A Laboratory Experimentation Based Ranking of Margalla Crush Aggregates

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Abstract-Aggregates are the stones used in road construction and subjected to take load coming from the vehicular traffic. Selection of aggregate source plays an important role and provides a guarantee towards the pavement performance. In Pakistan, aggregates manufactured in Margalla crush quarry is considered to be the best aggregates for the pavement construction. The source and consensus properties vary throughout the quarry. One cannot rely only on testing the physical properties from the single source. This study presents the results of mechanical and physical properties of twelve aggregate sources selected from Margalla aggregate crush quarry. A ranking based methodology has been adopted to minimize the number of sources for conduction of accelerated polish stone value and surface skid resistance test. Aggregate sources were ranked based on the specific gravity and other physical and mechanical properties. A ranking based on the difference between the 'before' and 'after' polish stone value has been used for a comparison with the physical properties. Ranking based on the original Polished Stone Values was not in line with what has been determined from the basic physical properties. This study reveals that instead of conducting a number physical and mechanical tests on aggregate, one can run PSV test and obtain similar ranking for the selection of specific aggregate source.

Keywords-Pavement, Consensus, Crusher, Ranking, Physical and Mechanical Properties

I. INTRODUCTION

Polished Stone Value (PSV) of an aggregate describes the correlation between the horizontal force and the vertical force established as a tire moves along the road surface [i]. The quality of road surface and its capacity to withstand the polishing effect of road traffic is of great significance in providing skid resistance. Aggregate polishing reduces micro texture, resulting in the rounding and smoothing of exposed particles. This is caused by wearing of particles on a microscopic scale. The higher the PSV value, the lower the rate of the traffic accidents, especially during the wet seasons [ii]

The correlation between PSV and skid resistance changes with the traffic flow, nature of pavements and other aspects. All factors must be taken into account in drafting specifications for road-works that contains test parameters for PSV. Aggregate comprising a PSV higher than 60 is considered as a high skid resistant aggregate. Lower is the PSV value, lesser will be the aggregate resistance to polishing. Aggregate used in road pavements must be hard and offer more resistance to wear against the dynamic load of the vehicles, the polishing effect due to traffic and the interior abrasive influence of repeated load. Accelerated Polishing Machine has widely been used to determine the relative quality of various sources of aggregate having similar mineral compositions [iii].

Erol studied the efficiency of aggregate imaging systems; Enhanced University of Illinois Aggregate Image Analyzer (E-UIAIA) and second generation of Aggregate Imaging System (AIMS-II), in assessing changes in shape and size properties of aggregates caused by the breaking, abrasion and polishing actions. Micro-Deval (MD) equipment was used in the laboratory to calculate such field degradation/polishing resistance of 11 aggregate samples with different mineralogical properties collected from all over the state of Illinois and adjacent states. More than 26,000 particles were scanned using both the imaging systems at different MD time intervals and monitored the changes in the overall morphological indices. In spite of differences in the image acquisition/processing capabilities, both E-UIAIA and AIMS-II successfully computed changes in morphological characteristics of particles from the MD testing. However, AIMS-II better reflects historical data on aggregate frictional characteristics obtained by Illinois Department of Transportation (IDOT). The imaging results were used to develop regression based statistical models to calculate the aggregate polishing and degradation trends by considering both the rate and magnitude of changes in shape properties [iv].

X. H. Chan studied the influence of freezing and thawing on the aggregate polishing resistance on road surface. Different aggregates samples were chosen and two plate specimens were formed using each sample. One sample was subjected to polishing load only and the other one was subjected to both loads of polishing and freeze-thaw actions. By comparing the changes in texture and the development of skid resistance, a statement was derived on the impact of a freezethaw effect for the short-term and long-term development of skid resistance [v].

X. H. Chan categorized the surface texture of aggregate during polishing by spectral and fractal methods based on the theory of rubber friction. The profile of the surface texture and dynamic coefficient of friction were monitored during polishing. Fractal investigation has shown that the variations in curve length of the profiles and amplitude were the main contributor to the loss of friction. Spectral investigation showed that the polishing action played a vital role in the evolution of micro texture [vi].

Pardillo calculated the skid resistance of two-lane rural road network system in the Spanish state. It was studied to estimate the effect of pavement situations on safety and to assess the influence of improving pavement friction on safety. Improvement in pavement friction was found to yield substantial decreases in the crash rates of wet pavement [vii].

