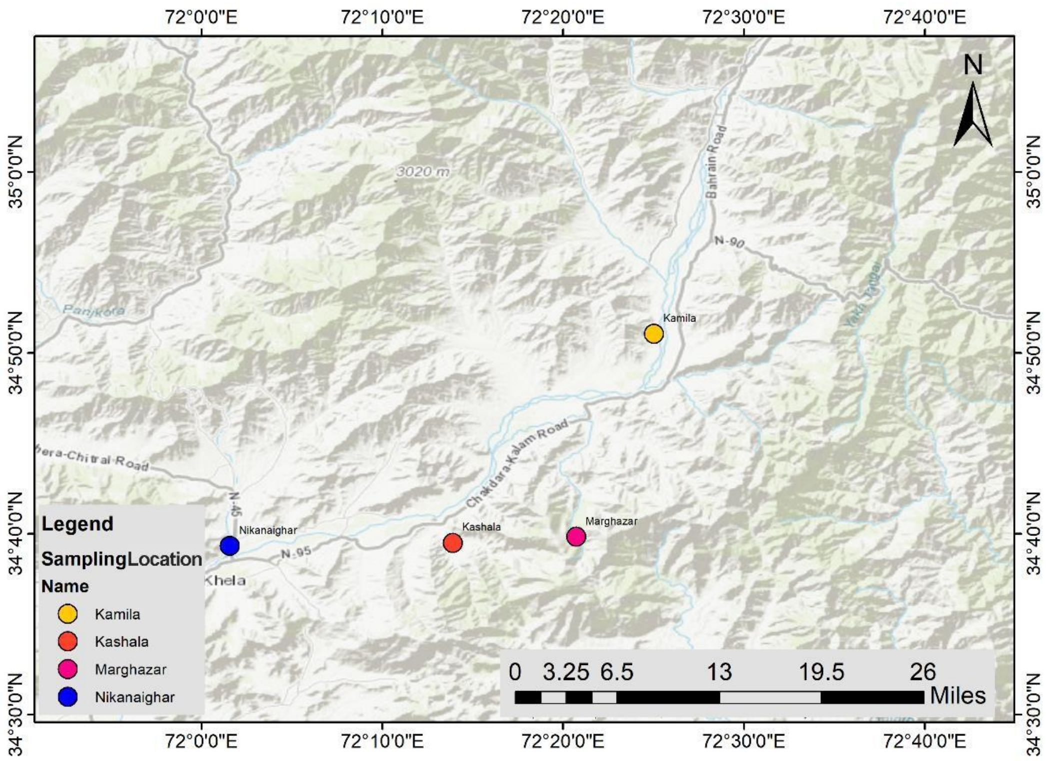


Figure 3.2 Sample location map

3.3 Laboratory Testing

Many factors influence how long an engineered structure will last. These variables include the particular kind of concrete used and the choice of course or fine-grained aggregates (Li et al., 2024; Baloch et al., 2021; Onsori, 2012). The selection of concrete, aggregates, and other building materials is crucial in large-scale construction projects. It guarantees that the materials won't degrade too much over the course of the structure's service life or compromise the intended engineering properties (Smith and Collis, 2001). In order to assess the suitability and performance of an aggregate, variety of tests need to be carried out following the defined standards introduced by international organizations such as American Society for Testing and Materials (ASTM), American Association of State Highways and Transportation Officials (AASHTO), British Standards (BS) and many others. The collected samples were prepared according to the defined standard requirements and are subjected to laboratory test that are explained in the section below:

3.3.1 Sieve analysis (AASHTO T27)

To determine particle size distribution by sieving, a known amount of material is placed on a stack of nested sieves with progressively smaller openings. The stack is shaken mechanically, separating the particles by size. After shaking, each sieve the materials retained are weighed, starting from the top. Subsequent sieves are added to the same pan for cumulative weighing, revealing the total weight of particles retained on all sieves above. Finally, the material passing the finest sieve is weighed, providing a complete picture of the sample's particle size distribution. Mechanical sieve shaker, if used, must provide a vertical or lateral and vertical motion to the sieve, causing the particles to bounce and turn so as to present different orientations to the sieving surface. Sieve shakers must provide sieving thoroughness within a reasonable time. to Oven, capable of maintaining 230 ± 9°F (110 ± 5°C). In situations when ovens are not accessible for testing in the field, test samples can be dried in appropriate containers over an open flame or on electric hot plates while being stirred enough to avoid overheating. Sieves with 40mm, 20mm, 10mm, and 4.75mm holes are usually used for coarse aggregates. Sieves with openings of 4.75 mm, 2.36 mm, 1.18 mm, 600 microns, 300 microns, 150 microns, and 75 microns are frequently used for fine aggregates. (AASHTO T27).

Figure 3.3 Sieve Analysis

3.3.2 Water absorption and specific gravity (ASTM C127)

Rock's water absorption refers to the amount of water it can take in when submerged. This absorbed water can influence the rock's strength by increasing internal water pressure, potentially weakening it. In essence, a rock's strength is inversely related to its water absorption: higher absorption indicates a weaker rock, while lower absorption suggests better resistance to weathering processes, indcating a stronger rock (Wong et al., 2016).

Rocks suitable for construction are categorized using the water absorption test (Siegesmund and Dürrast, 2010). It is preferable to utilize the rock as dimension stone if the water absorption test yields a value of less than 1% of water absorption by sample weight. This is because low values suggest that the rock has a good resilience to weathering (Siegesmund and Dürrast, 2010). The following formula is used to determine water absorption:

$$\text{Water content (W)} = \frac{Ww - Wd}{Wd \times 100\%}$$

Where,

Ww = water-saturated sample weight.

Wd = dry sample weight.

Specific gravity is a measure of rock density, expressed as the ratio of its weight in air to the weight of an equal volume of water (Crawford, 2013). Studies by Morganstern and Eigenbrod (1974) on various rock aggregates suggest that a rock susceptibility to weakening in water is linked to its origin and mineral composition (lithology). Rocks that expand upon water absorption tend to experience a more significant decrease in strength (Siegesmund and Dürrast, 2010).

The rock's engineering qualities decline due to its decreased density and strength. The relative density (specific gravity) and absorption of coarse aggregates are measured using this test technique (Al-akhaly, 2018). It is a dimensionless quantity that can be written as apparent relative density (apparent specific gravity), oven dry (OD), or saturated surface dry (SSD). Once the aggregate has dried, the oven dry density is computed. After soaking the sample aggregate in water for a predetermined amount of time, the SSD are calculated (Hall, 2004). Oven dry weight / (Oven dry weight-weight in water) equals specific gravity.

3.3.3 Los Angeles abrasion test (AASHTO T-96)

The Los Angeles abrasion machine, Model H-3860, complies with testing standards including ASTM C131, C535, and AASHTO T96. This machine evaluates the abrasion resistance of various materials like crushed rock, slag, and gravel, both crushed and uncrushed. It uses an abrasive charge to simulate wear and tear.

