Comparing the Consensus Properties of Aggregate Sources from KP to Margalla Using Image Analysis

Fazli Karim*, Shahid Iqbal†, Asim Farooq‡, Hanif Ullah§, Muhammad Imran**

Abstract

Hot Mix Asphalt (HMA) is a composite material composed of coarse aggregate, fine aggregate, filler, binder, and air voids. The macro-level characterization of aggregates for asphalt mixture production in Pakistan has introduced inconsistencies in estimating the actual performance of asphalt mixtures. Pakistan typically sources all aggregates needed for asphalt mixtures from Margalla, but there is a possibility that the quarry may be finished soon. To identify a nearby quarry, aggregate samples are collected from various quarries in Pakistan. The aggregates are examined using Scanning Electron Microscope (SEM), X-ray spectroscopy, and conventional index characteristics. The results showed that Margalla aggregate's coarse-grained configuration is the dominant reason for adequate physical properties compared to other aggregate sources. The Malakand aggregate is found to be comparable to Margalla due to its coarse-grained cum irregular loose-grained structure. Amorphous textures superseded dense, coarse-grained textures in some of the aggregate sources, resulting in increased water absorption. The local Malakand quarry is suggested for use in the construction industry based on macro and micro-level investigations.

Keywords**:** Hot Mix Asphalt; Scanning Electron Microscope; X-ray Spectroscopy; Aggregate; ASTM Standard.

Introduction

In order to create cement or asphalt concrete, inert components known as aggregates are combined in predetermined amounts with a binding substance. They provide concrete its strength, durability, and hardness while also acting as fillers or components that increase volume. A number of factors affect how long Hot Mix Asphalt (HMA) lasts, but volumetric characteristics like air voids (AV) and voids in mineral aggregates (VMA) have a major role (Karim et al., 2021). The Margalla

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aggregate is currently in practice and considered to be the best source of coarse aggregate for usage in subbase, base, and surface courses in Pakistan. Additionally, stone dust, a fine powder created as a byproduct of rock crushing, is utilized as a filler and binding material in the construction of highways (Parker et al., 1998). The Punjab province uses the aggregates from the Kirana Hills near Sargodha on a variety of road construction projects. A vast amount of strong and affordable aggregates is required to support the expanding road network (Gurley et al., 1988). Another prospective source of high-quality aggregates is the Dina quarry, which is close to Jhelum and now only produces aggregates for building construction. When choosing an aggregate for use in the building sector, consideration for aggregate characteristics is crucial (Javid et al., 2006). Any coarse- to medium-grained substance that is generated from natural (igneous, sedimentary, or metamorphic rocks) or synthetic (geosynthetic aggregates) components, depending on the source and technique of use, is referred to as an aggregate. The most commonly utilized component in the construction of pavement is aggregate (Bilqees and Shah, 2007). To withstand traffic impacts, aggregate mixtures must be able to tolerate plastic deformation and have a high resilience modulus (Little, 1998). Additionally, aggregates must be free of plastic particles, withstand disintegration and weathering in place, and drain properly (Sulehri, 2006).

In Pakistan, the main technique for creating aggregates is by first quarrying rocks and then crushing them into the required size (Zhand et al., 2020; Mouhamed and Qiu, 2017). Pavement engineers must consider a number of elements when choosing and identifying the quality of aggregates while planning the building of pavement (Price, 2003). Before being used as a component of a road, an aggregate must satisfy a standard specification. The backbone of Pakistan is a vast intercity network of roads and highways, which carries 96% of the nation's freight. In industrialized countries, productivity and economic progress depend on the extensive use of aggregates (Benhabib and Spiegel, 1994). In Pakistan, the bulk of the roads need to be upgraded due to their bad state. To speed up nation-building efforts, new roads, highways, and other infrastructure are required in addition to other national development projects (Ahsan and Gondal, 2016). Pakistan has a population of more than 208 million people and a total area of 796,095 square kilometers (Wazir et al., 2020). It also has a thorough road network of 228.026 kilometers. Building projects for businesses, individuals, the private sector, and the government are actively underway with support from the Pakistan National Highways Authority (NHA) (Ahsan, 2008). Over 70 nations are linked by the vast China-Pakistan

Economic Corridor (CPEC), which runs through Pakistan's Gwadar port. The CPEC project includes numerous long-term and short-term projects, such as roads, railroads, and fiber optic installations. These lines also contain tunnels and bridges. Additionally, both major and small building structures are included in this concept (Bhattacharjee, 2015; Shah, 2018; Ali, 2018; Qadir, 2021). The Pakistani road network greatly affects both domestic and international freight movement. Pakistan is connected to countless seaports, including Gwadar Port and Port Qasim, because of its geographic location in South Asia. The Pakistani road network is not only for the country's own use; it also serves as the only commercial route to Afghanistan, a landlocked nation. As a result, stable pavement strength is essential for the efficient operation of freight transit. Pakistan's motorways are thought to be the only route for Middle Eastern oil and petroleum to be transported. Large reserves of the prospective aggregate materials are needed for such large projects (Rehman et al., 2021).