Tang carried out a research for better understanding of road-surface texture evolution due to polishing. Surface profiles measured at various polishing stages were analyzed. Roughness parameters describing asperity, height and sharpness were calculated and their evolution was compared with the evolution of friction [viii].

Kane developed a model predicting road skid-resistance variations. Influential phenomena were incorporated and represented by simple mathematical functions. Model parameters were obtained by fitting to data provided by laboratory tests. Experimental roads have been tracked and cores were used to validate the model. Predictions based on the study were satisfactory and elaborated the mutual influence of involved mechanisms [xiii].

Several studies have been conducted in the past to ascertain the physical properties of the aggregates. Different parameters related to shape of an aggregate were also investigated in different research studies. Most of the studies reported the influence of shapes of particles in volumetric analysis. Little efforts are found correlating the physical properties of aggregates with their field performance parameters like skid resistance or abrasion. It is important to utilize the laboratory aggregate properties in assessing their field performance parameters. As such methodologies have not been developed to ascertain the relationships among different parameters that can predict the possible field performance of an aggregate.

Present study focuses on the quality of aggregates, especially the surface polishing resistance, being produced from Margalla quarry. Twelve representative aggregates quarries were selected initially at different location within the Margalla source. The selection of six representative quarries was made based on the initial physical and mechanical properties of aggregates. Sampling and selection of aggregate sample involve comprehensive trials and testing. The selection of specified testing methodology was carefully worked out to meet the desired objectives of this study. The objectives and the scope of study was comprehensively been reviewed and finalized to achieve effective results.

II. OBJECTIVES

Following were the main objectives of present study;

Determination of the mechanical and physical properties of aggregates selected from different source and proposes ranking of source based on these properties.

Measurement of aggregates polish stone value chosen from Margalla crush quarries and determination of British Pendulum Number (BPN).

Development and comparison of ranking using physical and mechanical properties of aggregates and polish stone value tests.

III. EXPERIMENTAL PROGRAMME

Two phase study was thus conducted on limestone Quarry's aggregate particles to accomplish the study objectives. Physical and mechanical properties were determined by aggregates shape test, aggregate crushing value, aggregates Impact Value and Loss Angeles tests in phase. Samples were polished using an accelerated polishing machine in first phase of the study. In the second phase, PSV values of different aggregate samples were determined using a friction tester and the relationship between the PSV and the physical properties were established.

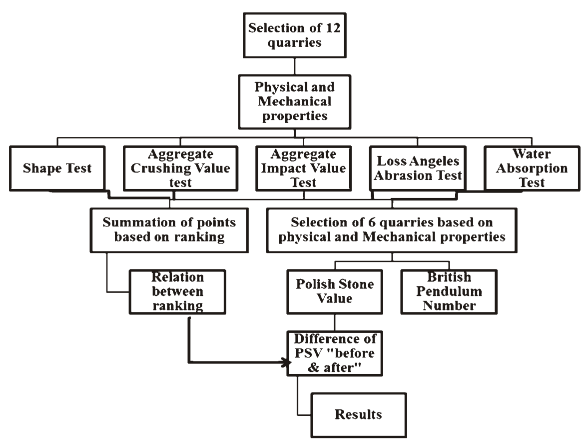


Fig. 1. Scope and methodology of the work

A. *Physical and Mechanical Properties*

The basic purpose of conducting such tests was to determine the aggregates quality against the pavements requirement. This type of testing proves useful to analyze aggregates basic quality and life expectancy. The aggregates shape analysis was performed by calculating flaky and elongated particles contained in it as per BS 812-105.1 and 105.2 [ix]. Sieve analysis was performed on aggregate samples containing minimum of 200 pieces to be tested as per BS 812. Flaky material passed through the gauge and elongated material retained on the gauge were being weighed. Results of flakiness and elongated indices have been reported in Table I.

Aggregate Impact Value was performed as per BS 812: part 112 [x]. This test indicates the resistance of aggregate to absorb sudden shocks. The oven dried aggregate material passing from 14mm and retained on 10mm sieves was filled in three layers with 25 gentle blows on each layer in a cylinder. A hammer of 13.5kg was dropped 15 times at the height of 15inch and residue was sieved at 2.36mm sieve. The amount of fine to 2.36mm sieve was defined as AIV as shown in Table I.

The aggregate crushing value was determined as per IS: 2386-1963. This test indicates aggregate resistance to crushing under increasingly applied compressive load. The oven dried samples of about 3.25kg was filled in three layers with 25 gentle blows on each layer with rounded end of temping rod. Load of 4 tons/min was applied at constant rate till the total applied load reached 40 tones. The material was sieved through 4.75mm sieve and the amount of fine to 4.75mm was defined as ACV as reported in Table I.