The H-3860 can also be used to determine the abrasion resistance limits specified in ASTM C33. The machine's core component is a heavy-duty motor (1HP) connected to a hollow steel drum via a variable speed controller. This controller regulates the drum's rotation speed, typically within a range of 30 to 33 revolutions per minute (rpm). An integrated counter keeps track of the drum's rotations and can be programmed to a specific number of cycles, automatically stopping the machine upon completion.

i. The machine consists of a steel drum that is hollow within and has a cylindrical shape. The drum is 20" in length and 28" in diameter. The drum is attached to a stub shaft on each of its closed ends, and it revolves on this shaft in a fixed horizontal position (Fig 4.6).
ii. Samples are inserted into the drum through an opening in the drum. After the sample is inserted into the drum, a dust-tight cover is placed over the opening that is bolted with a firmly positioned cover.
iii. To allow for an internal deviation in the drum's contour, the cover of the drum is shaped similarly to the drum itself. Shelf is positioned so that when the charge is released, it doesn't come into contact with either the cover or the shelf itself.
iv. A steel shelf that is removable is securely fastened to the interior of the drum using bolts that have a 3-½" diameter. The steel shelf is positioned so that, when measured around the circumference of the drum, it is at least fifty inches away from the aperture.

The abrasive charges used in abrasion testing consist of steel balls or, occasionally, cast iron with a diameter of 1-7/8" and a weight of between 390 and 445 grams. The primary goal is to grade the test sample so that abrasive charges can be applied appropriately.

Samples that pass through a 2 mm sieve and become stuck on a ¾ mm sieve are used to grade aggregate or samples. Additionally, samples should have a standard, constant weight. Prior to the test, the sample needs to be dry and clean. It should also have been baked in an oven set between 105°C and 110°C to ensure that any water has evaporated.

$$\%Loss \qquad W_R$$

Where

W_T = Total weight

W_T = Weight retained

Figure 3.4 Los Angeles Abrasion Test

3.3.4 Soundness (ASTM C88)

The soundness test of aggregates, as per ASTM C88/C88M-18a (Standard Test Method for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate), is a crucial evaluation of their resistance to weathering effects, including wetting and drying or freezing and thawing cycles, which can lead to disintegration.

Conducted through a standardized procedure involving soaking aggregates in a solution of sodium sulfate or magnesium sulfate and subjecting them to specified environmental conditions, the test measures the loss in weight as a percentage of the initial sample weight. Soundness is paramount for the durability and longevity of concrete and asphalt mixtures, with lower loss indicating better resistance to weathering. Factors influencing soundness include mineral composition, particle texture, and environmental exposure. Adherence to ASTM standards ensures consistency and reliability in evaluating aggregate soundness, aiding in the selection of suitable materials for construction projects and contributing to the long-term performance and safety of structures.

3.3.5 Flakiness and elongation (ASTM D 4791)

The percentages of elongated and flat fragments in coarse aggregate are ascertained using the shape test's scope. By affecting the aggregates' placement and consolidation, the particle arrangement in coarse aggregate affects the engineering qualities of aggregate used in construction. The measured value cannot be greater than 10%, according to the specification. The elongation and flatness of the particles in the current study were assessed using the ASTM D4791 technique. Elongated particles were determined by comparing their length to width and their width to thickness.

Figure 3.5 Flakiness and Elongation Test

3.3.6 Aggregate crushing value (BS 812-110)

Modern road construction demands two key mechanical properties from road stones: resistance to crushing under compaction and resistance to surface wear from traffic (Markwick and Shergold, 1945).

The Aggregate Crushing Value (ACV) test is a standard method to assess a material relative ability to withstand crushing under gradually applied compressive force. Developed at the Road Research Laboratory in Great Britain, the ACV test is typically conducted on aggregates ranging from 10 to 12.5 millimeters in size.

During the test, a pre-determined amount (around 500 grams) of oven-dried and sieved aggregate (10-12.5 mm) is placed in a cylindrical steel mold (7.5 cm diameter) in three equal layers. Each layer is then manually compacted 25 times with a tamping rod to ensure a level surface. A secure plunger is positioned on top, and a load is steadily applied, increasing to 40 tons over a 10-minute period (as specified in BIS 1970 & 2002 by the Bureau of Indian Standards).

The ACV, which indirectly reflects the aggregate's mechanical strength, is determined by the percentage of fines (particles passing a 2.36 mm sieve) produced after the test. Several factors influence the ACV result, including the sample size, total load applied and its rate of increase, drying conditions, and the method used to compact the aggregate within the mold before testing.

Figure 3.6 Aggregate Crushing test

3.3.7 Aggregate impact value test (BS 812-112)

Traffic on roads exposes aggregates to impacts that can break them down into smaller pieces. To prevent this disintegration, the aggregates need sufficient toughness. The Aggregate Impact Value (AIV) test measures an aggregate's resistance to sudden impacts, which can differ from its resistance to steady compressive loads.The AIV test involves a specific procedure. A small sample of coarse aggregates (10-12.5 mm size range) is placed in a cylindrical metal mold (75 mm diameter). The sample is then subjected to 15 blows from a standardized hammer (weight: 13.5-14.0 kg) dropped freely from a fixed height (380±5.0 mm) within an Impact Testing Machine (as specified in BIS 2002). The amount of material finer than 2.36 mm produced by the impacts indicates the aggregate toughness.

According to IS 383-1970 (BIS, 1970), the AIV is calculated as the percentage ratio of the weight of fines produced to the total weight of the sample. The following table summarizes the Indian Road Congress' classification of aggregates based on AIV for different road construction applications.

Figure 3.7 Aggregate Impact test

Table 3.1 Aggregate classification based on AIV (Kamani and Ajalloeian, 2019)

Aggregate Impact Value	Classification
<10%	Exceptionally Strong
10 – 20%	Strong
20-30%	Satisfactory for road surfacing
<35%	Weak for road surfacing

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Scope and Importance of the Study

Aggregates are crucial construction materials, particularly in concrete, road construction, and foundation. Strength, durability, hardness, and density are all physical and mechanical qualities that have a direct impact on structural performance and lifetime. Strong and durable aggregates help to increase the overall strength of concrete, resist wear in high-stress areas such as roadways and maintain foundation stability. The shape, texture, and porosity of aggregates have an impact on workability and water absorption, all of which affect the end product's durability and integrity. Choosing the correct aggregates is critical for creating safe and long-lasting constructions.

4.2 Physio-Mechanical Tests

The term "physio-mechanical properties of rocks" describes how rocks react to pressure or other applied loads. In the current research, mechanical properties were subjected to following tests:

- Sieves analysis
- Specific gravity and water absorption
- Loss Angles Abrasion value (L.A.A)
- Soundness test
- Flakiness and elongation test
- Aggregate crushing value
- Aggregate impact value

4.2.1 Soundness Test

Table 4.1 displays the outcomes of the AASHTO T 104-99 soundness test. The coarse aggregates were divided into three size fractions, as indicated in the table, according to their capacity to pass through particular sieves: 37.5 mm to 19.0 mm, 19.0 mm to 9.50 mm, and 9.50 mm to 4.75 mm. Following five cycles in sodium sulfate solution, each fraction underwent the soundness test and lost an average of 4.305% of their body weight. This value is significantly less than the acceptable durability threshold of 12%. The range of weight loss for each size fraction was 3.8% to 4.5%. This low weight loss indicates that the coarse aggregates have a good resistance to weathering, which may support their use in our project (depending on other material properties).

Table 4.1 Soundness analysis of Kashala Formation.

