Evaluation of Aggregates from Various Quarries in Pakistan for Applicability in Road Construction

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Abstract. Pakistan has considerable aggregate resources owing to its extensive mountainous ranges, sets a foundation to investigate the aggregates in this study. Employing an experimental methodology, the study specifically examines and compares the physical, mechanical, and chemical properties of coarse aggregates, adhering to NHA and international specifications. Acknowledging the variability in source and consensus properties across regions, aggregate samples of varying sizes were collected from three quarries. The study aimed to investigate and compare the findings by testing samples of Thandyani, Swat, and Muzaffarabad regions by following BS and ASTM standards. Post-testing the aggregates from these quarries, the results generally aligned with some exceptions observed in Los Angeles Abrasion test, flakiness and elongation index. From results, it was realized that Muzaffarabad aggregates demonstrated better physical and mechanical properties proved to be more reliable and durable aggregates than other quarries. Due to serious environmental concerns and the depletion of natural aggregates, the study underscored the imperative to explore new quarries as alternative sources for aggregates, ensuring sustainable goals for the construction of main highways in Pakistan.
Keywords: Coarse Aggregates, ASTM, BS, Sustainability

1. Introduction

Aggregate is the most common material used in road construction. The importance of using the right type and quality of aggregate cannot be overemphasized. The bituminous and concrete surfacing are made up of aggregates as aggregates play a major role in the behaviors of pavement surfacing and provide strengths and durability to road structures economically [1]. Coarse aggregates are used in greater amount as compared to fine aggregates in concrete mix design because they show greater strength, bonding and are cheaper as compared to other concrete materials. For suitability and serviceability of aggregates as road materials, the aggregates must satisfy all international specifications i.e. specifications from US and UK are commonly used [2]. In Pakistan, the properties of the selected aggregates from different areas sometimes exceed the minimum requirements of the ASTM/BS specifications [3]. This mostly happens with aggregates which are easily available, are used rather than which are fit for the purpose of usage [4]. Selection of aggregates plays an important role as less consideration is given to their suitability and cost savings with appropriate quality. When a study is conducted on aggregates from various quarries near to a construction project, a good rational decision could be made on the choices and sources of aggregates, and alternatively this will lead to more cost-effective pavement designs of road structures [5]. Aggregates are evaluated through tests to determine their suitability for various applications such as in road pavements. Aggregates are used in pavement layers as a base material and as a chipping for surface dressing of roads and it generally comprises of 95% asphalt mixes [6]. The remaining portion consists of sand and bitumen which acts as a binding material in roads. Aggregates with unfavorable properties compromise the strength and durability of asphalt mixes and concrete,

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leading to flaws and durability concerns, impacting both performance and cost-effectiveness. Therefore, aggregates selection and recognition of their properties have considerable importance to pavement engineers in optimizing the design of their pavement structure.

Several studies have been conducted on the characterization and evaluation of aggregates in Pakistan. A research work has been undertaken to evaluate Dina aggregates for pavement construction. The aim of this contemporary study was to check ability of Dina aggregates as alternative of other aggregate sources for pavement construction [3]. A recent study evaluated Rajanpur aggregates for potential use in South Punjab, comparing the findings with those obtained from Margalla's aggregates [7]. Another study examined the engineering characteristic of aggregate sources from central and eastern salt range. The outcomes of the study indicated that Katha Saghral and Jabbi Wachira crushed gravel meet AASHTO limits for base and subbase [8]. The hydrophobic nature of the aggregates makes them suitable for asphalt concrete surface courses, particularly triple surface treatment [9]. In cement concrete work, the calcific composition of rock cast crushed aggregates is highly recommended. However, limitations include inadequate crushing facilities and lack of government approval for use in pavement structures. The aggregates in Azad Kashmir are already in use of local construction companies in different projects like housing and pavements [10]. Another study emphasized that aggregates, comprising 75% of concrete volume, significantly influence concrete properties and mix proportions of low serviceability and quality [11].

In Pakistan, aggregate selection and utilization is suboptimal. Margalla hills provide widely used aggregates, but they are depleting, necessitating the evaluation of new sources to alleviate strain on Margalla aggregates. Environmental concerns arise from mining activities, highlighting the urgency to identify alternative quarries of aggregates. The challenge of establishing standard aggregates in Pakistan remains to be addressed, with organizations such as National Highway Authority (NHA) and National Engineering Services of Pakistan (NESPAK) by conducting research on aggregates. To achieve this objective, this study aims to collect aggregates sourced from three distinct quarries which are Thandyani (Abbottabad), Swat, and Muzaffarabad (Kamsar). The study encompasses to examine their physical, chemical and mechanical properties in accordance with British Standards (BS) and American Standard for Testing Materials (ASTM) by comparing them with international specifications (EN 13242 and EN 13285) and NHA specifications [12-13].

2. Experimental Investigation

2.1. Field Work for Material Selection

In the evaluation of coarse aggregates, fieldwork was confined to selected quarries. The study includes selection of aggregates of varying sizes, 3/4”, 3/8”, and 1.5”, with tests conducted on each size category. Samples for testing were systematically collected from three strategic areas: Thandyani, Muzaffarabad, and Swat, chosen for their accessibility and government prioritization in infrastructure development. Collected aggregate samples underwent transportation laboratories for comprehensive testing and evaluation. The sampling protocol adhered to the ASTM 75-03 standard, ensuring methodological consistency across all sites. This meticulous approach aims to assess the physical, mechanical, and chemical properties of the coarse aggregates, providing valuable insights for their potential application in infrastructure projects.