Aggregate abrasion values were determined as per AASHTO T 96 [xi]. This test indicates the aggregates resistance to degradation and abrasion. The oven dried sample of about 5kg passing from 14mm and retained on 10mm sieve was placed in Loss Angeles machine. A fix 500 revolutions at a speed of 30-33 revolutions per minute were given. Then the material was sieved through 1.7mm sieve. The amount of fine to 1.7mm sieve was declared as loss Angeles abrasion value as reported in Table I.

Aggregate specific gravity and water absorption was determined as per AASHTO T85. Specific gravity was used in computation of voids in aggregates and volume occupied by aggregate in different mixes, whereas water absorption was used to determine variation in the mass of aggregate due to the water absorbed in the voids of the aggregates. Aggregates of about 2kg were immersed in water for approximately 15 hours to essentially fill the voids. After removing from water, the surface of the particle was dried and weighed. Then the submerged sample was weighed and finally the oven dried sample was weighed. Using the mass and weight, specific gravity and water absorption were calculated as reported in Table I.

TABLE I
RESULTS OF PHYSICAL AND MECHANICAL PROPERTIES OF AGGREGATES

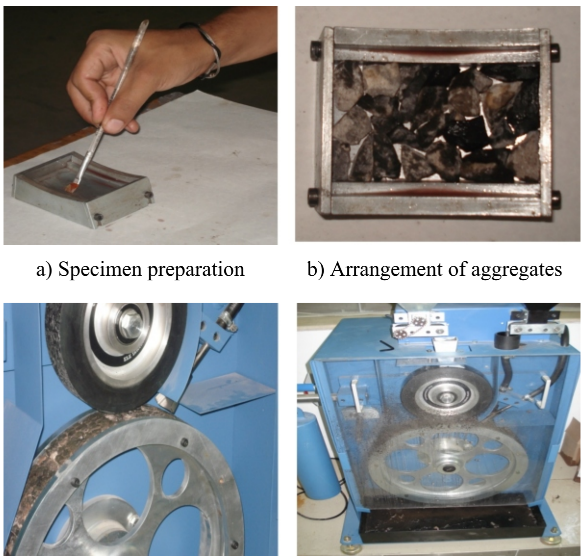
Margalla Quarry	Flakiness Index %	Elongation Index %	Aggregate Crushing Value %	Aggregate Impact Value %	Loss Angles Abrasive Value %	Water Absorption (%)	Total (sum1:6)	Ranking (a)	Specific Gravity	Ranking (b)	Sum (a+b)	Selected source
	1	2	3	4	5	6	7	8	9	10	11 (8+10)	
1	15	16	23	12	20	2.5	88.5	4	2.53	9	13	4
2	18	16	29	11	15	2.6	91.6	5	2.6	8	13	
3	19	22	17	20	25	2.9	105.9	10	2.49	12	22	6
4	22	23	19	12	10	1.5	87.5	3	2.79	5	8	
5	29	18	18	18	19	2.3	104.3	9	2.51	10	19	5
6	17	21	27	22	19	2.9	108.9	12	2.8	7	19	
7	23	13	9	13	16	2	76	1	2.9	2	3	1
8	25	17	11	17	12	1.7	83.7	2	2.64	4	6	2
9	16	21	15	21	20	2.7	95.7	6	2.68	6	12	
10	20	20	12	18	25	1.9	96.9	7	2.95	1	8	3
11	17	25	17	23	18	1.8	101.8	8	2.5	11	19	
12	27	19	22	15	21	2.6	106.6	11	2.84	3	14	

It may be noted from Table I that particles shape is within the range and production of more fines means that aggregates are soft and vice versa. Similarly, aggregate specific gravity and water absorption are also within acceptable range. Twelve sources were then ranked based on specific gravity and other test properties. A two set ranking was designed based on the index values showing an opposite trends. For example an increase in specific gravity indicates improvement in the aggregate property and vice versa. An increase in index value of other tested properties means a decrease in the mechanical properties and vice versa. The summation of ranking 'a' and 'b' as shown in Table I indicates an overall ranking of aggregate source, which was used to categorize aggregate source. Accordingly, ranking 1 and 2 as shown in the column 11 of Table I are categorized as good quality aggregate. Similarity, ranking 3 and 4 as medium and ranking 5 and 6 as poor quality aggregate, respectively. The aggregate as selected from six aggregate quarries were further subjected to aggregate PSVs and skid resistance tester.