Soundness of Aggregates AASHTO T-104-99								
Chemical Used		Sodium Sulphate		Sp. Gravity:	1.158	Temperature of Immersion Period		$25.7C^{O}$
Soundness of Coarse Aggregates							No Cycles:	5
Sieve Passing (mm)	Sieve Retained (mm)	Grading Original Sample Retained(%)	Corrected Gradation Retain %	Weight Test Fraction Before Test (g)	Weight Test Fraction After Test (g)	Loss in Weight After Test (g)	Loss After Test (%)	Average (%)
37.5	19.0	21.2	28.3	1500	1468	32	2.133	0.604
19	9.50	41.3	55.1	1005	987	18	1.791	0.988
9.5	4.75	12.4	16.6	305	255	50	16.393	2.714
Total		74.9	100	Loss of Coarse Aggregate (%)			4.305	

The results of the AASHTO T 104-99 soundness test are shown in Table 4.2. Based on how well they could pass through sieves, the coarse aggregates were separated into three size fractions, as shown in the table: 37.5 mm to 19.0 mm, 19.0 mm to 9.50 mm, and 9.50 mm to 4.75 mm. The table shows the weight of each fraction both before and after the test cycles, along with the weight loss percentage. The average loss of the coarse aggregates was 2.912%, a substantial decrease from the maximum of 12% recommended in the table. This implies that when exposed to weather, the coarse aggregates will probably be resilient.

Table 4.2 Soundness analysis of Kamila Amphibolite

Soundness of Aggregates							
AASHTO T-104-99							
Chemical Used		Sodium Sulphate	Sp. Gravity:	1.158	Temperature of Immersion Period		25.7C^{O}
Soundness of Coarse Aggregates						No Cycles:	5
Sieve Passing (mm)	Sieve Retained (mm)	Grading Original Sample Retained(%)	Corrected Gradation Retain %	Weight Test Fraction Before Test (g)	Weight Test Fraction After Test (g)	Loss in Weight After Test (g)	Average (%)
37.5	19	21.2	28.3	1510	1472	38	0.712
19	9.5	41.3	55.1	1005	980	25	1.372
9.5	4.75	12.4	16.6	300	285	15	0.828
Total		74.9	100	Loss of Coarse Aggregate (%)			2.912

Results of the AASHTO T-104 soundness test are shown in Table 4.3. The term "Sieve Passing" describes the largest size of particle that can pass through a particular sieve. For instance, the first row's "37.5" denotes that particles as small as 37.5 mm may pass. Three size fractions—19.0 mm to 9.50 mm, 19.0 mm to 37.5 mm, and 9.50 mm to 4.75 mm—were examined. All fractions combined saw an average weight loss of 5.205%, which is significantly less than the permitted durability limit of 12%. Weight loss for individual fractions varied from 2.513% to 20.530%. Even though the largest loss is alarming, the coarse aggregates appear to have good weathering resistance overall, making them possibly appropriate for your project (depending on other properties). It might be necessary to look into the reason behind the increased loss in the 9.50 mm to 4.75 mm fraction further.

Table 4.3 Soundness analysis of Marghazar Formation

Soundness of Aggregates AASHTO T-104-99									
Chemical Used		Sodium Sulphate		Sp. Gravity:	1.158	Temperature of Immersion		25.7C^{O}	
Soundness of Coarse Aggregates						No Cycles:		5	
Sieve Passing (mm)	Sieve Retained (mm)	Grading Original Sample Retained(%)	Corrected Gradation Retain %	Weight Test Fraction Before Test (g)	Weight Test Fraction After Test (g)	Loss in Weight After Test (g)	Loss After Test (%)	Average (%)	
37.5	19	21.2	28.3	1512	1474	38	2.513	0.711	
19	9.5	41.3	55.1	1007	987	20	1.986	1.095	
9.5	4.75	12.4	16.6	302	240	62	20.53	3.399	
Total		74.9	100	Loss of Coarse Aggregate (%)			5.205		

Table 4.4 displays the outcomes of the AASHTO T 104-99 soundness test. The coarse aggregates were divided into three size fractions, as indicated in the table, according to their capacity to pass through particular sieves: 37.5 mm to 19.0 mm, 19.0 mm to 9.50 mm, and 9.50 mm to 4.75 mm. Every fraction that was tested for soundness lost an average of 3.523% of its body weight after five cycles in a sodium sulfate solution. This value is significantly less than the acceptable durability threshold of 12%. Individual size fractions showed weight losses ranging from 1% to 14%. This low weight loss indicates that the coarse aggregates have a good resistance to weathering, which may support their use in our project (depending on other material properties).

Table 4.4 Soundness analysis of Nikanai Formation

Soundness of Aggregates AASHTO T-104-99								
Chemical Used		Sodium Sulphate		Sp. Gravity:	1.158	Temperature of Immersion Perio		25.7C^{O}
Soundness of Coarse Aggregates						No Cycles:		5
Sieve Passing (mm)	Sieve Retained (mm)	Grading Original Sample Retained(%)	Corrected Gradation Retain %	Weight Test Fraction Before Test (g)	Weight Test Fraction After Test (g)	Loss in Weight After Test (g)	Loss After Test (%)	Average (%)
37.5	19.0	21.2	28.3	1490	1475	15	1.007	0.285
19	9.50	41.3	55.1	1008	994	14	1.389	0.766
9.5	4.75	12.4	16.6	308	262	46	14.935	2.473
Total		74.9	100	Loss of Coarse Aggregate (%)			3.523	

The AASHTO T 104-99 test method, also known as the “Soundness of Aggregate by Use of Sodium Sulfate or Magnesium Sulfate,” evaluates the resistance of aggregates to weathering. Here’s a standard table summarizing the aggregate values for the soundness test, the data related to the soundness test for aggregates, which evaluates their resistance to weathering. It sieves sizes, ranging from 37.5 mm to 0.150 mm, specifies the maximum allowable weight loss of 12% for each size, and indicates the mass of the sample used for each sieve size, which is 2500 grams except for the 37.5 mm sieve, which uses a 5000-gram sample. The results of our test are for all the samples are below the standard maximum allowable weight loss.

4.2.2 Loss Angles Abrasion value (L.A.A)

Table 4.5 shows the results of the AASHTO T-96 Los Angeles Abrasion test. Here, coarse aggregates underwent simulated abrasion cycles after being divided into four size fractions: 37.5-25.0 mm, 25.0-19.0 mm, 19.0-12.5 mm, and 12.5-9.50 mm. The weight of each fraction is shown in the table both before and after the test, showing a 38.2% overall weight loss. The aggregates may be more prone to abrasion than those with lower weight losses, even though AASHTO T-96 does not specify a single pass/fail limit. This might be a significant component of your project, depending on how you plan to use it.

Table 4.5 Los Angeles Abrasion of Kashala Formation

Los Angeles Abrasion of Aggregate
AASHTO T - 96

Asphaltic Base Course Class "B"

Sieve Size (mm)			Class - A	Class - B	Class - C	Class - D
Passing	Retained					
37.5	25.0		1250±25			
25.0	19.0		1250±25			
19.0	12.5		1250±25	2500±25		
12.5	9.5		1250±25	2500±25		
9.5	6.3				2500±25	
6.3	4.75				2500±25	
4.75	2.36					5000±25
Total Weight	W_1	g	**5006**			
Retained weight on 1.7mm, After 500 Revolutions	W_2	g	**3095**			
Loss after 500 Revolutions	$100\times(W_1 - W_2)/W_1$	%	**1911**			
No of the Balls			**12**	11	8	6
Loss by Abrasion:			**38.2 %**			

Table 4.6 Los Angeles Abrasion of Kamila Amphibolite

Los Angeles Abrasion of Aggregate AASHTO T - 96								
Sieve Size (mm)			**Class - A**	**Class - B**	**Class - C**	**Class - D**	**Total**
Passing	**Retained**						
37.5	25.0		1250±25				
25.0	19.0		1250±25				
19.0	12.5		1250±25	2500±25			
12.5	9.5		1250±25	2500±25			
9.5	6.3				2500±25		
6.3	4.75				2500±25		
4.75	2.36					5000±25	
Total Weight	W_1	g	**5006**				
Retained weight on 1.7mm, After 500 Revolutions	W_2	g	**4145**				
Loss after 500 Revolutions	$100\times(W_1 - W_2)/W_1$	%	**861**				
No of the Balls			12	11	8	6	
Loss by Abrasion:			**17.2 %**				

Table 4.6 displays the Los Angeles Abrasion test results after AASHTO T-96. Here, coarse aggregates underwent simulated abrasion cycles after being divided into four size fractions: 37.5-25.0 mm, 25.0-19.0 mm, 19.0-12.5 mm, and 12.5-9.50 mm. A total of 17.2% weight loss is shown in the table, which breaks down the weight loss for each fraction. In contrast to aggregates with lower losses, this weight loss indicates moderate abrasion resistance, even though AASHTO T-96 lacks a universal pass/fail benchmark. This factor needs to be taken into account in light of how your project plans to use the aggregates. It may be required to conduct additional testing or find alternative aggregate sources for applications that require high abrasion resistance.