To investigate engineering characteristics including specific gravity, impact value, water absorption, and hardness, aggregate samples from the Pakistani quarries of Margalla, Sargodha, and Sakhi Sarwar are gathered. Sakhi Sarwar revealed a failure to adhere to the American Society for Testing and Materials (ASTM) standard limitations, in contrast to all other specified sources of aggregates (Khalid and Asim, 2020). To investigate aggregate's engineering characteristics, such as hardness, specific gravity, water absorption, and gradation, aggregates are collected from various sources in Bangladesh, including Tamabil, Sylhet, Panchagarh, and Patgram. Except for Panchgarh, all of the sources for the aggregate confirmed the specification limits. However, it is discovered that the Patgram source's Los Angeles abrasion value is higher than that of the other sources (Khan et al., 2023). Aggregates are taken from five sources: Chiniot, Margalla, Sikhanwali, Takial, and Khairabad. An investigation is conducted on engineering characteristics including soundness, aggregate impact value, Los Angeles abrasion value, and fractured faces of aggregate. All the aforesaid sources, excluding Sikhanwali, confirmed the specification limits, but the Margalla source is the best in terms of performance (Rehman and Azad, 2020). To analyze the consensus qualities, aggregates are gathered from the Margalla, Mansehra, and Pir-Sohawa sources. The aggregate's consensus properties are all examined. The aggregates produced by the Malakand and Mansehra sources met the specification limits. The Pir-Sohawa source did, however, meet the gradation, impact value, and specific gravity specification limitations but fell short of the Los Angeles abrasion and crushing parameters (Arshad and Yan, 2012). For the purpose of researching engineering qualities such as impact value, specific gravity, water absorption, and abrasion values, aggregates from Sarghoda, Margalla, Mangla, and Barnalla are gathered. The Mangla source is the only one out of all the sources to fall short of standard values for some of the attributes as per specified restrictions. However, other sources are able to obtain aggregate qualities within specified bounds (Abbas and Sabeer, 2017). Six different sources of aggregates are looked at in Ukraine and Poland. Physical properties are examined for all sources. The aggregates from Ukraine met specifications in terms of crushing strength and water absorption. The Polish aggregates' hardness values, however, did not support the specification's lower and upper boundaries. In comparison to aggregates obtained from sources in Poland, it is determined that aggregates from Ukraine are adequate for utilization (Piasta et al., 2016). The aggregates taken from Margalla and Dina are compared on the basis of their engineering properties. Margalla aggregates are considered the best for use in the pavement industry, while Dina aggregates are found to be low in hardness values and absorption (Arshad and Yan, 2012). The Margalla aggregate used in asphalt mixtures provides adequate resistance to withstand traffic and the environment (Arif et al., 2020). Due to a dearth of up-to-date standards-based research on local aggregates, Pakistan normally sources the aggregates needed for engineering projects from Margalla. Only Margalla aggregates are used in Pakistan's Khyber Pakhtunkhwa and Punjab provinces' infrastructure projects. There is a possibility that the elected quarry will be over as a result. Only a few studies, to the author's knowledge, have used only macro-level research to assess and compare nearby quarries with Margalla quarry. Therefore, the current research is aimed at investigating the aggregate collected from local quarries using macro- and micro-level research so that a local quarry can be recommended for engineering infrastructure in Pakistan. The main contribution of this research study are as follows:

1) Using macro-level techniques to compare the consensus characteristics of aggregates from various Khyber Pakhtunkhwa quarries to those of typical Margalla aggregates. 2) To validate the consensus characteristics of the aggregates calculated in step 1, Using Micro-Level methods. 3) To lower the likelihood that the Margalla quarry would be finished and, as a compensation, and to save money and time on logistics by suggesting a nearby quarry for Khyber Pakhtunkhwa's infrastructure projects.

Materials and Methods

The current study is carried out at the Highway and Transportation Engineering laboratory of Sarhad University, and Center of Excellence in Geology, Peshawar, Pakistan. The combined aggregate with varying sizes, including coarse, fine, and filler, are gathered from Pakistani quarries named Margalla, Swabi, Malakand, Besai, and Kohat as shown in Figure 1.

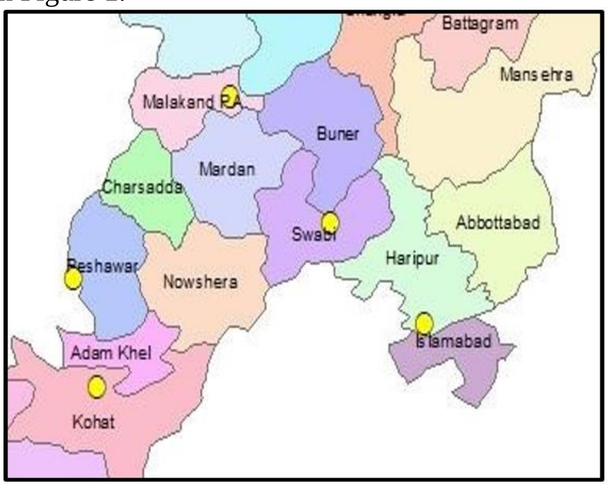


Figure 1: Selected Quarries for Current Study (Mineral Transformation Plan, 2025).

