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ORIGINAL CONTRIBUTION

Marshal Stability Analysis of Asphaltic Concrete: A comparative strength based investigation of KP Pakistan Principal Aggregate Quarries

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***Abstract*— Various types of hot asphalt (mixture of mineral aggregate and bituminous binder–bituminous mixture) are used in the construction of flexible pavements, depending on the project requirements, to ensure optimal use of the asphalt. From all available asphalts, each country uses a combination of those that are considered to be the most appropriate to their climatic and traffic conditions. Asphalts are characterized by the particle size distribution of the aggregate mixture. Theoretically, there are unlimited types of asphalts, namely, from asphalts consisting only of almost single-sized coarse aggregates to mixtures consisting only of fine aggregates (sand). The goal of bitumen laboratory testing is to describe its qualities, determine its appropriateness, and forecast its behaviour over the course of the pavement's service life. All technological, mechanical, rheological, physical, and chemical attributes are included in the term typical properties. The purpose of the report is to collect aggregate samples from Malakand, Dara Adam Khel, Basai, and Karak quarries and to compare its Physical and Mechanical Properties with Margalla aggregate by using the Marshall Method of design for asphalt concrete.**

***Index Terms*— Aggregate, Asphalt, Los Angeles Abrasion, Flash and Fire, Marshal Stability**

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I. INTRODUCTION

In low temperatures, asphalt is brittle and hard, but in hot temperatures, it is flexible. As a pavement material, it has a variety of failures, including low-temperature cracking, fatigue cracking, and rutting (or permanent deformation) at high temperatures, all of which impair its quality and performance [1]. In recent decades, asphalt pavement mileage has expanded significantly in unison with the rapid development of road transportation, helping Pakistan's economic and social development [2]. However, as traffic volumes and axle weights increase, especially due to the influence of overloaded traffic, early asphalt pavement deterioration happens more frequently, becoming a stumbling block to the development of road transportation in Pakistan [3]. Several variables contribute to the early deterioration of asphalt pavement, including the material's qualities, building method, construction quality, harsh environment, traffic volume, and loads [4]. Unsuitable asphalt mixture design is also thought to be a major factor in the early deterioration of asphalt mixtures [5]. Any increase in the service life of road pavements has a major economic benefit, and any asphalt adjustments are performed to improve the service life and performance of asphalt pavements [6]. A long-lasting road surface is a need for economic development in most countries. The use of renewable bio-origin materials for the construction of road pavement has recently become more popular as a result of both environmental conservation and diminishing natural resources [7]. Bitumen modification is now known to use bio-binders or bio-origin polymers. Bio-derived oil can also be used as a bitumen flux additive or a Reclaimed Asphalt Pavement (RAP) rejuvenator [8]. The utilisation of recycled resources is required by the rising demand for paving materials. Material from milled asphalt pavement is used to construct new pavement in hot, warm, or cold technologies [9]. The recycling process might be carried out on-site, in a remote location, or at an asphalt plant. The primary benefit of recycling milled asphalt mixtures is that it cuts down on the amount of raw material (aggregate and bitumen) utilised in the production of new asphalt mixtures [10].

Asphalt can be made using reclaimed materials from the demolition of road surfaces. This saves money on manufacturing while also conserving natural resources like bitumen and aggregates [11]. Recycling, on the other hand, can only be justified if the resulting pavement's performance and lifetime are comparable to or better than normal combinations. The

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performance of RAP-containing mixtures hasn't always been as expected [12]. The possibility of premature cracking caused by aged bitumen is one of the key reasons why agencies are reticent to boost the permitted RAP concentration in mixtures [13]. Another issue that has been raised is the diversity of RAP material, which makes it difficult to confidently predict that the parameters of the generated mixture would match the laboratory design. Finally, there have been reports of concerns with production technology, such as excessive emissions and issues with mixture consistency, which have resulted in poor pavement performance [14].