Fig. 1. Aggregates of different quarries

2.2. Development of an Experimental Setup Flowchart

This study endeavors to create an experimental design for testing on the coarse aggregates in the laboratory for different quarries samples (Figure 2) . Multiple studies on the coarse aggregates revealed that the sampling techniques and the testing methodologies remained under several improvements with passage of time. Prior studies demonstrated that mostly pavement diseases are resembling with properties of coarse aggregates [14-16]. Numerous research studies [17–19], affirm that coarse aggregates possessing favorable morphology play a pivotal role in imparting adequate strength and ensuring robust structural stability to asphalt and concrete pavements. The inclusion of coarse aggregate is acknowledged as a key contributor to enhancing the pavement's strength. The abrasion resistance and morphological characteristics of coarse aggregates emerge as influential factors in determining the overall performance of concrete mixtures in road pavements. This insight underscores the significance of considering coarse aggregates, alongside their specific attributes, to optimize the strength and stability of road pavements. The designed flowchart describes about the research methodology for testing on coarse aggregates by collecting from three different quarries (Figure 2). The collected samples will undergo different manual sorting before testing as aggregates size is important in determining the dimensions of the pores space between two aggregate particles [20]. The aggregates will undergo different tests (Table 3) to determine their physical, chemical and mechanical properties. The reason to determine the chemical and mechanical properties besides measuring physical properties of aggregates is mainly to study all the failure factors occurring in road and asphalt pavements [21]. The tests are performed according to the ASTM, AASTHO and BS on coarse aggregates in the laboratories [3, 22-24]. The current experimental design flowchart proposed to perform tests three times on every single sample size of aggregates for their validation of results.

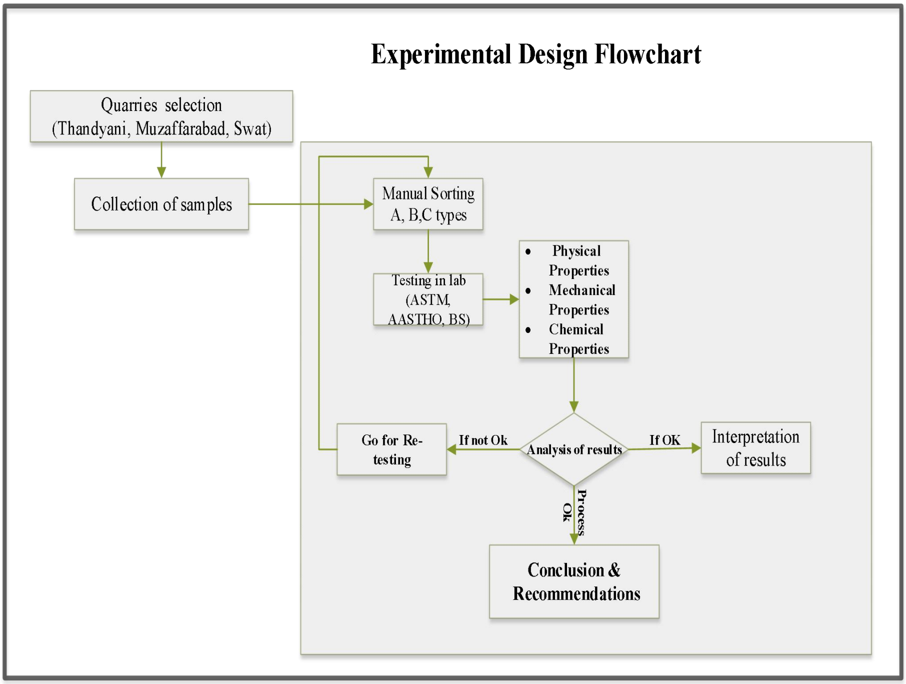

Fig. 2. Flowchart of experimental methodology

2.3. Chemical Composition of Aggregates

Natural aggregates comprise of several materials such as silica minerals, carbonate minerals, sulphate minerals, zeolites, iron sulfide minerals and clay minerals. When natural aggregates are used in asphalt pavements, they compose 90-95% weight of the asphalt mixture by playing a key role in asphalt mix design [25]. In order to investigate the aggregates, the effect of chemical composition on the physical and mechanical properties of coarse aggregates were explored in this study. The chemical composition of coarse aggregates for this study is in Table 1.

Table 1. Chemical composition of aggregates

Constituent	Calcareous Limestone Aggregate	Basaltic Aggregate
SiO_2	4.29	57.3
Al_2O_3	0.20	14.9
MgO	0.44	2.38
CaO	52.5	3.32
Na_2O	0.03	4.93
K_2O	0.087	2.29
TiO_2	<0.1	1.18
Loss on ignition	40.7	2.51

[26] investigated that coarse aggregate properties can be further enhanced by adding Al_2O_3 and SiO_2 whereas CaO effects the aggregates performance negatively. However, researchers have merely qualitative understandings about chemical composition effects on coarse aggregates workability and performance [27]. Table 1 shows the results for various test conducted on the two types of course aggregates with chemical composition according to the international standards.

2.4. Testing Methodology

For evaluation of coarse aggregates, the field work was limited to aggregates of selected quarries of Muzaffarabad, Swat and Thandyani (Figure 3) . The sample were transported to the concerned laboratories for testing and evaluation. Sampling of coarse aggregates of all sites was done according to the ASTM 75-03 standard. The study includes testing the aggregates of various sizes, specifically 3/4", 3/8", and 1.5". Each sample size of all quarries was divided into three types (A, B, C) of materials and the average value of each quarry size was considered for result after performing the tests. The purpose of dividing each quarry sample into sub types was to examine the physical properties and mechanical properties carefully in details. These quarries were selected because of their easy accessibility and their visibility to the government for infrastructure development purposes. NHA specifications and international standards were followed carefully to compare the obtained results of these quarries.

Fig. 3. Different quarries sites

The tests performed in the laboratory are listed in Table 2. All the tests were examined conducted according the ASTM/BS standards and testing procedures were followed accordingly.

Table 2. Name of different types of tests

S. No	Tests	ASTM/BS/AASHTO
1	Sieve analysis	C-136
2	Specific Gravity & Absorption Test	C-127
3	Clay lumps and friable particles	C-142
4	Los Angeles Abrasion Test	C-131
5	Light weight particles in aggregates	C-33
6	Soundness of aggregates	C-88
7	Flakiness and elongation index	BS 812
8	Aggregates Fractured Faces	D-5821
9	Aggregate impact test	D 58-74

Sieve Analysis Test: Through sieve analysis, the particle size distribution of a material is determined. The test methodology mainly focusses to separate fine particles from coarse particles by passing them through different sizes or number of sieves. The method measures mass fractions within size ranges, constructing a cumulative mass distribution. It is the oldest method for particle size distribution and is used commonly in many construction material industries. Aggregates of all quarries were graded according to NHA-A and NHA- B specifications for this study. The gradation limits of NHA-A and NHA -B specification for aggregate base course and asphaltic base course are mentioned in Table 3 [13].