B. *Aggregate Polish Stone Value*

Aggregates passing from 14mm and retained on 10mm sieves from 6 different crushers at Margalla quarry were collected. Four replicates were performed on each crusher as per BS 812: Part 114: 1989. Arrange the sample in a single layer with the most flat surface of the molds. Aggregates must be arranged with appropriate interlocking and minimum gaps between them. A total of 28 molds were prepared, four from each crusher and four from control stone.

The Accelerating Polishing machine as shown in Fig. 2 contains road wheel around which 14 specimens are fixed (simulating the road). The wheel has speed of 320 ± 5 RPM. A rubber tired wheel is attached on a weighted arm (simulating the vehicle wheel and suspension). The machine was first operated using flour emery for 3 hours, washed and then for 3 hours using corn emery. The flour emery hopper (silver) feeds directly onto the tired wheel via a spreader chute. The corn emery hopper (black) feeds directly to the specimens via a chute at a rate of 27 ±7 g/min continuously with water on to the road wheel for a period of 3h ± 1 min as per BS 812: Part 114 [xii]. British pendulum number (BPN) was noted before and after polishing action using friction tester.



a) Specimen preparation b) Arrangement of aggregates

c) Arrangement of specimen d) Polishing action

Fig. 2. Polishing of Aggregate particles

C. *Skid Resistance Tester*

Skid resistance tester as shown in Fig. 3 was used to determine frictional resistance between a rubber slider (mounted on the end of a pendulum arm) and the road surface.

Fig. 3. Surface friction tester

The contact length of rubber slider was set between 125 and 127 mm on the provided scale. One slider edge can normally be used for at least 100 different settings (500 swings). Each time the slider was fixed to a small aluminum plate and this whole unit could easily be removed for replacement by pulling out the pin. New sliders were roughened before use by swinging several times over a piece of dry road.

The pendulum released from the horizontal position hit the surface and the needle position indicates reading of the pointer to the nearest whole number. This operation was performed five times, after rewetting the specimen each time, and record the mean of the last three readings to the nearest 0.1. The test was repeated if two mean values of control specimen differed more than 4.7.

IV. Results and Discussion

A. *British Pendulum Number*

The results obtained before and after the PSV test have been tabulated in Table II. It may be noted from Table II that the difference between the 'before' and 'after' value was sensitive to the source. However, BPN values before PSV test ranges from 62.7 to 80.8, which is relatively a more narrow range as compared to BPN values after PSV (Ranging from 45.25 to 71.03). . This reduction in the BPN range was attributed to the polishing effect. Polishing reduces the roughness and brought different source particles into more similar surface characteristics. However, the effect of source can be determined from their individual values.

TABLE II
BPN of Samples Before and After PSV Test

Crusher	BPN before PSV Test			BPN after PSV Test			Difference
	Mean	S. Deviation	Covariance	Mean	S. Deviation	Covariance	Before to after
1	70.93	1.97	2.59	57.68	3.42	5.63	13.25
3	62.75	3.23	4.18	45.25	2.33	3.84	17.5
5	71.75	3.18	4.17	56.58	2.29	3.86	15.17
7	80.78	2.74	3.6	71.03	2.03	3.42	9.75
8	77.43	1.91	2.47	67.18	2.85	4.73	10.25
10	75.78	4.12	5.28	63.4	3.75	6.17	12.38
Control	76.9	1.54	2.01	52.81	1.64	3.11	24.09

Statistical analysis were performed on the data to determine the accuracy of the results. The mean value, standard deviation and the covariance were utilized to understand the agreement between the values of replicates and the variations within the samples. PSV computed ranged between 57 and 62 as against PSV standard range of 55 to 66. It may be noted that average value of standard deviation is around 3, so the results are in a reasonable accuracy. Variation in the results of replicates also indicates a uniform process of manufacturing of aggregate and selection of particles for testing purpose. Average value of BPN before and after the polishing has been observed as 73.24 and 60.2, respectively. Fig. 4 illustrate the results of Table II.