Table 4.7 Los Angeles Abrasion of Marghazar Formation

Los Angeles Abrasion of Aggregate
AASHTO T - 96

Asphaltic Base Course Class "B"							
Sieve Size (mm)			**Class - A**	**Class - B**	**Class - C**	**Class - D**	**Total**
Passing	**Retained**						
37.5	25.0		1250±25				
25.0	19.0		1250±25				
19.0	12.5		1250±25	2500±25			
12.5	9.5		1250±25	2500±25			
9.5	6.3				2500±25		
6.3	4.75				2500±25		
4.75	2.36					5000±25	
Total Weight	W_1	g	**5006**				
Retained weight on 1.7mm, After 500 Revolutions	W_2	g	**3198**				
Loss after 500 Revolutions	$100 \times (W_1 - W_2)/W_1$	%	**1808**				
No of the Balls			**12**	11	8	6	
Loss by Abrasion:			**36.1 %**				

Table 4.7 displays the Los Angeles Abrasion test results in accordance with AASHTO T-96. In this instance, coarse aggregates were divided into four size fractions (37.5-7.50 mm) and subjected to Los Angeles Abrasion machine simulations of abrasion cycles. A total of 36.1% weight loss is shown in the table that breaks down the weight loss for each fraction. Although there isn't a universal pass/fail benchmark provided by AASHTO T-96, this weight loss implies that the aggregates may be more prone to abrasion than those with lower losses. This factor needs to be taken into account in light of how your project plans to use the aggregates. It may be essential to conduct additional testing or find alternative aggregate sources for high-wear applications that require exceptional abrasion resistance.

Table 4.8 Los Angeles Abrasion of NakaniGhar Formation

Sieve Size (mm)			Class - A	Class - B	Class - C	Class - D
Passing	Retained					
37.5	25.0		1250±25			
25.0	19.0		1250±25			
19.0	12.5		1250±25	2500±25		
12.5	9.5		1250±25	2500±25		
9.5	6.3				2500±25	
6.3	4.75				2500±25	
4.75	2.36					5000±25
Total Weight	W_1	g	**5006**			
Retained weight on 1.7mm, After 500 Revolutions	W_2	g	**3358**			
Loss after 500 Revolutions	$100\times(W_1 - W_2)/W_1$	%	**1648**			
No of the Balls			12	11	8	6
Loss by Abrasion:			**32.9 %**			

Table 4.8 displays the Los Angeles Abrasion test results in accordance with AASHTO T-96. In this instance, coarse aggregates were divided into four size fractions (37.5-7.50 mm) and subjected to Los Angeles Abrasion machine simulations of abrasion cycles. The weight loss for each fraction is shown in the table, with a total loss of 32.9%.

Base Coarse Aggregate: According to the AASHTO T-96 standard, the maximum allowable loss for base coarse aggregate is 45%. Based on the test results, the Kashala Formation and Nakani Ghar Formation both fall within this limit, suggesting they are suitable for use as base coarse aggregate. The Kamila Amphibolite and Marghazar Formation, with higher weight losses, may not meet the requirements for base coarse aggregate.

Surface Coarse Aggregate: The maximum allowable loss for surface coarse aggregate is 40%. The Kashala Formation comfortably meets this criterion, while the Nakani Ghar Formation is close to the limit. The Kamila Amphibolite and Marghazar Formation, with significantly higher weight losses, are not suitable for surface course applications.

Concrete Aggregate: Concrete aggregate can tolerate a maximum loss of 50%. All four formations fall well within this limit, indicating that they are all suitable for use as concrete aggregate.

4.2.3 Flakiness and elongation test

4.2.3.1 Flakiness index analysis (BS 812-105.1:1989)

Table 4.9 Flakiness and elongation test of Kashala Formation

Flakiness Index				
Fraction	**Total w.t**	**Passing Wt of Flakiness sieve**	**Passing %**	**Actual Flakiness %**
37.5 - 25.4	510.0	480.0	30.0	5.9
25.4 - 19.0	875.0	820.0	55.0	6.3
19.0 - 12.5	590.0	570.0	20.0	3.4
12.5 - 9.5	450.0	410.0	40.0	8.9
9.5 - 6.3				
Total % of flakiness				**24.4**
Elongation				
Fraction	**Total w.t**	**Retain Wt of Elongation sieve**	**Passing %**	**Actual Elongation %**
50 - 37.5				
37.5 - 25.4	545.0	485.0	60.0	11.0
25.4 - 19.0	920.0	865.0	55.0	6.0
19.0 - 12.5	540.0	525.0	15.0	2.8
12.5 - 9.5	510.0	459.0	51.0	10.0
9.5 - 6.3				
Total % of Elongation				**29.8**

Table 4.9 presents the results of the Flakiness Index Test, which show an overall flakiness index of 24.4%. According to this value, 24.4% of the coarse aggregate particles in all size fractions—which normally range from 37.5 mm to 12.5 mm—exceed a given elongation ratio, which is usually 5:1. Although there isn't a set standard for flakiness, some organizations set limits depending on the application. Along with other aggregate qualities and your unique project requirements, you should assess how a 24.4% flakiness index will affect your project. In contrast to less demanding uses, high-performance applications such as high-traffic pavements may require stricter limitations on flakiness.

4.2.3.2 Elongation Index Analysis (BS 812-105.2:1990)

Table 4.9 also displays the results of the Elongation Index Test, which indicate an overall elongation index of 29.8%. This number indicates that a minimum elongation ratio (typically 5:1) is exceeded by 29.8% of the aggregate particles. Higher elongation indices can cause segregation during placement and have an impact on how workable newly mixed asphalt or concrete is. Elongation can also lessen packing density, which affects durability and long-term strength. Depending on the project, some agencies may specify elongation limits. In your project, the

29.8% elongation index should be taken into account along with other aggregate characteristics and your particular project requirements. For example, elongation constraints may be more important for high-traffic pavements than for less demanding applications.