Table 3. NHA specification for gradation limits

Sieve Sizes	Aggregate base course		Asphaltic base course	
	A	B	A	B
1½"			90-100	100
1'	70-95	75-95		75-95
¾"			56-75	65-80
½"				
3/8"	30-65	40-75		45-60
#4	25-55	30-60	23-40	30-45
#8			15-30	15-35
#10	15-40	20-45		
#40	8-20	12-25		
#50			4-10	5-15
#100				
#200	2-8	5-10	3-6	2-7

Figure 4 represents the sieve shaker apparatus through which different number of sieves are arranged to obtain the % passing and % retained on each size. The arrangement for these aggregates starts from 1 ½" to sieve# 200 for particle size distribution.

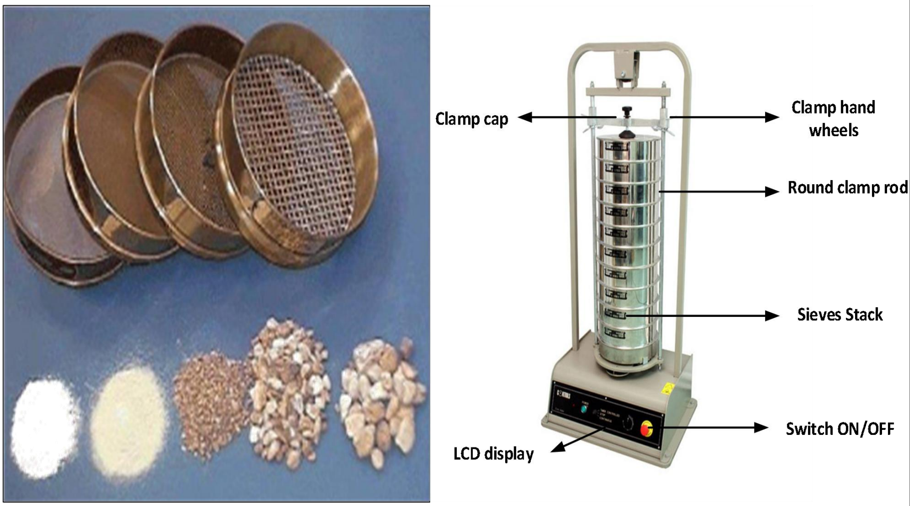

Fig. 4. Different sieve sizes with sieve shaker

Specific Gravity and Absorption Test: Specific gravity is a dimensionless ratio comparing aggregate density to water's density. It serves as a key indicator of material quality, crucial in construction for assessing density and porosity of coarse aggregates. It is calculated by comparing the weight of coarse aggregates to an equal volume of water, expressing a value >1 is denser material, while a value <1 indicates lower density. Specific gravity is instrumental in diverse fields, providing essential information for coarse aggregates material characterization and their selection. The absorption test evaluates a coarse aggregates water absorption capacity, crucial for assessing porosity and durability. Absorption test involves immersing a sample, measuring weight gain, and expressing results in percentage (%). The absorption test results play a vital role in construction and engineering applications for designing durable structures. NHA specification (T-84) for water absorption test is less than 2%.

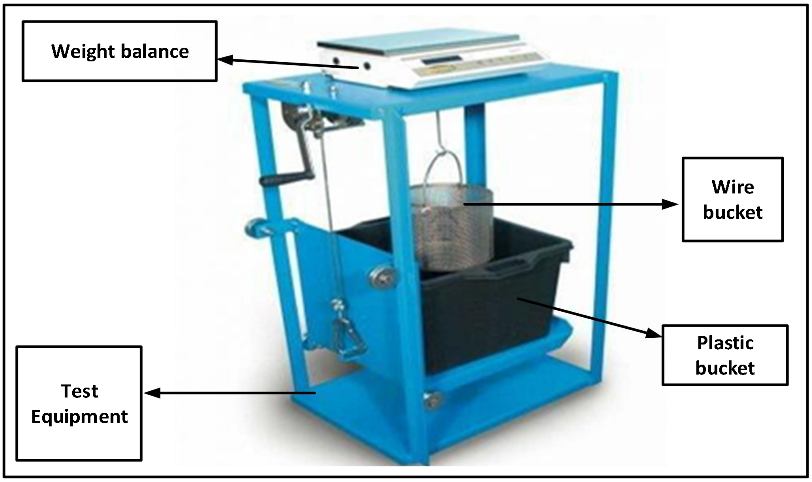

Fig. 5. Apparatus for testing specific gravity and water absorption

The specific gravity and other parameter are determined by the following formulas:
The weight of aggregates suspended in water using a basket in a saturated state. = W_2
$Weight\ of\ the\ basket\ suspended\ in\ water\ =\ W_2$
$Weight\ of\ saturated\ surface\ dry\ aggregate\ in\ air\ =\ W_3$
$Weight\ of\ the\ oven\ dried\ aggregate\ =\ W_4$
$Weight\ of\ the\ saturated\ aggregate\ in\ water\ =\ W_1 - W_2$
$Weight\ of\ water\ equal\ to\ volume\ of\ aggregate\ =\ \frac{W_3}{W_1 - W_2}$

$$Specific\ gravity = \frac{W_3}{(W_3 - (W_1 - W_2))} \tag{1}$$

$$Apparent\ specific\ gravity\ = \frac{W_4}{(W_4 - (W_1 - W_2))} \tag{2}$$

$$Water\ absorption\ = \frac{(W_3 - W_4)}{W_4} \times 100 \tag{3}$$

Clay Lumps and Friable Particles: The purpose of this test is to identify clay lumps and friable particles existing in the coarse aggregates. Conforming to ASTM standard, C-117 guidelines for precise test sample preparation, and subsequently, sample is ensured through drying in an oven at 110°±5°C (230°±9°F) in the laboratory. The minimum quantities per sample and coarse aggregate sizes are shown in Table 2. The specified limits of NHA for granular sub-base aggregates, base course aggregates, asphaltic base course and concrete mix design is maximum 1%.