The aggregate samples are assessed for hardness, impact values, flakiness, elongation index, soundness, and water absorption in accordance with ASTM standard because it governs worldwide. In order to meet the aforementioned goals, Energy Dispersive Spectroscopy, and Scanning Electron Microscopy (SEM) are also used to evaluate the aggregate’s elemental composition, mineral composition, and morphological structure. Results from investigations at both the macro and micro levels are compared, and conclusions are drawn. The complete methodology is presented in Figure 2.

In this investigation, SEM JEOL JSM IT 100 equipped with features for Energy Dispersive X-ray Spectroscopy (EDS), Backscattered Electron Detector (BSED), and Secondary Electron Detector (SED) is employed at magnifications ranging from 100 to 30,000, as shown in Figure 3a (Karim, and Hussain, 2021). To expose the material's interior structure, the aggregate specimens are first sliced using a diamond saw to prepare the sample. The material is subsequently divided into specimens measuring 10 mm by 10 mm by 6 mm, and 8 mm by 8 mm by 6 mm. The sample is next coated with gold (4 nm thick) thin film by Gold

Sputter Coater in order to render the surface of the sample conductive, as shown in Figures 3b and 3c. This metal coated layer is so thin that it preserves and allows SEM to see the entire micro pattern on the sample's surface, as illustrated in Figure 3c. SEM image analysis is used to thoroughly investigate the materials and record the results.

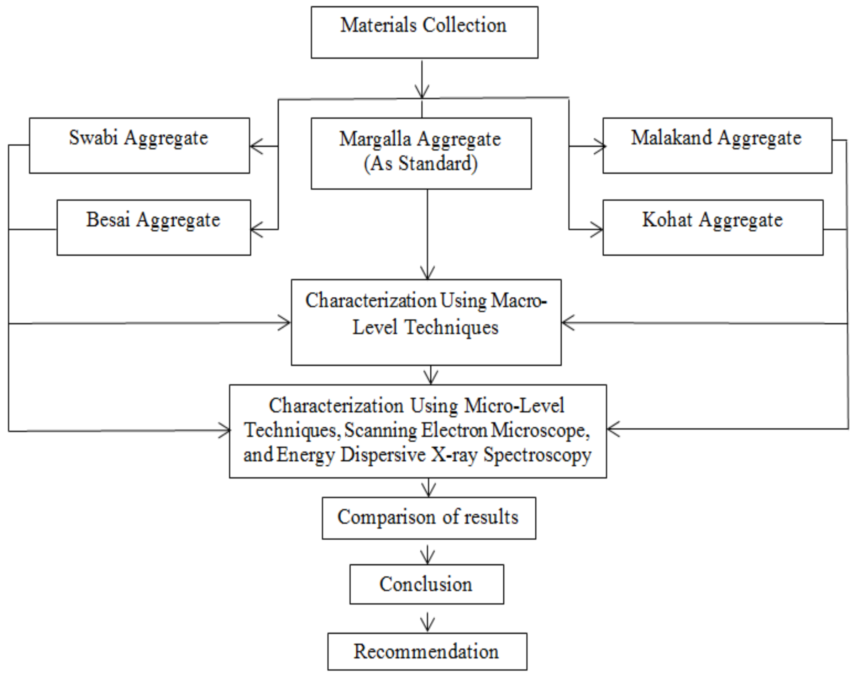


Figure 2: Flowchart representing research methodology.

Figure 3: (a) SEM Set-up, (b) Gold Coater, (c) Sample Coating.

Results and Discussion

According to ASTM criteria, the combined aggregate blends are produced using the designated quarries depicted in Figure 1. All of them confirmed the specification limits as shown in Figure 4.

The abrasion value of aggregate measures how robust the material is to support loads. Aggregates with a lower abrasion value are more resistant to abrasion. Any form of aggregate's abrasion value must be less than 50%. According to the test, described in ASTM C131, the findings for the specified aggregate sources are obtained, where the Margalla aggregates have a lower abrasion value than the other types of aggregates at 20.64%. The abrasion value for Malakand aggregates is 25.48%, whereas it is 28.94%, 29.58%, and 34.2% for Kohat, Swabi, and Besai, respectively. Figure 5 displays the abrasion values for all aggregate sources.

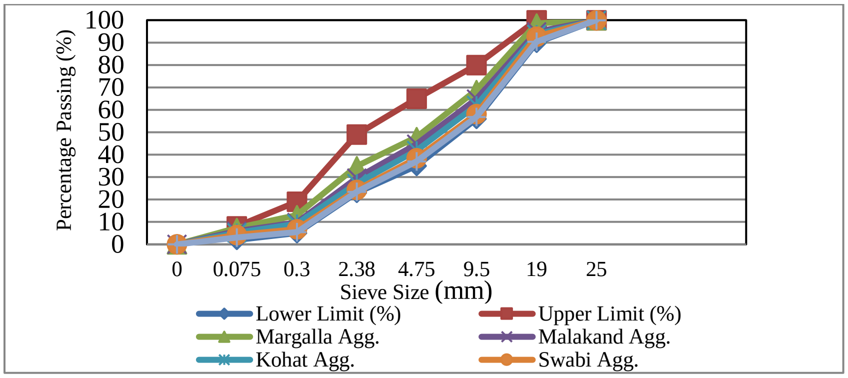


Figure 4: Grain Size Distribution Curves.