Table 4.10 Flakiness and elongation test of Kamila Amphibolite

Flakiness Index				
Fraction	Total w.t	Passing Wt of Flakiness sieve	Passing %	Actual Flakiness %
37.5 - 25.4	528.0	505.0	23.0	4.4
25.4 - 19.0	911.0	875.0	36.0	4.0
19.0 - 12.5	619.0	590.0	29.0	4.7
12.5 - 9.5	514.0	495.0	19.0	3.7
9.5 - 6.3				
Total % of flakiness				16.7
Elongation				
Fraction	Total w.t	Retain Wt of Elongation sieve	Passing %	Actual Elongation %
50 - 37.5				
37.5 - 25.4	528.0	510.0	18.0	3.4
25.4 - 19.0	911.0	895.0	16.0	1.8
19.0 - 12.5	619.0	605.0	14.0	2.3
12.5 - 9.5	503.0	490.0	13.0	2.6
9.5 - 6.3				
Total % of Elongation				10.0

4.2.3.3 Flakiness index analysis (BS 812-105.1:1989)

Table 4.10 presents the results of the Flakiness Index Test, which show an overall flakiness index of 16.7%. This figure shows that 16.7% of the coarse aggregate particles in all size fractions, which are normally in the range of 37.5 mm to 9.5 mm, are longer than a given elongation ratio, which is usually 5:1. Although there isn't a set standard for flakiness, some organizations set limits depending on the application. Together with other aggregate qualities and your unique project requirements, you should assess how a 16.7% flakiness index will affect your project. For example, compared to less demanding uses, high-performance applications may require stricter limitations on flakiness.

4.2.3.4 Elongation index analysis (BS 812-105.2:1990)

Table 4.10 also displays the results of the Elongation Index Test, which indicate an overall elongation index of 10.0%. This number indicates that a minimum elongation ratio, usually 5:1, is exceeded by 10.0% of the aggregate particles. Higher elongation indices can cause segregation during placement and have an impact on how workable newly mixed asphalt or concrete is. Elongation can also lessen packing density, which affects durability and long-term strength. Depending on the project, some agencies may specify elongation limits. In your project, the 10.0% elongation index should be taken into account along with other aggregate characteristics and your unique project requirements. For example, elongation constraints may be more important for high-traffic pavements than for less demanding applications.

Table 4.11 Flakiness and elongation test of Marghazar Formation

Flakiness Index				
Fraction	**Total w.t**	**Passing Wt of Flakiness sieve**	**Passing %**	**Actual Flakiness %**
37.5 - 25.4	528.0	480.0	48.0	9.1
25.4 - 19.0	911.0	820.0	91.0	10.0
19.0 - 12.5	619.0	570.0	49.0	7.9
12.5 - 9.5	514.0	474.0	40.0	7.8
9.5 - 6.3				
Total % of flakiness				**34.8**
Elongation				
Fraction	**Total w.t**	**Retain Wt of Elongation sieve**	**Passing %**	**Actual Elongation %**
50 - 37.5				
37.5 - 25.4	528.0	475.0	53.0	10.0
25.4 - 19.0	911.0	845.0	66.0	7.2
19.0 - 12.5	619.0	546.0	73.0	11.8
12.5 - 9.5	503.0	459.0	44.0	8.7
9.5 - 6.3				
Total % of Elongation				**37.8**

4.2.3.5 Flakiness index analysis (BS 812-105.1:1989):

Table 4.11 presents the results of the Flakiness Index Test, which show a high flakiness index of 34.8%. This indicates that a considerable proportion (almost 35%) of the aggregate particles are longer than the required elongation ratio. Higher flakiness can lower the packing density of aggregates in concrete or asphalt, potentially compromising strength and durability, though there isn't a universal limit. Take into account this finding along with other aggregate qualities and the particular requirements of your project. More stringent flakiness restrictions may be required for high-performance applications, such as heavily trafficked pavements.

4.2.3.6 Elongation index analysis (BS 812-105.2:1990)

A high elongation index of 37.8% is also shown by the Elongation Index Test results in Table X. This suggests that a significant portion of particles—nearly

38%—have an excessive elongation ratio. Similar to flakiness, high elongation can cause segregation during placement and impair the workability of newly mixed asphalt or concrete. Additionally, it can lower packing density, which will affect durability and strength over time. Depending on the project, some agencies may have elongation limits. Along with other aggregate properties and your particular needs, the high elongation index in your project should be taken into account. For example, elongation constraints may be more important for high-traffic pavements than for less demanding applications.

Table 4.12 Flakiness and elongation test of NakaniGhar Formation

Flakiness Index				
Fraction	**Total w.t**	**Passing Wt of Flakiness sieve**	**Passing %**	**Actual Flakiness %**
37.5 - 25.4	528.0	500.0	28.0	5.3
25.4 - 19.0	911.0	865.0	46.0	5.0
19.0 - 12.5	619.0	585.0	34.0	5.5
12.5 - 9.5	514.0	490.0	24.0	4.7
9.5 - 6.3				
Total % of flakiness				**20.5**
Elongation				
Fraction	**Total w.t**	**Retain Wt of Elongation sieve**	**Passing %**	**Actual Elongation %**
50 - 37.5				
37.5 - 25.4	528.0	490.0	38.0	7.2
25.4 - 19.0	911.0	875.0	36.0	4.0
19.0 - 12.5	619.0	585.0	34.0	5.5
12.5 - 9.5	503.0	480.0	23.0	4.6
9.5 - 6.3				
Total % of Elongation				**21.2**

4.2.3.7 Flakiness Index Analysis (BS 812-105.1:1989):

Table 4.12 displays the results of the Flakiness Index test, which show a flakiness index of 20.5%. This indicates that a sizable fraction (roughly 20%) of the aggregate particles are thicker than the required ratio. Although there isn't a set limit that is universally acknowledged, a flakiness index of 20.5% might be regarded as moderate.

4.2.3.8 Elongation index analysis (BS 812-105.2:1990)

A moderate elongation index of 21.2% is also shown by the Elongation Index test results in Table 4.12. This implies that a significant proportion (approximately 21%) of particles have an unsuitable length-to-width ratio. Similar to flakiness, moderate elongation may cause segregation during placement and have an impact on how workable fresh concrete or asphalt mixtures are. Moreover, it can lower packing density, which will affect its long-term robustness and durability.

4.2.4 Impact value of aggregate (ASTM C131)

Table 4.13 Impact test of Kashala Formation

Sample Name	1	2
Weight of aggregate before test W1	415	405
Weight of aggregate passing 2.36 mm sieve W2	50	45
% Impact value = W2/W1*100	12.0	11.1
Average=	11.6	

Table 4.13 displays the Aggregate Impact Test results in accordance with ASTM C131. This test assesses the coarse aggregates' ability to shatter under impact. A standardized weight of aggregate is put through several controlled impacts as part of the test. The percentage of aggregate particles that fractured during the test and passed a particular sieve size—typically 2.36 mm—is shown in the table. Table 4.13 indicates that Sample 1 had an aggregate impact value of 12.0%, whereas Sample 2 had an 11.1% value and an average of 11.6.

Greater resistance to impact fracture is typically indicated by lower aggregate impact values. The study's analysis of aggregates from the Kashala formation shows comparatively low impact values, indicating good resistance to fracturing under impact loads. Interpreting these results, however, needs to be done in conjunction with specified thresholds or requirements for the particular needs of your project. For example, depending on the magnitude of expected impact forces, certain applications may require even lower impact values.

Table 4.14 Impact test of Kamila Amphibolite

Sample Name	1	2
Weight of aggregate before test W1	310	325
Weight of aggregate passing 2.36 mm sieve W2	21	23
% Impact value = W2/W1*100	6.8	7.1
Average=	6.9	

Table 4.14 displays the Aggregate Impact Test results in accordance with ASTM C131. This test assesses the coarse aggregates' ability to shatter under impact. Several controlled impacts are applied to a standardized weight of Kamila amphibolite aggregate during the test. The percentage of aggregate particles that fractured during the test and passed a particular sieve size—typically 2.36 mm—is shown in the table. Sample 1 displayed an aggregate impact value of 6.8%, whereas Sample 2 displayed a value of 7.1%, as indicated in Table 4.14.

