Suitability Study of Locally Available Granitic Rocks Aggregate For Roads Construction in District Dir

By

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(2018-NUST-MS-TN-00000275304)

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This is to certified that the
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THESIS ACCEPTANCE CERTIFICATE

It is certified that Mr. Mian Muhammad Wasim, Registration No. 00000275304, of MS Transportation Engineering of batch 2018 has completed his thesis work and submitted the final copy which was evaluated and found to be complete in all aspects as per policy of NUST/Regulations, is free of plagiarism, errors and mistakes and is accepted as partial fulfillment for award of MS degree. It is further certified that necessary amendments as pointed by GEC members of the scholar have been incorporated in the said thesis.

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Date: ____

Signature **(Dean/Principal)**: _______________________

Date: ____

DEDICATION

Dedicated to my beloved Country, my teachers, Family and Engineers, who are working day and night for better future of Pakistan.

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*Unending glory to **Allah**, The Exalted, who granted me the primary inspiration and stamina all along to complete this humble work. This small contribution, if just and correct, is only a drop of appreciation for His Ocean of munificence*.

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ABSTRACT

A considerable amount of aggregates are acquired from rocks and natural gravel that are widely utilized in the construction of road infrastructures after crushing them into desired size. District Dir is rich with granitic rocks and easily accessible to extract for construction purpose but lack in usage of locally available rock aggregates for roads construction makes the projects delay and cost overrun. The aim of this study is to check the suitability of this locally available granitic rocks aggregate for road construction through proper laboratory testing and comparative analysis with other standard aggregates. Its reliability is measured on these standard engineering parameters including Loss Angeles Abrasion Test, Aggregate impact value, Aggregate crushing value, water absorption, specific gravity, soundness, flakiness index, and elongation value. After finding physical properties, HMA samples were prepared for further performance evaluation tests. These tests were performed to measure its resistance to rutting and moisture damage. According to test findings all the results of test are within the acceptable limits of agencies (ASTM ASHTOO BS). Whereas, the specimen prepared from Dir granitic rocks aggregates showed 24% less resistance to rutting than Margallah aggregate sample. Additionally, a cost comparison analysis reveals that Dir aggregate is 10% more affordable than aggregate acquired from Margallah. Any project's overall cost may be reduced by using local aggregate as construction material, and it can also significantly improve the socioeconomic well-being of the local populations.

Key Words: Asphalt, coarse aggregate, physical properties, rutting, ITS

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LIST OF ABBREVIATIONS

AASHTO – American Association of State Highway & Transportation Official

AC – Asphalt Concrete

Agg – Aggregate

ASTM – American Society for Testing and Materials

Gmb – Mix Bulk Specific Gravity

Gmm – Mix Theoretical Maximum Specific Gravity

HMA – Hot-Mix Asphalt

LVDT – Linear Variable Differential Transformer

JMF – Job Mix Formula

NHA – National Highway Authority

LVDTs – Linear Variable Differential Transducers

NMAS – Nominal Maximum Aggregate Size

SGC – Superpave Gyratory Compactor

VA – Volume of Air Voids

VFA – Voids filled with Asphalt VMA – Voids in Mineral Aggregate

OBC – Optimum Binder Content

Chapter 1: Introduction

1.1 Background

Pakistan's road system plays a key role in the movement of people and commodities. The country's road network is one of its most important assets, and Pakistan now needs better roads than ever before due to rising traffic and the expansion of trade along the CPEC routes. Majority of roads in Pakistan are flexible pavements known as multi-layered structural system and it is the most preferred paving technique for developing roads and highways. In order to keep flexible pavement functioning at a satisfactory level of service, many sorts of maintenance and rehabilitation costs are involved. Different studies and research have been conducted worldwide by various researchers in an effort to lower the cost of constructing and maintaining pavement. To reduce these costs proper selection of aggregate is require which should maintaining the desirable engineering properties of aggregate and easily accessible. District Dir is rich with granitic rocks and easily accessible to extract for construction purpose but lack in usage of locally available rock aggregates for roads construction makes the projects delay and cost overrun. The aim of this study is to check the suitability of this locally available granitic rocks aggregate for road construction through proper laboratory testing and comparative analysis with other standard aggregates.