The most significant material for road, highway, motorway, and airport pavements is asphalt concrete, which plays a critical role in the serviceable life of the pavement [15]. As a result, asphalt concrete and all of its ingredients are evaluated in a laboratory before being used to ensure that it will function properly for the duration of the design life [16]. Aggregate makes up over 90% of asphalt concrete, and its qualities, such as skid resistance, different types of cracking, and road durability, are all influenced by it [17]. Any increase in the service life of road pavements will, of course, be a huge financial boon, and any changes to asphalt pavements are made in the hopes of extending their service life and improving their performance [6].

II. MATERIALS AND METHODS

This study is done to evaluate the different properties of aggregates available in the different areas of KP, Pakistan.

A. Materials

Following are the material used in this research study described as under.

1) *Aggregate*

Aggregate is mineral-based granular material such as sand, gravel, shale, slag, or crushed stone. Silica gravels, sandstone, chert, limestone, and dolomite are examples of aggregate. Siliceous gravels are extremely strong and durable. Sandstone's porosity and absorption affect its strength and durability. Chert is a thick, robust aggregate that is reactive to alkalis in numerous forms. Limestone and dolomite are softer than silicate, making them ideal aggregate sources with a wide range of porosity and absorption [18]. Hard stone, such as sandstone, granite, and limestone, has been utilised to build monuments and buildings for millennia. Aggregates, among other materials, were used to construct the Roman Empire's massive network of roads and aqueducts. These stones were frequently mined from quarries that were located far away from the location where they were to be used. In the contemporary age, the advent of cement and asphalt considerably increased the demand for aggregate. The use of raw materials made of stone is increasing day by day as the construction industry develops.

Fig. 1. Different aggregate types

2) *Bitumen*

Bitumen is a dense, very viscous petroleum-based hydrocarbon that can be found naturally in deposits such as oil sands and pitch lakes, or obtained as a byproduct of crude oil distillation (refined bitumen). In certain places, particularly in the United States, bitumen is referred to as asphalt, despite the fact that the term refers almost entirely to the road-paving material made from a mixture of gravel, sand, and other fillers in a bituminous binder. Despite the fact that tar is a consequence of coal carbonization and pitch is made by distilling coal tar, bitumen is also referred to as tar or pitch. It is mostly employed in the road construction industry, and it is used to provide bituminous asphalt binder to our professionals. The expansion of bitumen use is directly tied to the rise of mobility around the world, particularly the advent of the automobile [19]. Indeed, its use on the world road has aided in resolving the problem of road dust created by tarmac traffic. Bituminous pavements gradually covered practically all roadways throughout the world. After the Second World War, bitumen naturally replaced tar due to its several verifiable properties. As a result, it was unavoidable for it to become industrialised.

Fig. 2. Bitumen

3) *Asphaltic concrete*

a hot mix Asphalt is made up of a variety of aggregate sizes and mineral fillers that are uniformly mixed and coated with asphalt cement, each with its own set of qualities that make it more ideal for various design and construction reasons. Selection, proportioning, and characterization of individual materials are required before constructing asphalt paving mixes in order to achieve the desired quality and attributes of the completed mix. Aggregates were acquired from Margalla Crush quarries, Karak quarry, Dara Adam Khel Quarry, Basai Quarry, and Malakand Quarry for the current study. Rock asphalt and natural asphalt were employed as building materials in the early nineteenth century. These asphalt materials had been utilised for waterproofing for over 7,000 years [20]. In England, hot tar was employed to glue the fractured stones together as early as 1820. Warren Brothers of Cambridge, Massachusetts, patented this sort of mix, known as tarmacadam, in 1910. APAC, one of the major asphalt mix firms in the United States, grew out of this company. N.B. Abbott and C.E. Evans created the first bituminous HMA pavements in the United States in Washington, D.C., in 1868 and 1873, respectively. Coal tar was employed as a binder in both projects. President Grant, on the other hand, appointed a committee of army engineers to investigate the usage of asphalt on roadways in 1876. This group proposed that sheet asphalt manufactured from Trinidad Lake asphalt be used to pave Pennsylvania Avenue in Washington, D.C. Despite the constant traffic at the White House, the pavement remained in excellent condition for 11 years. Refined petroleum asphalt first appeared in the mid-1870s. By 1910, refined petroleum asphalt had achieved a permanent market dominance over producers of rock, natural, and sheet asphalt. Aside from cost, oil corporations could manufacture asphalt at a lower cost. Another trait that distinguishes asphalt from concrete is its flexibility. Upkeep on asphalt is frequently less expensive than maintenance on concrete. Contractors, government agencies and trade associations in the asphalt sector - such as the National Asphalt Pavement [21].