Table 4. Specifications for Sampling of Aggregates

Particles size making up Test Sample	**Minimum Weight of Test Sample in grams**
4.75 to 9.5 mm (No. 4 to 3/8-inch sieves)	1000
9.5 to 19.0 mm (3/8 to .3/4inch sieves)	2000
19.0 to 37.5 mm (3/4 to 1.5-inch sieves)	3000
Retained on 37.5 mm (1.5-inch sieve)	5000

The formula used for calculation of clay lumps and friable particles is:

$$P = \frac{(W - R)}{W} \times 100 \quad (4)$$

$P = \% \, of \, clay \, lumps \, and \, friable \, particles$
$W = total \, weight \, of \, test \, sample$
$R = weight \, retained \, on \, designated \, sieve$

Los Angles Abrasion Test: The assessment of aggregates resistance to wear is termed abrasion of aggregates. This involves placing aggregates with specified grading into a horizontally mounted cylindrical drum. Steel balls are added to the drum, and the rotation is initiated with a designated number of revolutions for the drum. The tumbling and dropping of aggregates caused by the balls result in abrasion and attrition. Subsequently, the aggregates undergo sieving through a 12-number sieve, and the percentage passing is recorded. The resulting grading is then compared against standard limitations to determine the abrasion characteristics of the aggregates. The specified limit of NHA (T-196) for sub-base aggregates is maximum 50%, aggregates base course, concrete and asphalt base course is 40% maximum.
The formula used for mass percentage is as:

$$Loss = \frac{M_{orignal} - M_{final}}{M_{orignal}} \times 100 \quad (5)$$

Where $M_{orignal} = orignal \, sample \, mass \, (g)$
$M_{final} = final \, sample \, mass \, (g)$

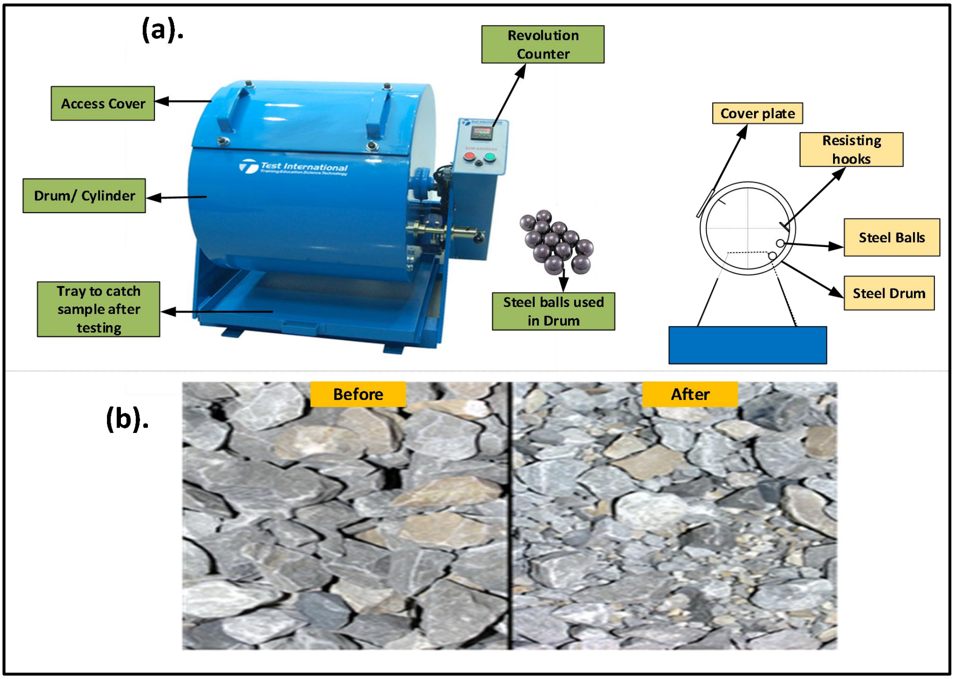

Fig. 6. (a) Los Angles abrasion testing machine **(b)** Samples before and after L. Angles test

Light Weight Particles in Aggregate: This test is performed in laboratory by using ASTM C - 33 to check the lightweight particles in fine and coarse aggregates. Zinc chloride having specific gravity 2.0 is used to separate particles. In this method, aggregate is oven dried for 24 hours and then dried simple is put in distilled water for some time. After that lightweight particles are collected through skimmer, these are passed though sieves by following specifications and finally percentage of light weight particles is determined. The specified limit of NHA for aggregates is maximum 2%.

Soundness of Aggregates: An aggregate is called unsound when its volume changes, which is induced by freezing and thawing cycle which results in deterioration of concrete. This test is used to determine the aggregate resistance to disintegration caused by weathering affects. By submerging and drying the aggregate sample having specified numbers, the aggregate is sieved to calculate or determination of percentage loss of materials. According to NHA specification (T-104), the maximum limit values for all types of aggregates and concrete is ≤12%.

Flakiness Index and Elongation Index Test: Flakiness Index (FI) represents weight percentage of particles with a thickness less than 3/5 (0.6 times) of their mean dimension, while the Elongation Index (EI) denotes the weight percentage of particles with a length greater than 9/5 (1.8 times) of their mean dimension. The testing procedure is uniform for both indices, adhering to specified standards for initial aggregate sorting. Testing is restricted to sizes not smaller than 6.3mm. Initially, aggregates are sorted according to sieve standards, weighed within each group, and subsequently tested using a length gauge to measure particles along their least dimension. The calculation involves determining the weight of particles passing through each slot, and FI is then determined by expressing the weight of flaky particles as percentage of the total sample weight. The maximum acceptable limit for flaky particles is set at 30 percent. Should the values surpass these limits, the aggregate is deemed unsuitable for construction applications. The specified limit of NHA (D-4791) for asphalt base course is ≤ 15% and for asphalt wearing course is ≤10%.

$$Flakiness\ Index\ (FI) = \frac{weight\ of\ flaky\ particles}{Total\ sample\ weight} \tag{6}$$

$$Elongation\ Index\ (EI) = \frac{weight\ of\ Elongated\ particles}{Total\ sample\ weight} \tag{7}$$