Greater resistance to impact fracture is typically indicated by lower aggregate impact values. According to these findings, the Kamila amphibolite samples examined in this investigation show a fair amount of resistance to breaking under impact loads.

Table 4.15 Impact test of Marghazar Formation

Sample Name	1	2
Weight of aggregate before test W1	375	350
Weight of aggregate passing 2.36 mm sieve W2	65	60
% Impact value = W2/W1*100	17.3	17.1
Average=	17.2	

The Aggregate Impact Test results following ASTM C131 are presented in Table 4.15. This test evaluates the coarse aggregates' ability to shatter under impact. Several controlled impacts are applied to a standardized weight of Marghazar formation aggregate during the test. The percentage of aggregate particles that fractured during the test and passed a particular sieve size—typically 2.36 mm—is shown in the table. As shown in Table 4.15, Sample 1 exhibited an aggregate impact value of 17.3%, while Sample 2 had a value of 17.1%.

Greater resistance to impact fracture is typically indicated by lower aggregate impact values. The comparatively high impact values of 17.3% for Sample 1 and 17.1% for Sample 2 in this instance imply that, in comparison to aggregates with lower impact values, the Marghazar formation aggregates may be more prone to fracturing under impact loads.

Table 4.16 Impact test of Nikanai Formation

Sample Name	1	2
Weight of aggregate before test W1	350	315
Weight of aggregate passing 2.36 mm sieve W2	38	28
% Impact value = W2/W1*100	10.9	8.9
Average=	9.9	

Table 4.16 displays the Aggregate Impact Test results in accordance with ASTM C131. This test assesses the coarse aggregates' ability to shatter under impact. A standardized weight of Nikanai formation aggregate is repeatedly struck under controlled conditions during the test. The percentage of aggregate particles that fractured during the test and passed a particular sieve size—typically 2.36 mm—is shown in the table. Table 4.16 indicates that Sample 1 had an aggregate impact value of 10.9%, whereas Sample 2 had an average value of 9.9 with a value of 8.9%.

The Aggregate Impact Value (AIV) is a measure of an aggregate's resistance to sudden shocks or impact. Based on the AIV, aggregates can be categorized as follows:

- Low Impact Value (< 20%): Aggregates with AIV values below 20% are considered strong and tough, making them suitable for high-wear environments like roads and pavements.
- Medium Impact Value (20-30%): Aggregates with AIV values between 20% and 30% are moderately strong and can be used in some construction applications.
- High Impact Value (> 30%): Aggregates with AIV values above 30% are weak and less resistant to impact, making them unsuitable for heavy-duty construction.

The Kashala Formation exhibits an AIV of 11.6%, which falls into the low impact value category. This indicates that it is a strong and tough aggregate, suitable for use in demanding applications.

The Kamila Amphibolite has an AIV of 7.0%, also placing it in the low impact value category. This suggests that it is a moderately strong and tough aggregate.

The Marghazar Formation has an AIV of 17.2%, which falls into the medium impact value category. While it may be suitable for some applications, it might not be the ideal choice for high-wear environments.

The Nakani Ghar Formation has an AIV of 10.4%, which also falls into the low impact value category. This indicates that it is a strong and tough aggregate.

Overall, the Kashala Formation and Nakani Ghar Formation demonstrate superior impact resistance, making them suitable for applications requiring durable and resilient aggregates.

4.2.5 Sieve analysis

Table 4.17 Sieve Analysis of Kashala Formation

Sieve Analysis ASTM-C 136 /AASHTO-T27,T88				
Description:			**Date:**	
Sieve Size		**Cumulative Retained Weight**	**Retained**	**Passing**
Inch	mm	g	%	%
2"	50	0.0	0.0	100
1"	25	290	9.7	90.3
3/4"	19	930	31.1	68.9
1/2"	12.5	1806	60.4	39.6
3/8"	9.5	2057	68.8	31.2
No.4	4.75	2290	76.6	23.4
Reduce Weight of Sample (g)				
No.8	2.38	2371	79.3	20.7
No.50	0.300	2754	92.1	7.9
No.200	0.075	2963	99.1	0.9
TOTAL DRY SAMPLE BEFORE WASHING (g):		**2990**		

According to ASTM-C 136/AASHTO-T27, T88 standards, the sieve analysis shown in table (4.17) indicated that the Kashala Formation was a well-graded material containing a sizable amount of fines. A preponderance of finer particles was indicated by an increase in the cumulative retained weight with decreasing sieve size. The analysis revealed retention on larger sieves, but 99.1% of the material was retained on the No. 200 sieve (0.075 mm), emphasizing the dominance of the finegrain size fraction. This implies that there may be coarser particles present in the formation.

Table 4.18 Sieve Analysis of Kamila Amphibolite

Sieve Analysis				
ASTM-C 136 /AASHTO-T27,T88				
Description: Kamila			**Date:**	
Sieve Size		**Cumulative Retained Weight**	**Retained**	**Passing**
Inch	mm	g	%	%
2"	50	0.0	0.0	100
1"	25	135	4.2	95.8
3/4"	19	860	26.8	73.2
1/2"	12.5	1778	55.4	44.6
3/8"	9.5	2093	65.2	34.8
No.4	4.75	2379	74.1	25.9
Reduce Weight of Sample (g)				
No.8	2.38	2555	79.6	20.4
No.50	0.300	2969	92.5	7.5
No.200	0.075	3171	98.8	1.2
TOTAL DRY SAMPLE BEFORE WASHING (g): 3210				

The Kamila amphibolites' sieve analysis is displayed in Table (4.18); the material is well-graded and contains a sizable amount of fines. In particular, 98.8% of the material was retained on the No. 200 sieve (0.075 mm), demonstrating the fine-grained nature of the Kamila amphibolites.

Table 4.19 Sieve Analysis of Marghazar Formation

Sieve Analysis ASTM-C 136 /AASHTO-T27,T88				
Description:			Date:	
Sieve Size		Cumulative Retained Weight	Retained	Passing
Inch	mm	g	%	%
2"	50	0.0	0.0	100
1"	25	232	5.7	94.3
3/4"	19	862	21.2	78.8
1/2"	12.5	2196	54.0	46.0
3/8"	9.5	2541	62.5	37.5
No.4	4.75	3045	74.9	25.1
Reduce Weight of Sample (g)				
No.8	2.38	3293	81.0	19.0
No.50	0.300	3855	94.8	5.2
No.200	0.075	3997	98.3	1.7
TOTAL DRY SAMPLE BEFORE WASHING (g):		**4066**		

According to ASTM-C 136/AASHTO-T27, T88 standards, the sieve analysis presented in Table (4.19) indicates that the Marghazar Formation is well-graded, with a predominance of fine particles. 100% of the material passed through the 50 mm sieve, as shown in the sieve analysis graph, indicating the absence of any particles larger than 50 mm. On the other hand, only 1.7% of the particles were able to pass through the 0.075 mm sieve, indicating that the majority of the particles were larger than that size and adding to the formation's fine-grained texture. This finding supports the idea that the Marghazar Formation contains a well-graded spectrum of particle sizes, with a concentration in the fine grain size fraction.