Fig. 3. Asphaltic concrete

B. Methodology

The following method is followed for achieving the objectives of this investigation.

- Material is collected from five major sources of KP, Pakistan known as Karak quarry, Malakand quarry, Margalla quarry, Basai quarry, and Dara Adam Khel quarry.
- Tests were performed on aggregate from all the sources to find its best suitability for road construction as per AASHTO specifications. Experiments performed are Gradation Analysis, Soundness, Water Absorption, and Los Angeles Abrasion Test.
- Experimental performances done on bitumen are Flash & Fire, Penetration, and Softening Point test.
- Hot-mix Asphalt is added to the specified amount of aggregates in grams at 3.5%, 4%, 4.5%, 5%, and 5.5% of Bitumen content to measure its strength.
- Marshal stability test is performed on the asphalt cubes cast from aggregates of various sources to compare its strength characteristics.

III. RESULTS AND DISCUSSION

A. Experimental Findings of Quarries Aggregates

Following are the test results of different quarries aggregates performed in the CECOS University lab.

1) Gradation analysis

Following are the outcomes of Gradation Analysis for all the quarries aggregate

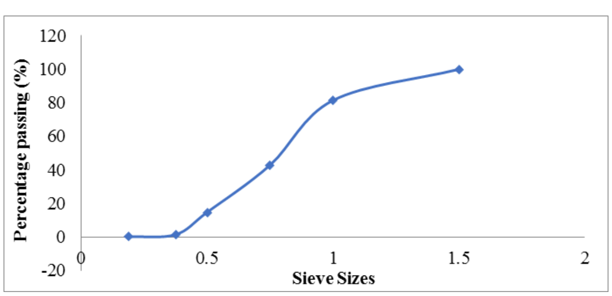

Fig. 4. Gradation curve of Karak quarry aggregate

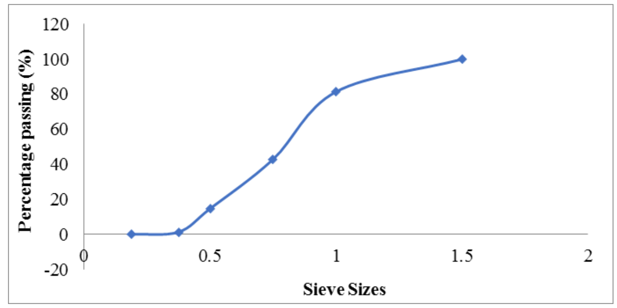

Fig. 5. Gradation curve of Malakand quarry aggregate

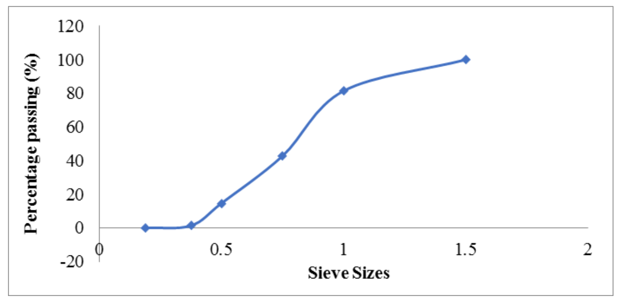

Fig. 6. Gradation curve of Maragalla quarry aggregate