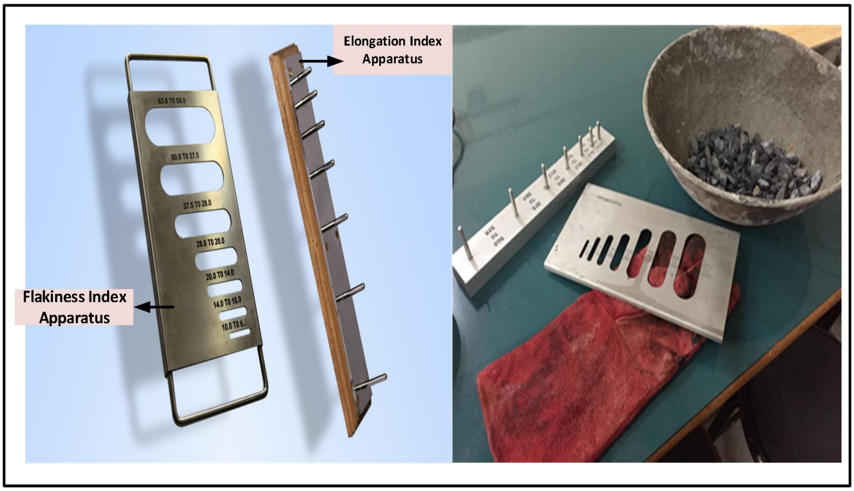

Fig. 7. Flakiness and Elongation test gauges

Fractured Faces Aggregate: It is defined as the face which is being fractured by mechanical means or by natural means and should not have slightly blunted or sharp edges. The test method describes the procedure to be performed in the laboratory for determining the fractured particles in the coarse aggregates. The sample which is retained on 4 number sieves is compared with aggregates of natural faces. The specified limit of NHA for fractured faces aggregates is ≥90%. The formula used for fractured faces calculation is as follow:

$$\frac{Fractured\ faces\ particles}{Total\ weight\ of\ particles\ retained\ on\ No{:}\ 4\ sieves} \times 100 \tag{8}$$

Aggregate Impact Value Test: The aggregate impact value test generally gives the relative strength of course aggregates against impact loading. This test requires impact testing machine, weighing balance, various size of sieve and tempering rod for the blows. This test is carried out by taking about 350gm of aggregate sample and then place the sample in the impact testing machine cup by giving 25 blows to each layer. After the test the aggregate will be taken out from the machine and subsequently subjected to pass through 2.36mm (#8) sieve and outcomes are reported as the percentage of fines passing through a 2.36mm (#8) sieve. Figure 7 depicts every part of this apparatus more precisely and clearly.

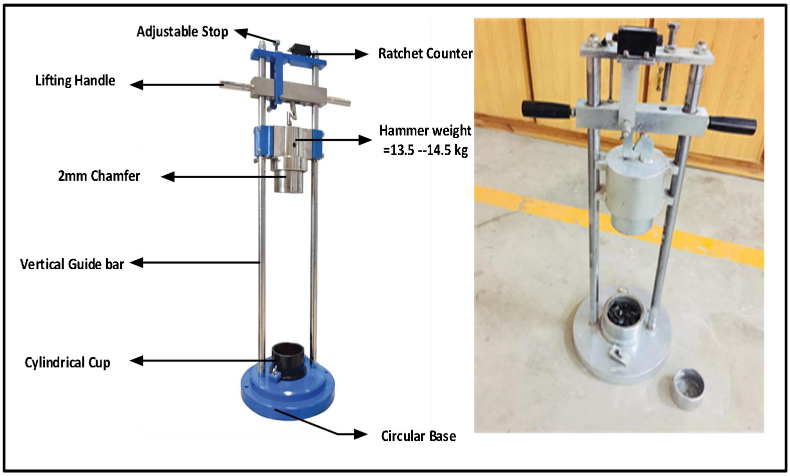

Fig. 8. Aggregate Impact Value apparatus

The aggregate impact value of aggregates is calculated by following formula:

$$AIV = \frac{weight\ of\ passing}{orignal\ weight\ of\ sample} \times 100 \quad (9)$$

3. Results and Discussions

The results of laboratory investigations were obtained from the three different quarries (Thandyani, Muzaffarabad and Swat) conducted to compare the results with international specifications.

3.1. Sieve Analysis Test

The aggregates of all three quarries were subjected to sieve analysis as tests were performed on three types of particles distributions i.e., for ¾", 3/8" and 1.5" size. The first pass indicates for 80 – 100% passing the sample from #4 mesh screen. After that, 60-90% sample must pass through this mesh screen. At least 5-15% mesh must pass through # 200 sieve, showing that material is extremely fine. The sieve analysis of Muzaffarabad and Swat aggregates was mostly similar and depicts the gradient curve fulfilling the NHA requirement for sub-base and asphaltic course. The gradation curve for all three quarries is consistent and in defined limits of the tests. The test was performed on the aggregates for every single sample of each size precisely observing the particle size distribution. Figure 9. shows the sieve analysis graph trends for all quarries as Swat and Muzaffarabad quarries aggregates showing better results comparatively with Thandyani aggregates as aggregates passed between 15-40% through #10 sieve for aggregate course according to NHA-A and NHA-B gradation limits. Swat aggregates showed 47% passing on sieve #04 for type A and type B aggregate base course fulfilling the NHA gradation limits. The overlapping of values in the figures depicts that coordinates of all different quarries' aggregates are lying on same position on the gradient curves.