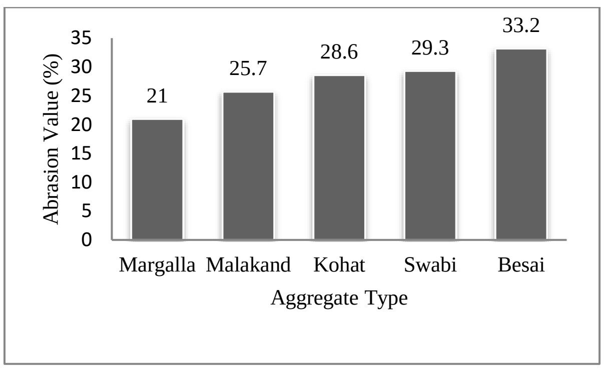


Figure 5: Variation in abrasion values of aggregate.

Flakiness index testing is used to calculate the percentage of aggregate particles that are flaky for all sources. Because the range for the flakiness index value is 15%, it is recommended that the percentage of flaky aggregates used in a required blend not exceed 15%. As compared to all other sources, the flakiness index value for aggregates from Margalla is lower at 4.2%, whereas aggregates from Malakand had a flakiness index value of 7.6%. For the aggregates of Kohat, Swabi, and Besai, the flakiness index values are, respectively, 8.7%, 12.8%, and 14.4%. The aforesaid Figure 6 depicts the flakiness index for all sources.

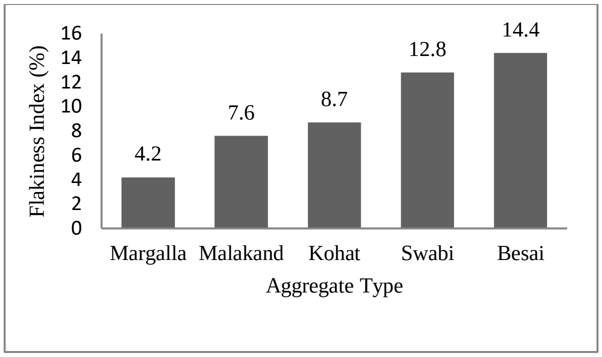


Figure 6: Variation in flakiness index of aggregate.

By using the elongation index test as per ASTM D4791, the percentage of aggregate particles that are lengthened is calculated for all sources. Since the range for the elongation index value is 15%, the amount of aggregate particles that are elongated should not be greater than 15%, as doing so will make the aggregates unsuitable for application. Margalla aggregates has an elongation index value of 4.6%, which is lower than all other sources, while Malakand aggregates had an elongation index value of 8.7%. The aggregates from Kohat, Swabi, and Besai possessed flakiness index values of 9.2%, 12.4%, and 14.1%, respectively. Figure 7 lists the elongation index values for all sources.

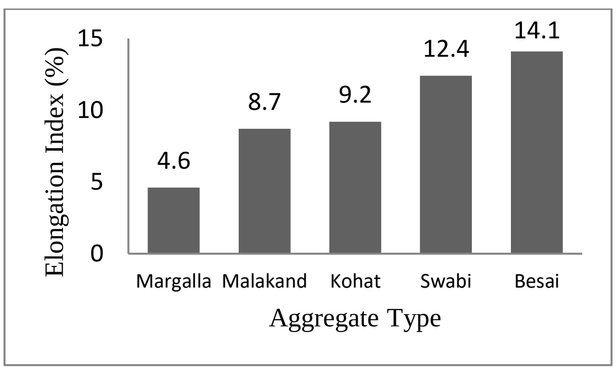


Figure 7: Variation in elongation index of aggregate.

The amount of aggregates that are crushed when a load is applied is referred to as the impact value of the aggregates. A higher impact value of the aggregates indicates that they are not sturdy enough to withstand the impact of loads. 10% is the typical aggregate impact estimate. All of the aggregates have impact values that are lower than the limit, according to the test findings on the various aggregate sources. The impact values recorded are 5.7% 7.2%, 8.1%, 8.3%, and 9.4% for the aggregates of Margalla, Malakand, Kohat, Swabi, and Besai respectively. Figure 8 presents the impact values for all specified sources.

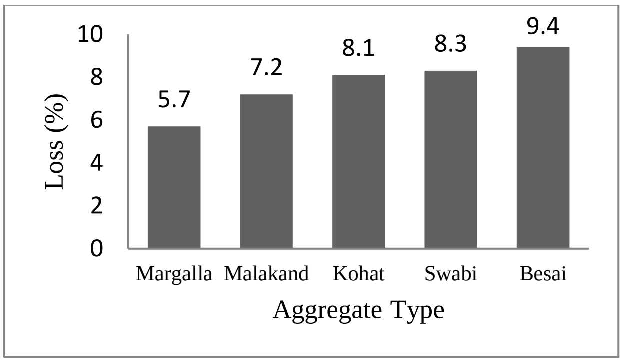


Figure 8: Variation in loss of impact value of aggregate.