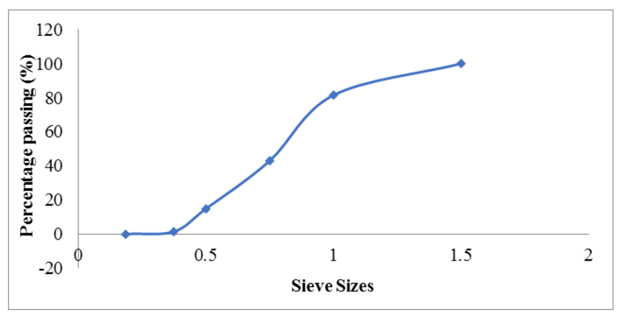

Fig. 7. Gradation curve of Dara Adam Khel quarry aggregate

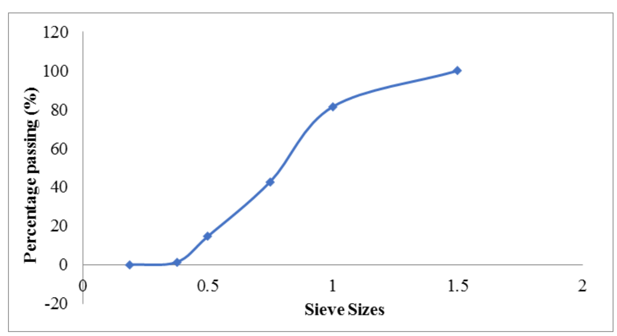

Fig. 8. Gradation curve of Basai quarry aggregate

2) Fineness modulus

Following are the outcomes of Fineness Modulus for all the quarries aggregate achieved from the results of Gradation Analysis.

TABLE I
FINENESS MODULUS OF ALL THE DIFFERENT AGGREGATES

S No.	Aggregates	Specification Reference	Results	Recommended Values
1	Margalla	AASHTO T-27 AASHTO T-11	3.67	>3.1
2	Malakand	AASHTO T-27 AASHTO T-11	3.66	>3.1
3	Dara	AASHTO T-27 AASHTO T-11	3.66	>3.1
4	Basai	AASHTO T-27 AASHTO T-11	3.58	>3.1
5	Karak	AASHTO T-27 AASHTO T-11	3.58	>3.1

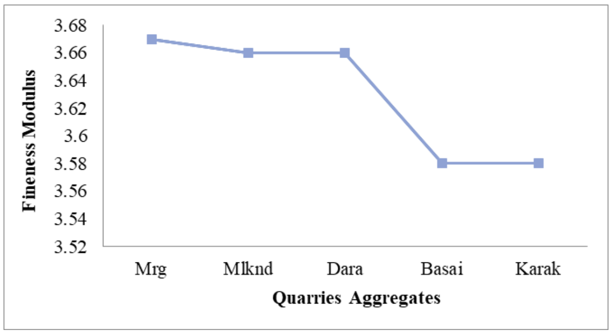

Fig. 9. Fineness modulus for all quarries aggregates

3) *Los Angeles Abrasion test*

Following are the outcomes of the Los Angeles Abrasion Test for all the quarries aggregate achieved from the results of Gradation Analysis

TABLE II
LOS ANGELES ABRASION TEST FOR ALL QUARRY AGGREGATES

S No.	Aggregates	Specification Reference	Results	Recommended Values
1	Basai	AASHTO T-96 ASTM C-131	25.50%	<30
2	Karak	AASHTO T-96 ASTM C-131	19.85%	<30
3	Dara	AASHTO T-96 ASTM C-131	19.56%	<30
4	Malakand	AASHTO T-96 ASTM C-131	18%	<30
5	Margalla	AASHTO T-96	16%	<30

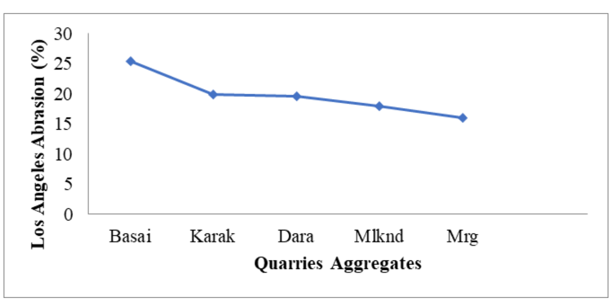

Fig. 10. Loss Angeles Abrasion test for all quarry aggregates

4) *Absorption test*

Following are the outcomes of the Absorption test for all the quarries aggregate:

TABLE III
LOS ANGELES ABRASION TEST FOR ALL QUARRY AGGREGATES

S No.	Aggregates	Specification Reference	Results	Recommended Values
1	Karak	AASHTO T-166	1.96%	<2%
2	Basai	AASHTO T-166	1.26%	<2%
3	Malakand	AASHTO T-166	1.10%	<2%
4	Margalla	AASHTO T-166	1.04%	<2%
5	Dara Adam	AASHTO T-166	0.84%	<2%

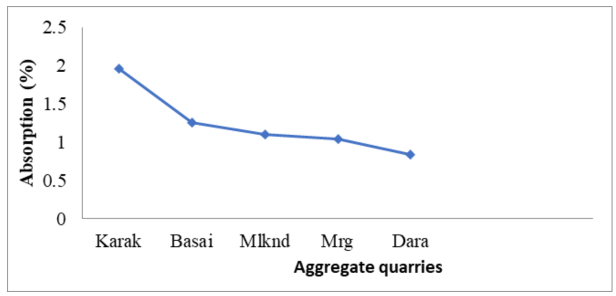

Fig. 11. Absorption values for all quarry aggregates

5) *Soundness test*

Following are the outcomes of the Soundness test for all the quarries aggregate.

TABLE IV
SOUNDNESS TEST FOR ALL QUARRY AGGREGATES

S No.	Aggregates	Specification Reference	Results	Recommended Values
1	Karak	AASHTO T-104 ASTM C-188	11.30%	12 (Max)
2	Basai	AASHTO T-104 ASTM C-188	10.80%	12 (Max)
3	Malakand	AASHTO T-104 ASTM C-188	6.40%	12 (Max)
4	Dara	AASHTO T-104 ASTM C-188	3.66%	12 (Max)
5	Margalla	AASHTO T-104 ASTM C-188	3.33%	12 (Max)

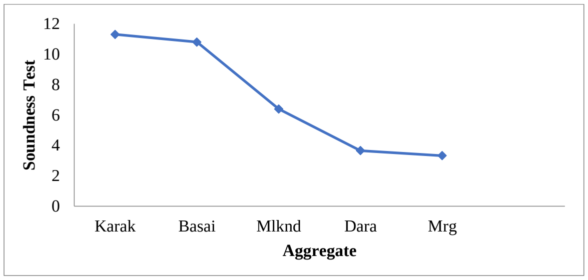

Fig. 12. Soundness test for all quarry aggregates

6) *Experimental findings of bitumen*

Following are the tests performed on the bitumen shown collectively in the table below.

TABLE V
EXPERIMENTAL PERFORMANCE ON BITUMEN

S No.	Test Descriptions	Units	Test Methods	Results	Max/ Min
1	Penetration @ 250C	1/10mm	ASTM D-5	60-70	-
2	Softening point	0C	AASHTO T-53	50	Min
3	Ductility test	Cm	ASTM T-113	100	Min
4	Flashpoint	0C	AASHTO T-92	185	Min
5	Fire point	0C	AASHTO T-92	225	Min

7) *Determination of Optimum Binder Content (OBC) by Marshal mix design*

Table VI represents the determination of the optimum binder content. It is to make the comparison among all the different percentage contents of bitumen in the aggregates out of which the higher value of indirect tensile strength will be considered as the optimum binder content.

TABLE VI
DETERMINATION OF OBC

AC (%)	Stability (KN)	Flow (mm)	Gmb (g/cc)	Gmm (g/cc)	Air Voids (%)	VMA (%)	VFA (%)
3.5	7.30	3.259	2.326	2.493	6.690	14.419	53.602
4	9.43	3.112	2.358	2.479	4.874	13.693	64.403
4.5	9.21	3.407	2.386	2.468	3.326	13.132	74.675
5	8.58	3.75	2.389	2.457	2.767	13.475	79.462
5.5	7.64	4.014	2.387	2.451	2.611	14.002	81.352