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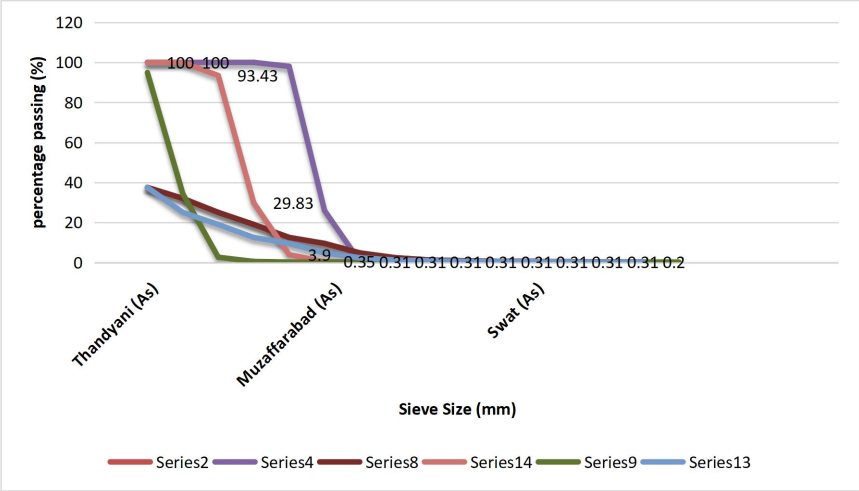

Fig. 9. Particle size distribution of coarse aggregates

3.2. Specific Gravity and Water Absorption Test

The test was performed by following ASTM C-127 and sample specimen was surface dried keeping it in the oven. The sample aggregates were immersed again into the water for 24 hours and weighted (SSD) then. After being subjected to an additional 24-hour period of oven drying at 110°C, the sample was weighed again. Calculated through the weighing of aggregates in various states such as saturated surface dry, saturated, and oven-dry conditions, the parameters of oven-dried bulk specific gravity, apparent specific gravity, and saturated surface dry bulk specific gravity were determined. Apparently, the percentage of water absorption for all three quarries aggregates were determined by using its formula (e.q. 3), revealing that Thandyani and Muzaffarabad aggregates meeting the specified requirements of NHA specifications for all types of aggregates while Swat aggregates exceeding the specified limit i.e., 2% asphalt base course and granular base course. Tests were repeated to ensure the water absorption of Swat aggregates and thus, all the times the results were crossing the specified values of water absorption. The specific gravity of Muzaffarabad aggregates remained less than 3% for sub base course and aggregate base course aligning within the requirements while Thandyani aggregates and Swat aggregates showed relatively higher value than Muzaffarabad aggregates surpassing the specified limit 3% of NHA standards.

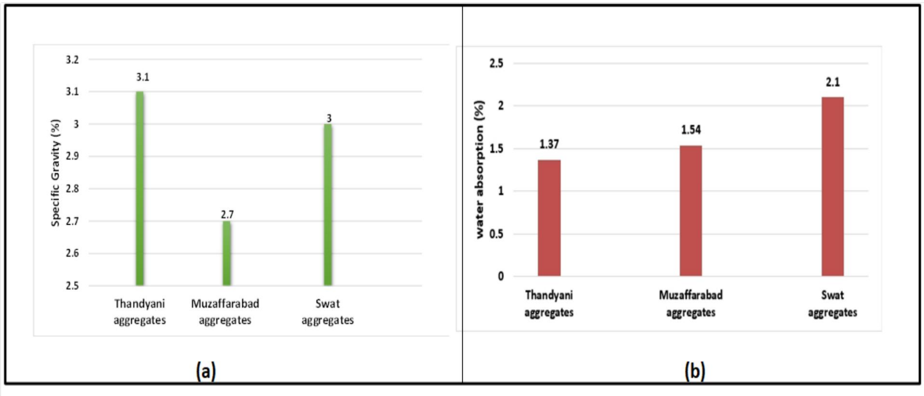

Fig. 10 (a, b). Specific gravity and water absorption of different types of aggregates

3.3. Aggregate Impact Value Test (AIV)

The AIV of Muzaffarabad aggregates were found extremely good for base and sub-base layers as the value is below 20% indicating it exceptionally strong (Figure 11). The aggregates are considered very good for road and rigid pavements based upon the obtained results. The AIV of Swat and Thandyani aggregates satisfies as good for granular base course and asphalt base course satisfying NHA- A and NHA-B specified limits. The value criteria of international standards for aggregate impact value test is as mentioned:

<20% Exceptionally resilient

10 – 20% Strong enough

20 – 30% Suitable for road surfacing.

>35% Not recommended for road surfacing due to weakness.

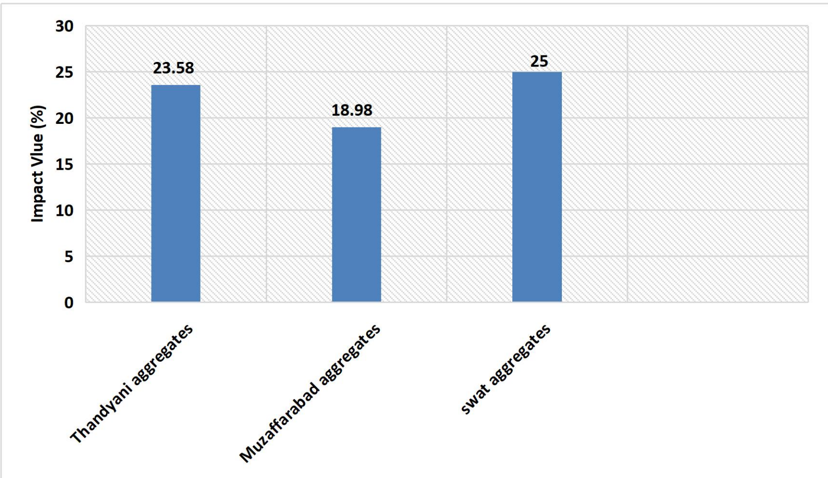

Fig. 11. Aggregate Impact Value of different aggregates

3.4. Los Angles Abrasion Test

For determination of durability and toughness of the coarse aggregates, this study recommends to employ Los Angles Abrasion test. The test examines the deterioration of coarse aggregate samples when they are placed in a drum along with steel balls. field. The test exhibits a reasonable correlation with the generation of dust during handling the sample and hot mix asphalt (HMA) production., where higher L.A. abrasion loss values are linked to increased dust generation. According to NHA specification (T-196), the AIV value of Thandyani aggregates depicts more better results than Muzaffarabad and Swat aggregates for aggregate base course and asphalt base course but weaker results for granular sub-base course (Figure 12), however, the other quarries results are also satisfying and lying within the specified boundaries values for aggregate base course i.e ≤40%.