Damage to the wearing course of the pavement results from the weathering and disintegration of the aggregates caused by freezing and thawing. The soundness test is conducted as per the procedure described in ASTM C88. Low soundness values indicate that aggregates are more resistant to the impacts of weathering and freezing/thawing. Less than 18% of the aggregates soaked in magnesium sulphate are considered sound. According to the findings of the soundness test, the Margalla aggregates have a low degree of unsoundness value of 5.2%, whereas for the Malakand, Kohat, Swabi, and Besai are 8.1% , 9.7%, 9.9%, and 11.2%, respectively, indicating that all of these values are below the limit. Figure 9 describes the degree of unsoundness values for all sources.

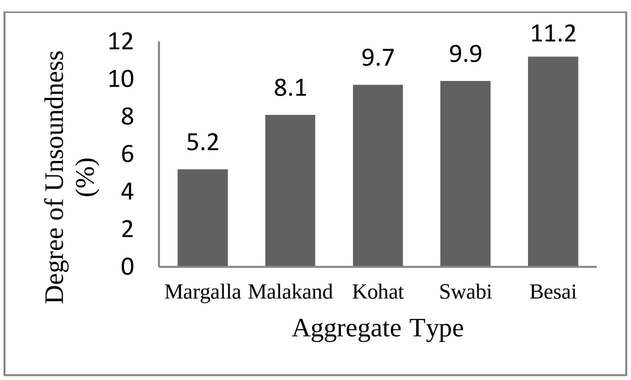


Figure 9: Variation in degree of unsoundness of aggregate.

The angularity or roughness of an aggregate particle is represented by its fracture face. Due to its use in wearing courses, which results in surface roughness that is ideal for friction between the road surface and the tyres of the vehicles, the fractured face of aggregate is particularly important to note. The aggregates used in the asphalt mixture for the wearing course will be better suited if the fracture faces of the aggregates are greater. According to the results of the fracture face test performed on all aggregate sources, Margalla aggregates have the highest fracture value of 99.7%. This is because Margalla aggregates more than from any other source have aggregates with fractured faces, as shown in Figure 10.

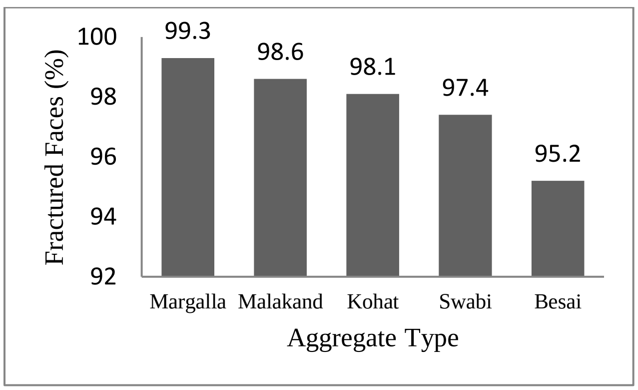


Figure 10: Variation in fractured faces of aggregate.

The two main characteristics of aggregates required to create mixes for the construction of roads are specific gravity and water absorption, which are evaluated as per ASTM 127. Between 2.5 and 3 is the specific gravity range. Each aggregate used in this test, drawn from various quarries, has a specific gravity that falls within the acceptable range. Additionally, the values for water absorption are within the range. Margalla aggregates had a specific gravity of 2.89, whereas Malakand aggregates had a specific gravity of 2.81, which is higher than that of other quarry aggregates. The aggregates from Kohat, Swabi, and Besai have specific gravities of 2.7, 2.68, and 2.57, respectively. Additionally, the Margalla aggregates have low water absorption of 0.38, while the Malakand aggregates had a water absorption value of 0.52. Kohat, Swabi, and Besai have water absorption values of 0.76, 0.79, and 0.94 respectively. The variation in specific gravity and water absorption values is shown in Figure 11, and 12.

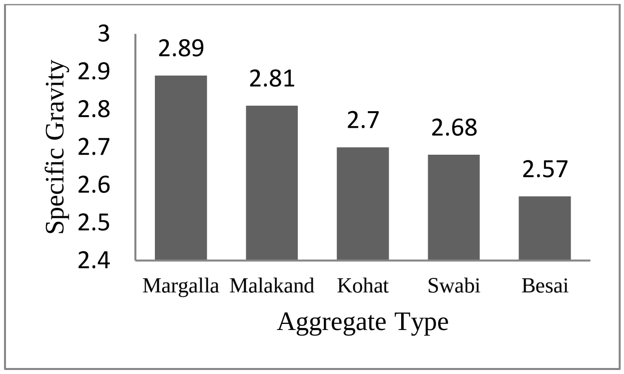


Figure 11: Variation in specific gravity of aggregate.