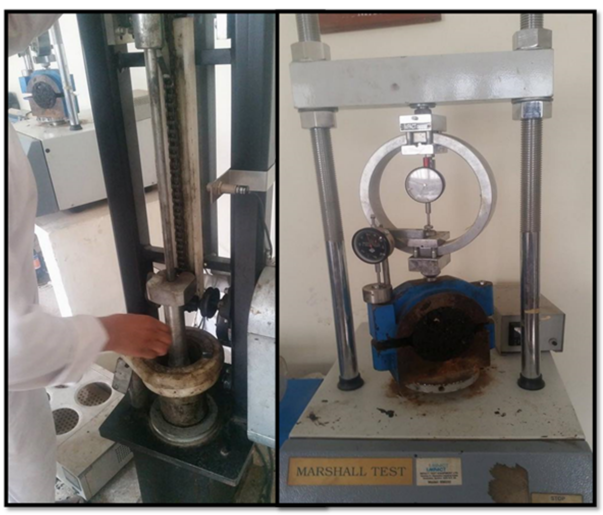

Fig. 13. Marshal stability performance

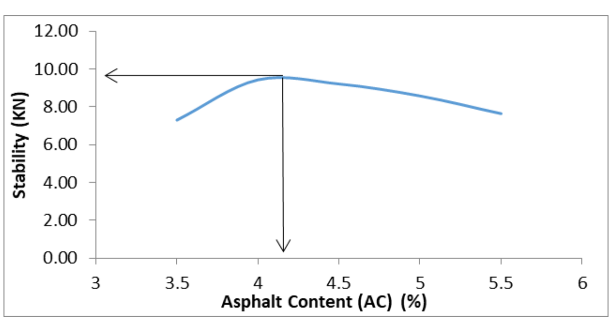

Fig. 14. Stability against Asphalt Contents (AC)

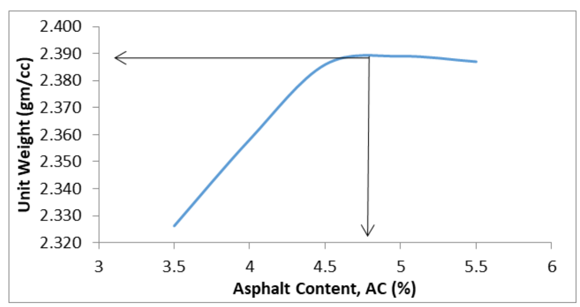

Fig. 15. Unit weight against AC

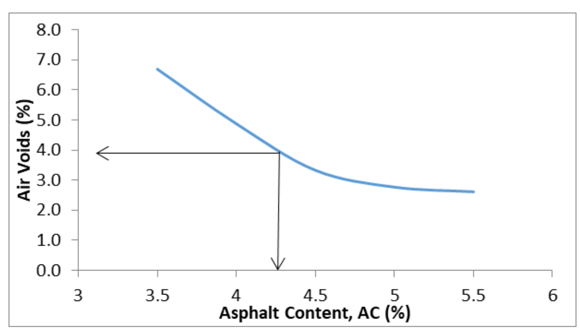

Fig. 16. Air voids against AC

Discussion: From Figure 14, 15 and 16 of Stability, Unit weight, and Air voids respectively, Optimum binder content obtained was 4.38 for which Flow and VMA were 3.72mm and 13.2% respectively i.e., according to specifications of Asphalt Institute.