The study area is in Wari town, District Dir Upper, Khyber Pakhtunkhwa, Pakistan, which is geologically located in western of Kohistan Island Arc. Granitic rocks are exposed in the Wari area between latitude and longitude (35.0070°N, 72.03°E Respectively) of the upper Dir kpk Pakistan. Study area is located along N45 road.

1.2 Problem statement

Dir is undeveloped district there is one highway N-45 which is two-lane two-way road, the traffic is high on this highway because it connects two other districts with motorway as well (Chitral and Bajawar). So provincial government has decided to build Dir motorway which will solve this traffic issue in addition to this the CPEC route will also pass-through District Dir.

Substantial amount of coarse aggregate will be required for these upcoming mega projects. Limestone from Margallah is the primary suppliers of authorized coarse aggregate in every govt projects in district Dir, and they are also the most expensive sources because of the associated transportation expenses. There is a research gap since no particular study has been done to assess the potential of locally available coarse aggregate in Pavement construction. Therefore, it is necessary to assess this aggregate source to see if it may be utilized in asphalt without risk. In any location, expenditures may be greatly decreased, and socioeconomic well-being will be much enhanced by adopting locally accessible resources.

The issue raised above indicates that it is necessary to study the engineering properties of locally available aggregate, compare them to aggregates that are frequently used in study area, and determine if they are appropriate for use in road construction (HMA).

1.3 Research Objective

The objective of this study is to investigate the suitability of granitic rock aggregates as a potential aggregates source for pavements construction**.**

1. Evaluation of local coarse aggregate's engineering properties as a pavement material for road construction.

2. To assess the rutting potential of HMA mixtures comprising Margallah and Dir granitic rocks aggregate mixes using a Double wheel-tracking machine.

3. To evaluate the moisture damage of HMA mixes containing Dir and Margallah aggregate mixes by Universal Testing Machine.

4. Cost comparison analysis of local aggregate with materials of Margallah.

1.4 Scope of thesis

This study will have an economic impact on the transportation sector since it will provide an affordable alternative to other expensive materials that are now transported from other areas and utilized in road construction. This study directly relates to the topic of transportation engineering. This research's field of application includes the examination of local granitic rocks aggregate use as a potential road aggregate.

1.5 Organization of report

The research thesis has been organized into Five Chapters and summarized below.

Chapter 1 This chapter is primarily concerned with providing a concise summary of the study explaining the significance of aggregate in road construction and its incorporation in Marshal Mix Design. This chapter also provides a problem statement that explains the goals and purpose of the study.

Chapter 2 This chapter discusses a review of the literature on the subject of aggregate selection, how it affects pavement design, and the main variables involved in using these materials. This chapter also describes many investigations conducted by various researchers and compares the outcomes of those studies.

Chapter 3 explains the research methodology used in this study, as well as the characteristics of two different materials and how to calculate the volumetric parameters for the preparation of Marshal bituminous mix, the Double Wheel Tracking Device (DWTD) test, and the indirect tensile strength (ITS) procedure.

Chapter 4 This chapter includes findings related to the strength and physical properties of aggregate, as well as data related to rutting, Gmm, Gmb, and ITS. This further elaborates the findings and discussions on the aggregate of two sources and also explains their economic impact on projects.

Chapter 5 The findings derived from the research's results are highlighted in this chapter. In order to comprehend the impact of using this aggregate, certain recommendations about test conditions and materials are discussed, and future study is proposed.

Chapter 2: Literature Review

2.1 Introduction

The most prevalent type of pavement is flexible pavement, which is mostly produced with asphalt concrete which is composed of aggregate and asphalt binder. Aggregates derived from rocks and natural gravel are widely utilized in the development of road infrastructures and other projects, these aggregates in-service performance is determined by their engineering properties. Aggregates of different sources are using in the construction of roads based on the desired quality and easily availability near to the project. This chapter covers a brief study of basic aggregate properties, literature on different sources of aggregates and response of asphalt mixes to the road performance tests (HWT & ITS).