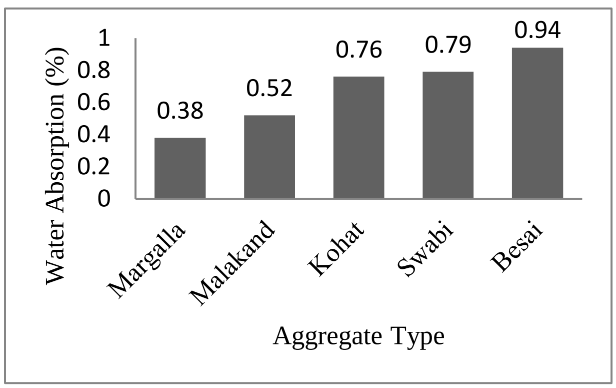
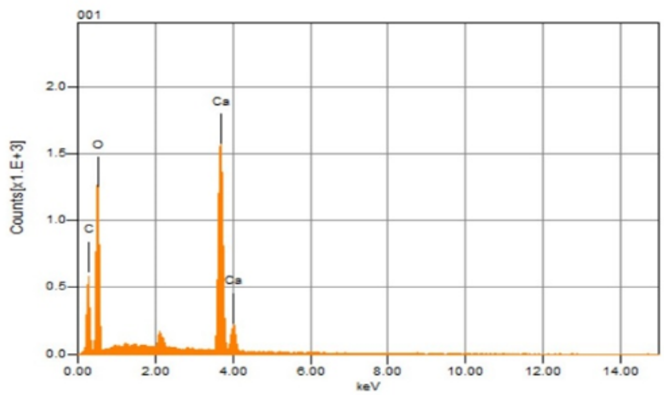


Figure 12: Variation in water absorption of aggregate.

Image Analysis using SEM and X-Ray Spectroscopy

A total of 45 samples are analyzed, with 15 samples used for each of the EDS, SEM, and X-ray spectroscopy analyses. The observations described below are made: The specified image shown in Figure 14 of the Margalla aggregate is taken at magnifying power x1000, with a bar scale of 10 micron, using SEM. The image demonstrates the presence of heavier, more uneven agate-coatings at the aggregate's surface, which may affect the durability of isolated Margalla aggregate primarily due to geological processes in the earth crust. The aggregate comprising coarse grains are more capable of withstanding traffic and environment as compared to the aggregate comprising amorphous structure. The morphology also exhibits loose or spaced-grained structure, which could result in varied characteristics. Compared to other forms of aggregate, the structure will respond to traffic and the environment efficiently. Figure 13's depiction of the morphology of the

Margalla aggregate reveals the mechanism generating the adequate consensus features noted during Macro-level analysis. Figure 14's illustration depicts the Margalla aggregate's elemental makeup, which includes calcium, carbon, and oxygen.



Formula	mass%	Atom%	Sigma	Net	K ratio	Line
C	16.10	23.26	0.03	14087	0.0047957	K
O	62.02	67.27	0.23	33254	0.0517343	K
Ca	21.89	9.48	0.11	88102	0.0665267	K
Total	100.00	100.00				

Figure 13: Elemental Composition of Margalla Aggregate.

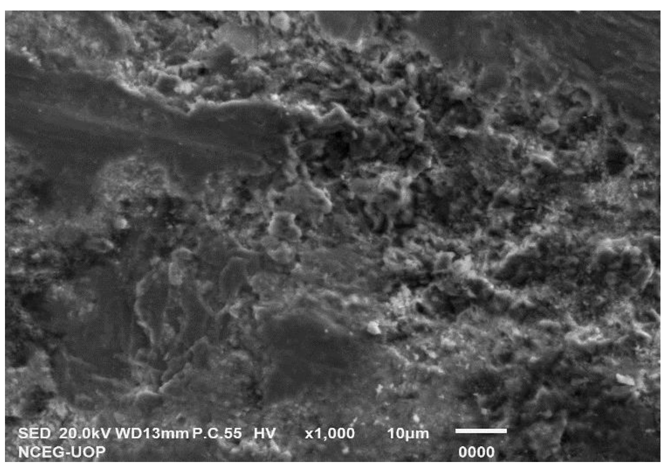
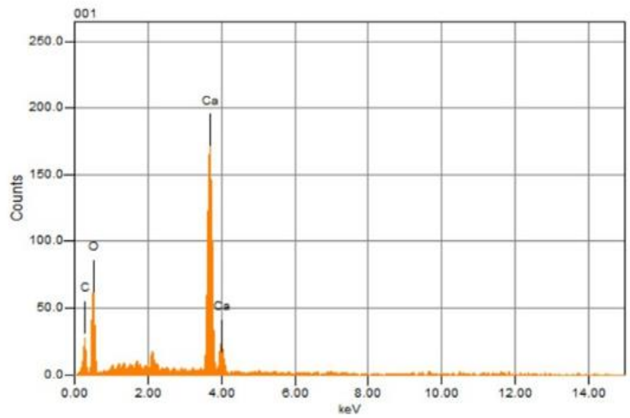


Figure 14: SEM Image of Margalla Aggregate.

SEM is used to capture the image of the Malakand aggregate shown in Figure 16 at a magnification of x1000 and a bar size of 10 microns. The majority of the amorphous-Cum-Crystalline irregular loos grained structure is shown by the morphological investigation. In comparison to Margalla aggregates, the structure will have lower response to traffic and the environment. The configuration of the Malakand aggregate, illustrated in Figure 14, follows the Margalla aggregate and reveals the mechanism underlying the adequate consensus features noticed during Macro-level analysis. The illustration in Figure 15 depicts the elemental makeup of Malakand aggregate, which has almost identical amounts of Calcium, Carbon, and Oxygen.



Formula	mass%	Atom%	Sigma	Net	K ratio	Line
C	11.54	18.53	0.10	665	0.0003048	K
O	53.74	64.77	0.95	1489	0.0031192	K
Ca	34.72	16.70	0.53	9106	0.0092579	K
Total	100.00	100.00				

Figure 15: Elemental Composition of Malakand Aggregate.