Table 4.20 Sieve Analysis of Nikanai Formation

ASTM-C 136 /AASHTO-T27,T88						
Description:			Date:			
Sieve Size		**Cumulative Retained Weight**	**Retained**	**Passing**		
Inch	mm	g	%	%		
2"	50	0.0	0.0	100		
1"	25	230	7.3	92.7		
3/4"	19	918	29.1	70.9		
1/2"	12.5	1821	57.7	42.3		
3/8"	9.5	2111	66.9	33.1		
No.4	4.75	2386	75.6	24.4		
Reduce Weight of Sample (g)						
No.8	2.38	2541	80.5	19.5		
No.50	0.300	2951	93.5	6.5		
No.200	0.075	3124	99.0	1.0		
TOTAL DRY SAMPLE BEFORE WASHING (g):			**3156**			

The Nikanai formation's sieve analysis is displayed in Table (4.20); the material is well-graded and contains a sizable number of fines. 99.0% of the material was retained on the No. 200 sieve (0.075 mm), demonstrating the fine-grained nature of the Nikanai formation.

4.2.6 Specific gravity and absorption of aggregates

Table 4.21 Specific Gravity and Absorption of Aggregates of Kashala Formation

Specific Gravity and Absorption of Aggregates			
COARSE AGGREGATE (AASHTO T-85)			
1. Weight of Oven dry Sample in air (g)	1388.1	1352.2	**Average**
2. Weight of Saturated Surface-dry Sample in air (g)	1394.6	1360.0	
3. Weight of Saturated surface-dry Sample in water (g)	929.5	906.4	
4. Absorption wt. (g)	6.5	7.8	
5. **% Absorption**	0.47	0.58	**0.53**
6. Specific Gravity			
a). Bulk oven dry	2.984	2.981	**2.983**
b). Bulk Sat. Surf dry	2.998	2.998	**2.998**
c). Aparent	3.027	3.033	**3.030**
d). Water Temperature During Testing	25 C°		

AASHTO T-85 standard was followed in determining the Kashala Formation's specific gravity and absorption. When the material was saturated and surface-dried, the average bulk specific gravity increased to 2.998 from 2.983 in the oven-dried state. The average apparent specific gravity was 3.030, excluding internal voids in the particles. The average water absorption capacity of the Kashala Formation was found to be 0.53%. According to these findings, the Kashala Formation is a reasonably dense substance with a limited ability to absorb water.

Table 4.22 Specific Gravity and Absorption of Aggregates of Kamila Amphibolite

Specific Gravity and Absorption of Aggregates			
COARSE AGGREGATE (AASHTO T-85)			
1. Weight of Oven dry Sample in air (g)	1222.4	1216.3	**Average**
2. Weight of Saturated Surface-dry Sample in air (g)	1230.1	1224.9	
3. Weight of Saturated surface-dry Sample in water (g)	784.0	780.5	
4. Absorption wt. (g)	7.7	8.6	
5. **% Absorption**	0.63	0.71	**0.67**
6. Specific Gravity			
a). Bulk oven dry	2.740	2.737	**2.739**
b). Bulk Sat. Surf dry	2.757	2.756	**2.757**
c). Aparent	2.788	2.791	**2.790**
d). Water Temperature During Testing	25 C°		

Kamila amphibolite's specific gravity and absorption were evaluated in accordance with AASHTO T-85 guidelines. The average weight of the oven-dried sample was 1222.4 grams, as shown in Table 4.22, and increased to 1230.1 grams following saturation surface-drying. The saturated surface-dry sample weighed on average, 784.0 grams when submerged in water. The average absorption determined by these measurements was 0.67%. According to the specific gravity results, the bulk saturated surface-dry state had a value of 2.757, while the bulk oven-dried value was 2.739. It was found that the apparent specific gravity, which does not account for interior particle voids, was 2.790. All things considered, these findings suggest that Kamila amphibolite have a moderate specific gravity and a low water-absorbing capacity.

The specific gravity and absorption values obtained for the Kamila Amphibolite in this study are generally consistent with those reported in the literature by Sajid et al. (2009). While there are minor variations, the overall agreement suggests that the Kamila Amphibolite exhibits typical characteristics for this type of rock.

The slightly higher absorption value observed in this study compared to the literature could be attributed to factors such as variations in the mineralogy or texture of the amphibolite samples. Further research may be needed to investigate the specific causes of this difference.

Table 4.23 Specific Gravity and Absorption of Aggregates of Marghazar Formation

Specific Gravity and Absorption of Aggregates COARSE AGGREGATE (AASHTO T-85)				
1. Weight of Oven dry Sample in air	(g)	2299.4	2716.3	**Average**
2. Weight of Saturated Surface-dry Sample in air	(g)	2325.2	2751.3	
3. Weight of Saturated surface-dry Sample in water	(g)	1480.7	1750.9	
4. Absorption wt.	(g)	25.8	35.0	
5. **% Absorption**		1.12	1.29	**1.21**
6. Specific Gravity				
a). Bulk oven dry		2.723	2.715	**2.719**
b). Bulk Sat. Surf dry		2.753	2.750	**2.752**
c). Aparent		2.809	2.814	**2.811**
d). Water Temperature During Testing		25 C°		

To find the Marghazar Formation's specific gravity and absorption, an AASHTO T-85 compliant test was carried out. Table 4.23 indicates that the oven-dried samples had an average weight of 2507.85 grams, which increased to 2538.25 grams following surface-drying to saturation. The saturated surface-dry samples weighed, on average, 1615.8 grams when submerged in water. The average absorption obtained from these measurements was 1.21%. The bulk oven-dried value of the specific gravity results was 2.719, and the bulk saturated surface-dry state resulted in a value of 2.752. It was found that the apparent specific gravity, which does not account for interior particle voids, was 2.811. In comparison to the Kashala Formation and Kamila amphibolites, these data generally show that the Marghazar Formation has a moderate specific gravity and a moderate capacity for water absorption.

Table 4.24 Specific Gravity and Absorption of Aggregates of Nikanai Formation

Specific Gravity and Absorption of Aggregates COARSE AGGREGATE (AASHTO T-85)			
1. Weight of Oven dry Sample in air (g)	1288.1	1252.2	**Average**
2. Weight of Saturated Surface-dry Sample in air (g)	1307.4	1260.0	
3. Weight of Saturated surface-dry Sample in water (g)	842.3	839.9	
4. Absorption wt. (g)	19.3	7.8	
5. % Absorption	0.97	0.62	**0.80**
6. Specific Gravity			
a). Bulk oven dry	2.984	2.981	**2.983**
b). Bulk Sat. Surf dry	2.811	2.999	**2.905**
c). Aparent	2.889	3.037	**2.963**
d). Water Temperature During Testing	25 C°		

AASHTO T-85 was utilized to ascertain the specific gravity and absorption of the coarse aggregates from the Nikanai formation, as shown in Table 4.24. The aggregates' specific gravities varied from 2.981 to 3.037 and their absorption percentages varied from 0.62% to 0.97%. These numbers show that the aggregates have the desirable qualities of density and porosity for use in construction applications.

The AASHTO T-85 standard provides guidelines for determining the specific gravity and absorption of coarse aggregates. These properties are crucial in assessing the suitability of aggregates for various construction applications.

Based on the test results, the Kashala Formation and Nakani Ghar Formation demonstrate higher specific gravity values and lower absorption rates. This suggests that they are denser and less absorbent aggregates, making them potentially suitable for applications where strength, durability, and resistance to moisture are important.

In contrast, the Kamila Amphibolite and Marghazar Formation have lower specific gravity values and slightly higher absorption rates. While they may still be suitable for certain applications, they might not be the ideal choice for situations requiring high density and low absorption.

The findings for the Nikanai Formation align well with the literature. Both our study and the research by Shah et al. (2022) indicate that this limestone is a suitable aggregate for construction applications.