2.2 Hot Mix Asphalt

Hot mix asphalt is used to make the flexible pavements. A binder and aggregates make up the structure of hot mix asphalt (HMA). Asphaltic concrete, plant mix, and bituminous mix are other names for hot mix asphalt. Aggregates are made up of coarse and fine particles in most cases. Flexible pavements are constructed using these materials. Wearing surfaces, subgrades, bases, and subgrades are just a few of the components that make up these pavements.

As per gradation curve criteria the maximum volume or a weight of the hot mix asphalt is dependent on the various categories of the aggregates. The different sieve sizes are included in these aggregates. Aggregates are classified as coarse, fine, or mineral filler based on their size. Hot mix asphalt accounts for such a large percentage of total volume, therefore careful selection and addition of various sizes of aggregates is required. Because of the stress in pavements, better-performing materials are considered in the construction to improve resistance. Bitumen is a heavy, viscous material that can be naturally found or produced after crude oil has been refined. Bitumen is made up of several carbon constituents such as sulphur hydrocarbons and carbon. Asphalt binder contains a lot of oxygen and carbon. When asphalt is placed at room temperature, it acts like a soft rubber and has a consistency similar to that of a soft rubber. When the temperature rises over a certain point, asphalt turns liquid. However, at sub-zero temperatures, the bitumen's properties approach to that of a brittle substance.

2.3 Aggregates

Aggregate refers to mineral components like sand, gravel, and crushed stone that are combined with a binding medium (such bitumen, portland cement, lime, and so on) to make compound materials (such as asphalt concrete and portland cement concrete). Aggregate is also utilized in both flexible and rigid pavement as a base and subbase courses. Aggregates can be both natural or manufactured. Natural aggregates are often removed via open excavation from bigger rock formations (quarry). Mechanical crushing is commonly used to reduce extracted rock to useable sizes. Manufactured aggregate is usually a product of other manufacturing industries.

Aggregates are granular material used in construction. Aggregate can be natural, manufactured or recycled. Natural aggregate derived from mineral sources that has just undergone mechanical processing and the manufactured aggregates are those which is of mineral origin produced by a thermal or other alteration process in industry, while the recycled aggregate produced by processing inorganic materials that were once utilized in construction.

Natural aggregates sources are main three rocks Igneous rocks, sedimentary rocks and metamorphic rocks. Igneous rock is the origin rock of Granite, basalt, dolerite, pumice and rhyolite. while sedimentary rocks produce limestone and shale. Metamorphic rock is parent rock for gniess and quartzite.

2.4 Granitic Rocks:

Granite is an igneous rock with grains large enough to be seen with the naked eye. It has a light appearance and occurs from the gradual crystallization of magma underneath the surface of the Earth. Main constituents are quartz and feldspar. Mica, amphiboles, and other minerals are also present, Granite, as shown in ***Figure 2.1***, can seem red, pink, grey, or white depending on the minerals that make up the rock, on white granite there are black mineral grains that can be seen all over the rock. Due to its prevalence among igneous rocks and widely found at the Earth's surface it is the most well-liked and well-known rock.

Figure 2.1: Shows Granite rock

In the cores of many mountain ranges, or batholiths, granite is widely distributed across the Earth's crust. The larger granite grains are evidence that it was formed by gradual cooling of magma over an extended period of time. As they develop deeper in the crest, they are brought to the surface by the uplifting process otherwise, they wouldn't have been visible at the surface. Even if granite is covered by sedimentary rocks and is not visible on the surface, it still exists. They exist below the sedimentary layer because the deeper crust contains magma chambers that erupt from the mantle. So, these hard rocks make the basement rocks of the crust, these are hard enough that can withstand the overburden of sedimentary rocks strata. Granite is utilized as a dimension stone because of its hard rock qualities, which make it ideal for the task. These can be polished, are resistant to abrasion, tough enough to support the weight, and inert to weathering.

2.5 Previous Research Findings on Aggregates

(AGBALAJOBI et al., 2019) studied mechanical and mineralogical characteristics of granitic rocks from Gbose Quarry Nigeria to check its suitability for road construction. Several physical laboratory tests were performed on aggregate samples i.e. water absorption, mineral composition, aggregate impact value, aggregate crushing value and flakiness and elongation indices. According to laboratory testing results, aggregate made from fresh, fine- to medium-grained granite from the Gbose Quarry complies with generally accepted limiting criteria for usage in concrete and as a aggregate for road construction. No case resulted in a value being obtained that was greater than acceptable limit. The aggregate from this selected area is more suitable for specific purposes, such as road construction and heavy-duty concrete flooring, because these values of aggregate crushing value, water absorption value, elongation, and flakiness index are close or within the defined limitation.