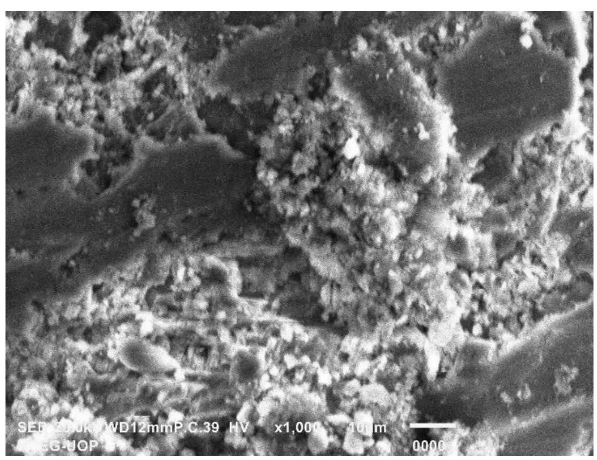
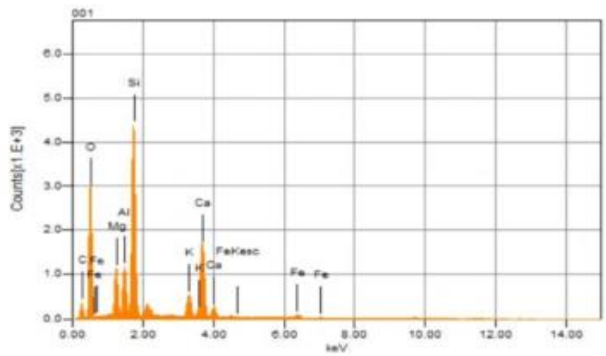


Figure 16: SEM Image of Malakand Aggregates.

The image illustrated in Figure 18 of the Swabi aggregate is taken at Magnifying power 1000, and a bar scale 10 Micron, using Secondary Electron Detector (SED) for surface morphology. The sedimentary clusters, in the image shown in Figure 18, are of coarse granularity. Weak aggregate clusters are weakly bonded together via weak interface bonds. The graphic in Figure 17 shows that Swabi aggregate has a completely different elemental makeup from Margalla and Malakand aggregate, with the highest percentages of oxygen, silicon, and other elements.



Formula	mass%	Atom%	Sigma	Net	K ratio	Line
C	11.28	17.71	0.03	9006	0.0030812	K
O	49.74	58.66	0.12	80036	0.1251341	K
Mg	4.54	3.53	0.04	37745	0.0230436	K
Al	3.84	2.68	0.03	40177	0.0196029	K
Si	15.80	10.61	0.07	163363	0.0769982	K
K	2.96	1.43	0.03	26839	0.0193742	K
Ca	10.32	4.86	0.05	95071	0.0721457	K
Fe	1.52	0.51	0.03	5690	0.0091739	K
Total	100.00	100.00				

Figure 17: Elemental Composition of Swabi Aggregate.

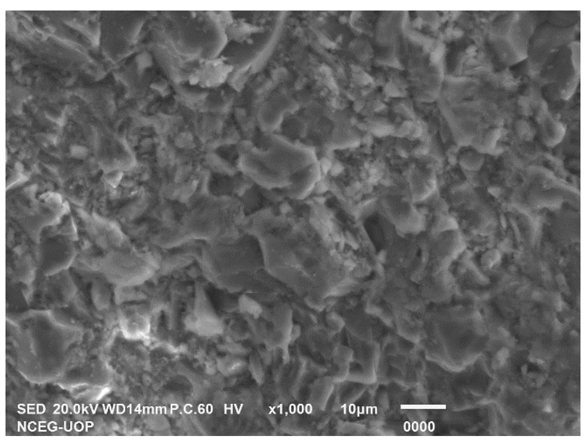
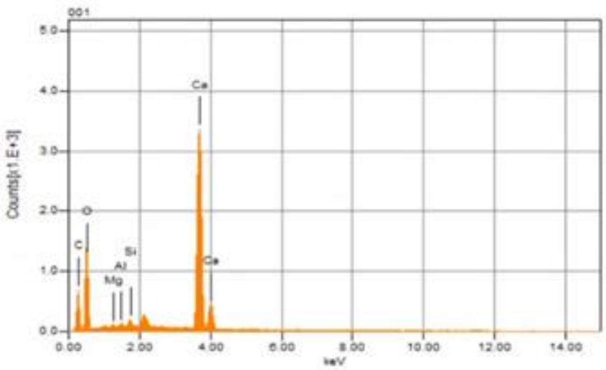


Figure 18: SEM Image of Swabi Aggregate.

The image illustrated in Figure 19 of the Kohat aggregate is captured at magnifying power 1000, and a bar scale 10 Micron, using SED for surface morphology. The image shows that the structure is amorphous with fewer coarse grain clusters. Kohat aggregate is weaker due to amorphous structure as compared to other aggregates. The graphic in Figure 20 shows that Kohat aggregate has a completely different elemental makeup from Margalla and Malakand aggregate, with the highest percentages of oxygen, silicon, and other elements.