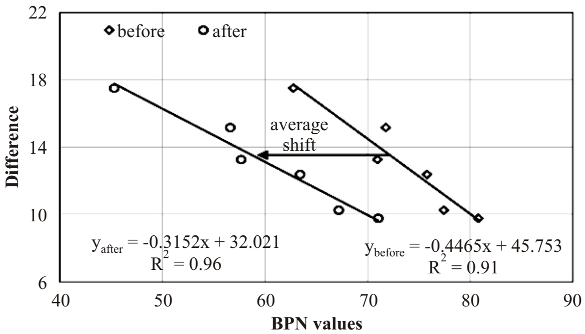


Fig. 4. Influence of PSV on BPN values

It may be noted from Fig. 4 that a significant reduction in the PSV has been observed from a polish stone value test, commonly known as BPN. Areduction of around 13% would be considered as the effect of polishing action on aggregate surface. The results of PSV test showed a reduction of BPN from 12% (good) to 28% (poor). A general range of BPN for Margalla crusher after PSV test may be considered as from 45 to 72. The effect of polishing on aggregate BPN can be ascertained from Table II.

B. Polish Stone Value

The PSV of each sample was calculated using the following relationship;

$$PSV = S + 52.5 - C \quad (1)$$

S= Mean value of BPN after PSV test
C= Mean value of BPN after PSV test

The average polish control stone value (C) of 52.81 has been used for calculation of PSV. PSVs computed for the six selected aggregate source have been presented in Fig. 5. The permissible limit has also been plotted in the same figure for a comparison purpose.

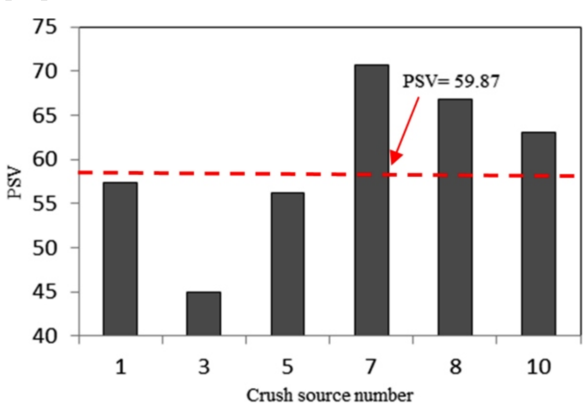


Fig. 5. Polish stone values of different aggregate crush quarries at Margalla

It may be noted from Fig. 5 that PSV is also a source sensitive properties that mainly depends on the properties of the source. This finding is in line with what has been reported in the previous literature. Only three aggregate sources meet the minimum acceptance criteria.

A comparison of aggregate source based on PSV ranking and physical and mechanical properties based ranking has been made in order to ascertain the similarity of both the rankings. Fig. 6 presents summation of ranking points based on the physical and mechanical properties and difference of PSV values as obtained before and the after.

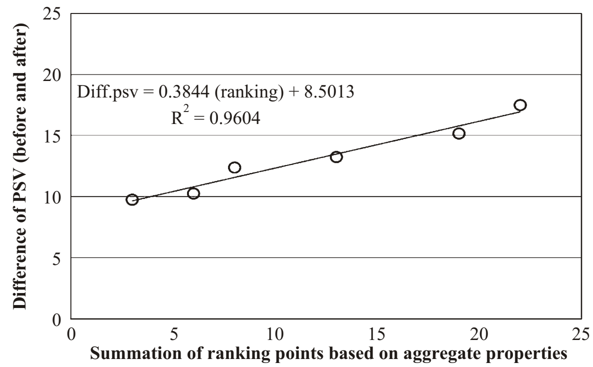


Fig. 6. Comparison of material properties based ranking and difference of PSV

It may be noted from Fig. 6 that a linear trend can be obtained between both types of ranking system. A reasonable relationship exists between both the criterions. It may be concluded from Fig. 6 that difference of PSV showed similar trends as with the physical and mechanical properties. With the proceeding discussions, it may be recorded as instead of conducting a number physical and mechanical tests on aggregate, one can run PSV test and obtain similar ranking for the selection of specific aggregate source.

V. CONCLUSION

Present study illustrates the experimental results of aggregate selected from different sources within Margalla crush quarry. A methodology has been proposed for ranking of materials for quality control. Twelve aggregate sources were initially selected and physical and mechanical properties were determined. A ranking based methodology has been adopted to minimize number of sources for conduction of further testing prior to their selection for any field construction job. The selected aggregates were further tested under PSV and surface skid resistance. Aranking based on the difference between the 'before' and 'after' polish stone value was also made. Results shows that polish stone value (BPN) of aggregate before and after the test does not predict aggregate material ranking, but the difference between "before" and "after" value predict same ranking as were observed from summation of physical index properties. This study reveals that both the ranking criteria of aggregate source yield similar results. Also the effect of polishing reduces the overall range of BPN by reducing the surface roughness, but the amount of reduction also depends on the source.

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