(Hassan et al., 2020) conducted a study on the aggregate potential of the Eocene-aged Sakesar limestone from Salt Range, they thoroughly studied the aggregate based on its geotechnical characteristics and engineering properties. The Sakesar Limestone was chosen with a fundamental focus on future economic aggregate source if demonstrated to have excellent potential due to its easy access and usage. To prove its potential and provide recommendations, the rock samples were examined using AASHTO standards methods and ASTM standards. Four different potential sites were sampled altogether, and they are Tobar Valley, Bestway Cement Plant Quarry, and Pail-Padhrar section. The appropriateness of the findings as potential subbases, base course, surface course, and concrete was assessed. The research shows that, with the exception of Dhak Pass aggregate, which is observed as weak and porous, all samples of Sakesar limestone come within ASTM's acceptable criteria and are categorized as appropriate aggregate for road building operations.

(Ullah et al., 2020) analyzed Late Permian Wargal limestone in the Kafar Kot Chashma region of the Khisor Range using geological engineering tests to determine its feasibility as a viable aggregate for use in building roads and other civil structures. Results indicated that limestone is a hard, tough and durable material. Limestone's hydrophobicity was demonstrated by coating and peeling a bitumen aggregate mixture at 25°C. The results of several laboratory tests also indicated that Wargal limestone may be utilized as a base course and sub-base course in asphalt and cement concretes without risk. It is possible to transport these aggregates to many others locations because of its easy accessibility.

(Mushtaque Ahmed & Maryam Maira, 2020) Sindh's volcanic rocks have been examined for their significant engineering qualities, and they are appropriate for use as aggregates in concrete and HMA. On aggregate samples, a variety of physical and mechanical tests were run. There are two primary categories of granites, depending on the mineral makeup of the plagioclase/orthoclase mineral component. The standard tests revealed that the Pink Granites and Grey Granites samples exhibited unique properties, particularly in terms of their resistance to abrasion. They were able to determine that both samples could create aggregates that were appropriate for pavement, but only the pink sample could make concrete aggregates using conventional standards as a benchmark. Technical control should be a part of the crushing circuit as well to guarantee that the desired gradation is obtained.

(Ahmed Pathan et al., 2018) conducted research on aggregate of district Jamshoro for the aim of the study samples were collected from four significant crushing facilities in the Petaro region, namely the Qasim, Parkar, Haroon, and Sundas crushers. The collection and evaluation procedures were carried out in accordance with ASTM standards. The laboratory tests included sieve analysis and gradation, specific gravity, the Los Angeles abrasion test, unit weight, and others physical tests were also conducted. The outcome of study was determined based on ASTM/AASHTOO SPECIFICATIONS, all the result were in the specified limits and the mentioned aggregate was declared as a potential aggregate for road construction as well as other civil structures.

(Malahat et al., 2018) In this research, six number of quarries from the district Mardan have been chosen for evaluation as potential sources of coarse aggregate for concrete (sawaldher, palodheri, babuzai, jamal ghari, maneri & palai). There have been no research studies conducted before, despite the fact that the aggregate from the six quarries chosen is already extensively used in the Mardan region. All the physical and mechanical tests were conducted on aggregates in UET Peshawar labs, and the results shows that Margalla can be substituted with Palai Crush since it satisfies international criteria. The Maneri aggregate didn't pass the chemical tests, but it did quite well in the physical and mechanical ones. If concrete made from this material comes into touch with a significant amount of water after construction, it may degrade. According to physical and technical studies, the samples from Palodheri and Jamal Garhi are not suitable for use in concrete, and Palodheri has not even passed the chemical testing, such as the ASR. However, the findings from the Shamozai aggregates were good. The aggregates from the Sawaldher quarry, like those from the Maneri region, demonstrated good results in physical testing but fell short in chemical tests, therefore these may be utilized in locations where there is a lower likelihood that they will come into contact with significant volumes of water.