Formula	mass%	Atom%	Sigma	Net	K ratio	Line
C	13.35	20.95	0.02	16643	0.0091534	K
O	53.62	63.16	0.19	35699	0.0897252	K
Mg	0.41	0.31	0.03	1860	0.0018250	K
Al	0.41	0.29	0.03	2459	0.0019290	K
Si	0.68	0.46	0.03	4329	0.0032797	K
Ca	31.52	14.82	0.10	191427	0.2335252	K
Total	100.00	100.00				

Figure 19: Elemental Composition of Kohat Aggregate.

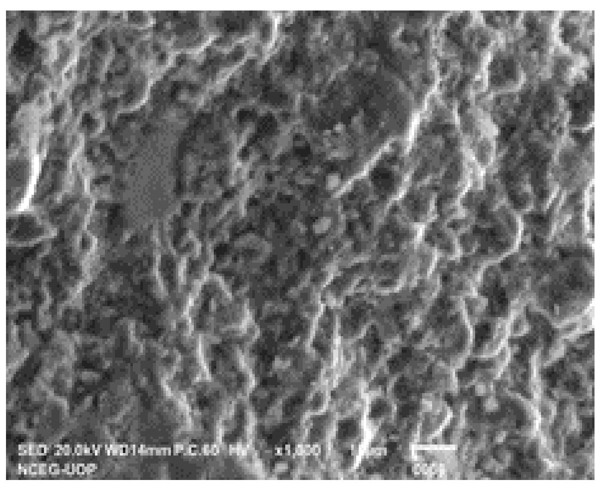
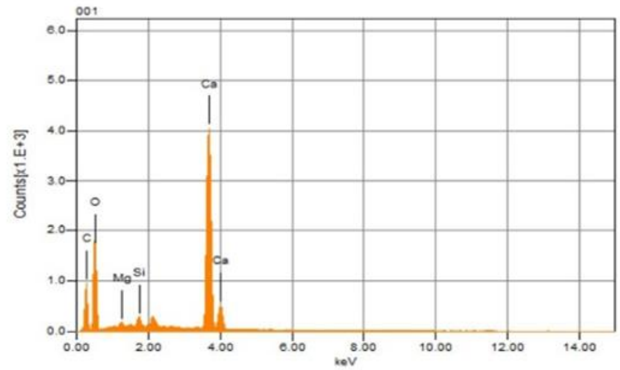


Figure 20: SEM Image of Kohat Aggregate.

The Besai aggregate image shown in Figure 22 is captured using the SED function of a scanning electron microscope for surface morphology at a magnification of 1000 and a bar scale of 10 microns. The image depicts a loose, amorphous covering surrounding a coarse-grained cluster. It is possible to perceive voids (emptiness) in morphological structure. Due to the external amorphous layer, the clusters are weaker than the Margalla aggregate because they are poorly connected. The graphic in Figure 21 shows that Besai aggregate has also has a different elemental makeup from Margalla and Malakand aggregate, with the highest percentages of oxygen, Calcium, and Carbon.



Formula	mass%	Atom%	Sigma	Net	K ratio	Line
C	14.49	22.26	0.02	22947	0.0108673	K
O	54.86	63.28	0.17	48049	0.1039867	K
Mg	0.56	0.43	0.03	3267	0.0027605	K
Si	0.92	0.60	0.03	7398	0.0048268	K
Ca	29.18	13.43	0.09	225300	0.2366646	K
Total	100.00	100.00				

Figure 21: Elements of Besai Aggregate.

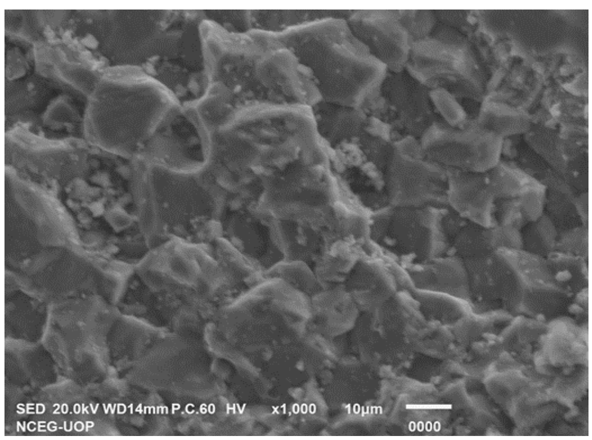


Figure 22: SEM Image of Besai Aggregate.

Conclusion

The study revealed that the Margalla aggregate's coarse-grained microstructural configuration is followed by the Malakand aggregate as demonstrated by micro-level study. The coarse-grained configuration of Margalla aggregate is the dominant reason of adequate physical properties as compared to other aggregate sources. The aggregates from all specified sources showed a declining trend in terms of physical properties. The shift in the aggregate's morphological structure from a coarse-grained to an irregular amorphous state is responsible for the declining trend. Due to its coarse-grained cum irregular-loose-grained structure, the Malakand aggregate is found to be nearly equivalent to the Margalla aggregate in terms of physical properties. The aggregates from specified sources exhibited an upward trend in water absorption, mostly due to a shift in morphological structure from a condensed, coarse-grained texture to an amorphous texture.

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