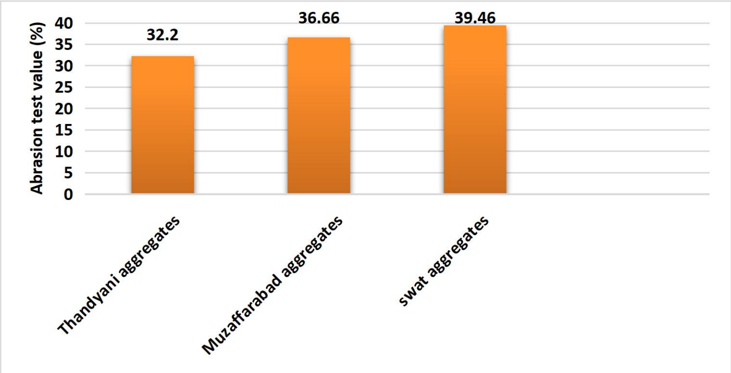

Fig. 12. Abrasion test values of various quarries

3.5. Fractured Faces Particles

The test is employed to check the quality of aggregates in the construction applications. The test was performed in the lab following ASTM D-5821 on all aggregates of mentioned quarries. Aggregates with high percentage of fractured faces tend to tend to resist wear and abrasion better and also contribute to improve interlocking and strength between particles enhancing the overall strength and durability of the construction. According to international specification [12], fractured faces should not be less than 90% in coarse aggregates. The fractured faces value of swat aggregates is below than 90% indicating that aggregates are less durable and strong as compared to Muzaffarabad and Thandyani aggregates in Figure 13. According to NHA specification, Muzaffarabad and Thandyani aggregates are suitable for aggregates base course, concrete and asphalt course as compared to Swat aggregates.

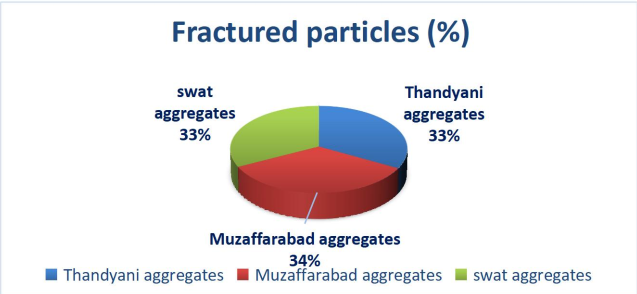

Fig. 13. Fractured faces particles of different aggregates

3.6. Light Weight Particles

The lightweight particles test in coarse aggregates is essential for assessing the quality and suitability of materials for construction applications. Lightweight particles, such as organic matter, clay lumps, and coal, can adversely affect the performance and durability of concrete mixes. This laboratory test involves separating and identifying these lightweight particles within the aggregate sample. One common method is ASTM C123/C123M, which provides standardized procedures for determining the amount of lightweight material in aggregates. The significance is that it has ability to ensure that aggregates used in construction meet specified quality standards. The maximum specified limit of this test according to NHA specification and international specification is 2%. The aggregates of Muzaffarabad, Thandyani and Swat are within the specified limits (Figure 14) depicting suitable for sub base, concrete, asphalt wearing and granular sub-base course materials.

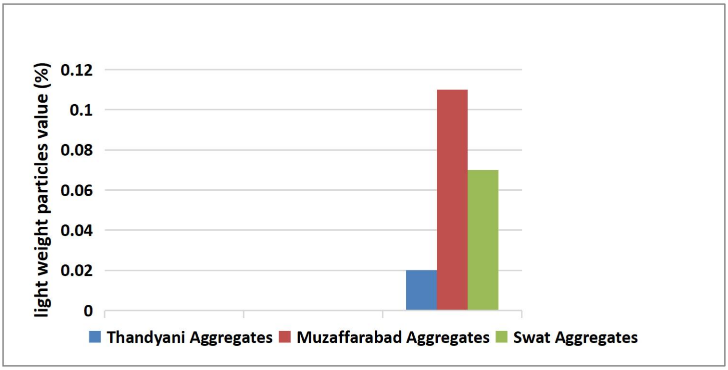

Fig. 14. Light weight particles of aggregates

3.7. Flakiness Index (FI) and Elongation Index (EI) Test

The FI and EI are vital parameters in the characterization of coarse aggregates, providing valuable insights into their shape characteristics and suitability in construction industry. The FI represents the percentage by weight of flat and elongated particles in relation to a specified thickness gauge. Lower FI values are preferable, indicating a higher proportion of cubical or equidimensional particles. Similarly, the Elongation Index assesses the percentage of elongated particles in the aggregate. A lower Elongation Index is desirable, signifying a higher percentage of non-elongated particles. Both indices play a crucial role in influencing concrete workability, compressive strength, and overall durability. Laboratory tests were undertaken to evaluate the shape characteristics of aggregates of different sizes, focusing on identifying whether they are flat or elongated. From figure 15, it is obvious that elongation index of all these quarries are within the specified limits i.e., 20-45%. In case of flakiness index, the Swat and Muzaffarabad aggregates fulfill the specified limits while Thandyani aggregates are showing results (31.1%) above than specified limit i.e., 15 -30%. According to NHA specification (D-4791), Thandyani aggregates are crossing the specified limits for asphalt wearing course and asphalt base course for flakiness index test while in case of elongation index, all quarries aggregates fulfill the required specification.

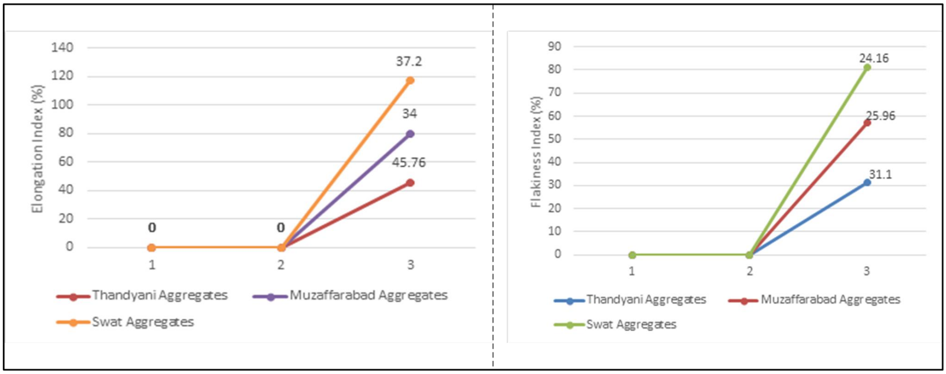

Fig. 15. Flakiness and Elongation Index of different types of materials

3.8. Soundness Test

In the case of Muzaffarabad aggregates, the soundness value is 6.6 %, while Swat and Thandyani aggregates exhibit values of 3.75% and 4.57%. After undergoing five cycles of immersion in a Na_2SO_4 solution followed by drying, the obtained percentage values fall within acceptable limits of 12% for base course and 10% for cement concrete. This indicates satisfactory soundness value for all the quarries aggregates for sub base, base course asphalt base course and asphalt wearing course according to NHA specification (T-104) and international standards.