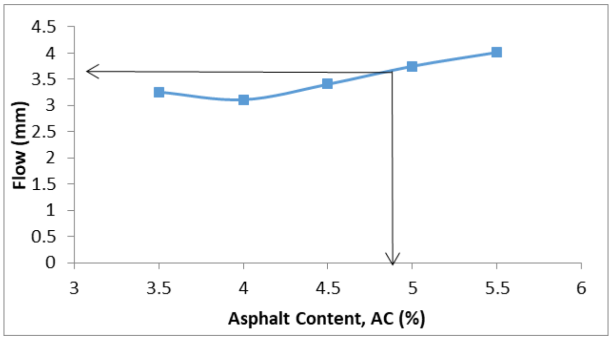

Fig. 17. Air voids against AC

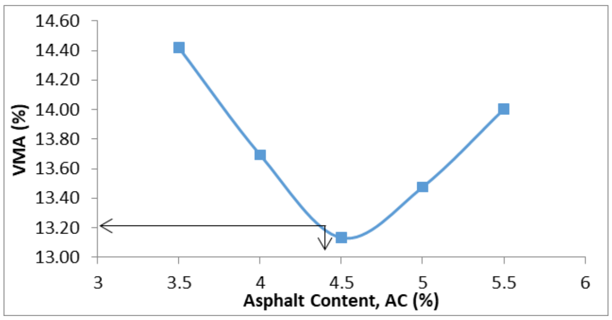

Fig. 18. VMA against AC

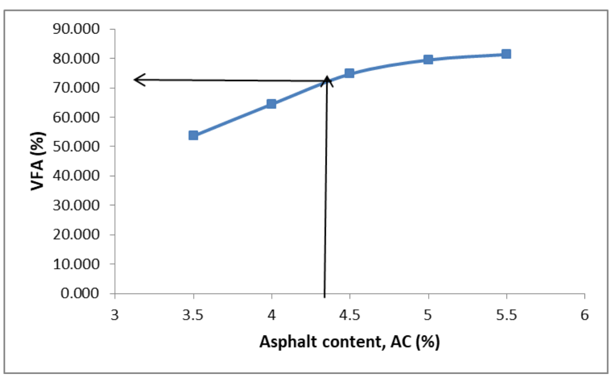

Fig. 19. VFA against AC

B. Indirect Tensile Strength (ITS)

Following is the equation to calculate indirect tensile strength after performing the Marshal Stability test. And also Table VII shows the standard size of the sample being used in the experiment.

$St = 2P/\pi tD$

Where St = tensile strength (psi), t = sample thickness (inches) P = maximum load (lbs), D = sample diameter (inches)

TABLE VII
SAMPLE STANDARD SIZE

S No.	Diameter (Inch)	Thickness (Inch)	Volume In3
1	4	2.5	31.4
2	10.16	6.35	514.55

1) Indirect tensile strength at OBC for all quarries aggregates

Table VIII shows the results of indirect tensile strength at OBC (4.38%) for all quarries aggregates.

TABLE VIII
INDIRECT TENSILE STRENGTH AT OBC FOR ALL QUARRIES AGGREGATES

S No.	ARL 60/70	Aggregates Quarry (Names)	Load (lbs)	Indirect Tensile Strength (Psi)
1	4.38%	Karak	1672	106.4
2	4.38%	Malakand	1738	110.7
3	4.38%	Basai	1475	93.94
4	4.38%	Dara	1584	100.89
5	4.38%	Margalla	1914	121.9

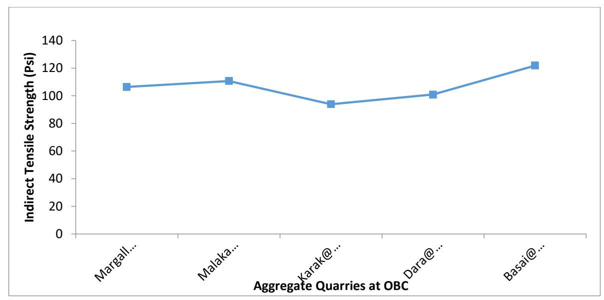

Fig. 20. Indirect tensile strength for all quarries aggregates

IV. CONCLUSION

Following are the conclusions for this investigation.

- When compared to other quarry materials, Margalla aggregates have the highest tensile strength.
- When comparing the aggregates' Los Angeles abrasion values, it is obvious that the Karak aggregate is softer than the Malakand and Margalla aggregates. Dara Adam Khel and Margalla aggregate are also softer than Basai aggregate. When used to wear rougher roads, it is more vulnerable to abrasion.
- The aggregates from Karak, Basai, and Dara Adam Khel quarries have larger pores and are more vulnerable to moisture absorption when compared to the aggregates from five other quarries.
- Overall, Margalla aggregates produce good results when compared to others, while the outcomes of Malakand quarry aggregate are acceptable.

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