Specific Gravity: our results show a specific gravity range of 2.981 to 3.037, which is consistent with the values reported in the literature. This suggests that the Nikanai Formation limestone is relatively dense, a desirable characteristic for construction aggregates.

Absorption: The absorption values we obtained (0.62% to 0.97%) are also within the acceptable range mentioned in the literature. This indicates that the limestone has a moderate water absorption capacity, which is generally favorable for construction materials.

Overall, this research results confirm the findings of the literature regarding the suitability of Nikanai Formation limestone as a construction aggregate. Its favorable specific gravity and absorption properties make it a promising material for various civil engineering projects.

4.2.7 Aggregate crushing test

Table 4.25 Aggregate crushing test of Kashala Formation.

Sample Name	**1**	**2**
Weight of aggregate before test W1	2835	2755
Weight of aggregate passing 2.36 mm sieve W2	525	495
% Crushing value = W2/W1*100	18.5	18.0
Average=	18.2	

As per ASTM D 5873 or AASHTO T 212, the aggregate crushing value for the Kashala formation was ascertained. This test determines the coarse aggregates' resistance to crushing under a compressive load. The weight of the aggregate before test (W1) for samples 1 and 2 was 2835 grams and 2755 grams, respectively, as can be seen in table 4.25. Following the test, it was determined that the aggregate weights that passed through a 2.36 mm sieve (W2) were 525 grams and 495 grams, respectively. The formula W2/W1 * 100 was then used to determine the percentage crushing value, yielding values of 18.5% for sample 1 and 18.0% for sample 2. For the two samples, the average crushing value was 18.2%. Higher resistance to crushing is indicated by lower crushing values, and vice versa. The Kashala formation in this instance appears to have a moderate resistance to crushing, as indicated by its crushing value of 18.2%.

Table 4.26 Aggregate crushing test of Kamila Amphibolite

Sample Name	1	2
Weight of aggregate before test W1	2795	2830
Weight of aggregate passing 2.36 mm sieve W2	475	495
% Crushing value = W2/W1*100	17.0	17.5
Average=	17.2	

The aggregate crushing value test results for two samples of kamila amphibolite are displayed in Table 4.26. The resistance of coarse aggregates to crushing under a compressive load is measured by their crushing value. The crushing values for samples 1 and 2 are 17.0% and 17.5%, respectively, according to Table 4.26. A higher resistance to crushing is indicated by lower crushing values.

Table 4.27 Aggregate crushing test of Marghazar Formation

Sample Name	1	2
Weight of aggregate before test W1	2795	2740
Weight of aggregate passing 2.36 mm sieve W2	490	465
% Crushing value = W2/W1*100	17.5	17.0
Average=	17.3	

In accordance with ASTM D 5873 or AASHTO T 212 guidelines, an aggregate crushing test (Table 4.27) was carried out to evaluate the Marghzar formation's resistance to compressive force. Two samples were used in this test, and each had a preliminary weight (W1) of roughly 2775 grams. Following crushing, an average crushing value of 17.3% was obtained by measuring the amount of material that passed through a 2.36 mm sieve (W2). Greater resistance to crushing is indicated by lower percentages. Based on this test result of 17.3%, the Marghzar formation therefore shows moderate resistance to crushing.

Table 4.28 Aggregate crushing test of Nikanai Formation

Sample Name	1	2
Weight of aggregate before test W1	2805	2845
Weight of aggregate passing 2.36 mm sieve W2	470	485
% Crushing value = W2/W1*100	16.8	17.0
Average=	16.9	

Following ASTM D 5873 or AASHTO T 212 guidelines, an aggregate crushing test (Table 4.28) was conducted to determine the Nikanai formation's capacity to withstand compressive force. Two samples, each with an initial weight (W1) of about 2,800 grams, were examined. The amount of material that passed through a 2.36 mm sieve (W2) was measured after the crushing process. Averaging 16.9% was the crushing value obtained; higher percentages indicated higher resistance to crushing. The Nikanai formation thus shows good resistance to compressive forces, according to this test result. The Kamila Amphibolite is high grade metamorphic rock that's why it has better strength and durability then limestone.

Table 4.29 Table showing all the standard and resultant values

Test	Standard Value/Range	Kashala Formation	Kamila Amphibolites	Marghazar Formation	Nikanai Formation
Sieves analysis	Gradation as per AASHTOT27	2990	3210	4066	3156
Specific gravity	2.5 - 3.0 (ASTM C127)	3.03	2.79	2.811	2.963
Water absorption	< 2% (ASTM	0.53%	0.67%	1.21%	0.80%
Loss Angles Abrasion value (L.A.A)	< 40% (ASTM C131)	38.20%	17.20%	36.10%	32.90%
Soundness test	< 12% loss	4.305	2.912	5.205	3.523
Elongation test	< 30% (ASTMD4791)	29.80%	10%	37.80%	21.20%
Flakiness test	< 30% (ASTMD4791)	24.40%	16.70%	34.80%	20.50%
Aggregate crushing value	< 30% (IS 2386)	18.20%	17.70%	17.30%	16.90%
Aggregate impact value	< 30% (IS 2386)	11.60%	6.90%	17.20%	9.90%

4.3 Conclusion

The physio-mechanical properties of the Kashala, Kamila, Marghazar, and Nikanai formations were investigated using a series of tests that followed applicable standards. The tests evaluated many characteristics, including size distribution, specific gravity and absorption, impact resistance, abrasion resistance, flakiness and elongation, and crushing resistance

4.3.1 Key findings:

- **Soundness:** Based on the AASHTO T-104 soundness test, all formations showed good resistance to weathering, with average weight losses falling below the 12% limit.
- **Abrasion Resistance:** Abrasion resistance varied, according to Los Angeles Abrasion tests. The largest weight loss was recorded by Kashala formation (38.2%), which was followed by Marghazar (36.1%), Nikanai (32.9%), and Kamila (17.2%). Each aggregate's suitability for a given application is determined by the level of abrasion resistance needed.
- **Flakiness and Elongation:** The elongation and flakiness indices differed among the formations. Kamila had lower values of flakiness and elongation than the Kashala and Nikanai formations. The marhazar formation exhibited the highest levels of elongation and flakiness, which may have an impact on the workability and durability of asphalt mixtures or concrete.
- **Impact Resistance:** All formations, with the exception of the Marghazar formation, which displayed higher impact values indicating a greater susceptibility to fracturing under impact loads, showed generally good resistance to impact, according to aggregate impact tests.
- **Sieve Analysis:** All formations showed a predominance of fine particles with a significant portion retained on the No. 200 sieve.
- **Specific Gravity and Absorption**: Throughout the formations, the aggregate specific gravities varied from moderate to high (2.7 to 3.0). For every formation, the overall level of water absorption was low.

- **Crushing Resistance:** All formations exhibited moderate resistance to crushing, according to aggregate crushing tests, with average crushing values ranging from 17.0% to 18.5%.

4.4 Recommendations

The following recommendations are provided:

- All tested properties and their applicability to the project specifications should be taken into account when choosing the best formation for a given application.
- Kamila or Nikanai formations might be a better option than Kashala formation for applications requiring high abrasion resistance. Marghazar formation may not be appropriate if high flakiness and elongation are significant concerns (such as high-traffic pavements).
- Additional testing or alternative aggregate sources may be required for applications requiring exceptional impact resistance, especially for the Marghazar formation.
- To guarantee appropriate workability and performance, the preponderance of fine particles in all formations should be taken into account during the mix design process for concrete or asphalt.

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