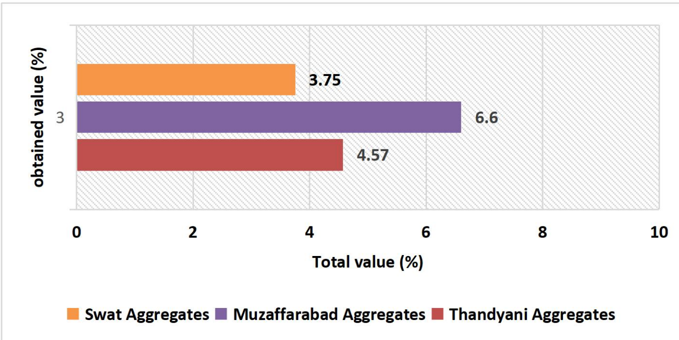

Fig. 16. Soundness test on different types of aggregates

3.9. Comparison of Results

In the comparison of Thandyani, Muzaffarabad, and Swat aggregates, all three regions generally meet the specified limits of NHA and international standards for clay lumps, water absorption, fractured particles, and light weight particles, demonstrating their suitability for construction. However, the Los Angeles Abrasion test reveals that Swat aggregates slightly exceed the maximum value of 25%, suggesting a potential concern for sub base course, aggregate base course and road surfacing applications. Additionally, the Elongation and Flakiness test indicates that Thandyani aggregates exhibit values higher than the specified limits, possibly affecting concrete workability. While Muzaffarabad aggregates meet the specified limits of NHA and international standards for most tests, the soundness test showed a higher susceptibility to sodium sulfate solution as compared to Swat and Thandyani aggregates, but lies within the specified limits. Overall, a comprehensive assessment of these aggregate properties is crucial for ensuring optimal performance in diverse construction scenarios. The table compares all the tests results of coarse aggregates of these three quarries within the specified limits.

Table 5. Comparison of results of different quarries

Name of the test	Thandyani aggregates	Muzaffarabad aggregates	Swat aggregates	Specified Limits
Clay lumps and friable particles test	0.44%	0.48%	1.47%	< 2%
Water absorption test	1.37%	1.54%	2.1%	<2% ok
Aggregate impact value test	23.58	18.98	25%	<20% Exceptionally resilient 10 – 20% Strong enough 20 – 30% Suitable for road surfacing >35% Not recommended
Los Angles Abrasion Test	32.2%	36.66%	39.46%	Maximum value 25% (NHA Specifications)
Fractured particles	90.7%	94.2%	89.12%	> 90 % ok < 90% fail
Light weight particles	0.02%	0.11%	0.07%	Maximum 2%
Elongation and Flakiness test	45.76%, 31.1%	34%, 25.96%	37.2%, 24.16%	E.I = 45%, F.I = 30%
Soundness Test	4.57%	6.6%	3.75%	sodium sulphate solution, ≤10% NHA Specification = <12%

4. Environmental Challenges and Countermeasures

The extraction of natural aggregates from these concerned quarries contribute to significant environmental concerns of alarming proportions. This study highlighted the following serious environmental issues associated with excavation of natural aggregates at these sites.

a. Extraction of natural aggregates from Muzaffarabad quarry is leading to soil erosion and causing the surface depletion of natural environment.
b. The release of dust and particulate matter generated from these three quarries aggregate plant industries contributing to air pollution, noise and visual blight.
c. Excavation of aggregates from Thandyani quarry affecting the aesthetic value of natural green environment of District Abbottabad and altering the natural landscape.
d. The sediments and pollutants generated from Swat aggregates industries causing the contamination of water and adversely affecting the natural water resources of the local area and sustainable environment.

The study underscores the importance of exploring alternative and eco-friendly approaches to replace the natural aggregates of these quarries with recycled concrete aggregates. The study further emphasizes to explore renewable energy sources instead for excavation of aggregates to reduce overall energy consumption during the crushing process in the plants. Strategically employing dust control technologies, noise reduction measures, and aesthetic design principles in excavation of natural aggregates at Muzaffarabad, Thandyani and Swat aggregates, can collectively minimize air pollution, disturbances to local ecosystems and ensure sustainable environment.

Conclusion and Recommendations

Aggregate samples from Thandyani, Muzaffarabad, and Swat underwent rigorous testing by following ASTM/BS standards to assess their physical, mechanical and chemical properties. Thandyani aggregates generally meet NHA and international standards, with exceptions in Los Angeles Abrasion, and Flakiness Index tests. Muzaffarabad aggregates showed exceptional results in specific gravity and fractured faces but deviated in Los Angeles Abrasion and Elongation Index tests. Swat aggregates generally comply with standards, with exceptions in Los Angeles Abrasion, specific gravity, absorption, and fractured faces tests. In conclusion, Muzaffarabad aggregates demonstrate superior resistance, durability, and stability, followed by Thandyani aggregates meeting NHA specifications with minor exceptions. Using these aggregates for diverse construction projects is cost-effective, readily available, and durable for road pavements. Future research in the same domain will concentrate on exploring the creep and shrinkage characteristics of concrete manufactured using aggregates acquired from these three quarries. Specific tests such as X-Ray Diffraction (XRD), X-Ray Florescence (XRF) and Scanning Electron Microscopy (SEM) can be performed on these quarries aggregates to analyze their crystalline structure, surface investigation through high resolution images and alkali-silica reactivity during the concrete mix design. Furthermore, recycled concrete aggregates can replace natural aggregates as an alternative source to achieve sustainable goals for green environment.

Disclosures: The authors declare no conflict of interests.

Data Availability: The data that support the findings of this study may be obtained from author on a reasonable request.

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