(Adanikin et al., 2018) Conducted a research study in which Crushed stone aggregates were tested from nine typical quarries in Western Nigeria. The mechanical and physical qualities of the aggregates were also assessed. The outcomes were contrasted against eleven worldwide standards (BS and ASTM Standards). All aggregate samples satisfied the criteria for density, water absorption, aggregate crushing value (ACV), and aggregate impact value (AIV). The analysis identifies Julius Berger quarry aggregates as having the highest mechanical strength.

(Munir et al., 2017) studied aggregate, utilizing an experimental technique, engineering characteristics of aggregates commonly utilized in Pakistan were compared. A total of four quarries provided aggregate samples that were taken in accordance with BS and ASTM standards. Numerous tests were conducted on the crushed rock from Margalla, Sargodha, Barnalla, and Mangla. Additionally, specimens were cast that underwent mechanical strength testing were prepared using the aforementioned material. The experiments showed that the aggregates from the quarries under investigation can be utilized for building. In construction industry, taking into account the economy and the environment, it is important to take these properties of aggregates into consideration. Different aggregate samples might have different features. Better mechanical properties were observed in the Margallah aggregate, whereas higher physical qualities were found in the Sargodha aggregate.

(Fladvad et al., 2017) in this research a investigation looked at the aggregates used in 18 different nations to build roads. With the help of this study, worldwide research on the subject may be better understood in order to comprehend the various techniques that are employed in aggregate use and pavement design. Crushed rock is recognized as the standard material in road building, as seen in the findings. The market for aggregates is multinational; for instance, the aggregate business is globally focused. Aggregates from Norway are utilised both locally and abroad. International standards, such as CEN and ASTM standards, together with local standards are used to control pavement materials. International standards offer a uniform system of classification for road materials, even though they do not establish explicit criteria. Although flexible pavements are normally built to the same specifications across the world, their construction techniques vary. Between the nations under study, there are significant differences in pavement thickness and aggregate size. Physical testing currently accounts for a substantial portion of aggregate selection and physical quality tests. Functional aggregate testing might be used to enhance aggregate use.

As per (Hafeez et al., 2015) Within Margalla aggregate crush quarry, twelve aggregate sources were tested for mechanical and physical characteristics. In order to minimize the number of sampling sources, a ranking-based technique was used for the testing of surface skid resistance and accelerated polish stone value. To rank aggregate sources, a variety of mechanical and physical features were taken into consideration. In place of various physical and mechanical tests, the PSV test on aggregate may be used to provide a ranking for the selection of exact aggregate sources.

(Saleem et al., 2013) looked into whether it is beneficial or bad to make concrete with locally accessible coarse particles. Aggregate samples were taken from three various quarries using ASTM sampling techniques. These aggregates' mechanical characteristics were tested in concrete using compression and tensile strength tests. The findings of this investigation showed that in Azad Kashmir, concrete built from local aggregates effectively retained sufficient mechanical properties. Performance of these aggregates was found to be comparable to that of Margallah and Sargodha aggregates. (Hussain & Yanjun, 2012) investigated Pakistan's prospective aggregate resources for paving projects. Dina's quartzite aggregate quarries have been used for many years in building construction. Examining the performance of Dina quarries as suitable sources of pavement aggregates was the main goal of this study. The Margalla aggregate, which is the most often used aggregate in pavement construction, was compared to the Dina aggregate in terms of a number of physical and mechanical characteristics. The aggregate attributes like specific gravity, water absorption, shape, impact value, crushing, los angles abrasion, and soundness are all in accordance with pavement requirements. A well performing asphalt mixture with Dina aggregate is likewise produced using Marshall's process. Based on these laboratory experiments, the Dina quarries in Punjab are possible suppliers of aggregate for the building of pavements.

(Gondal et al., 2009) studied Sakeasar limestone, Jutana formation and gravel from streams in the Jabbi-Warchha and Katha Saghral region these locally available rocks are crushed and used to make railroad ballast, unbound and bound pavements, and using in regular Portland cement and asphalt concrete. The current study assesses the engineering properties of these regional coarse aggregates for usage in concrete and roadways with the help of physical aggregates test in laboratory. Results indicated that

Both the Sakesar limestone and the Jutana Formation's coarse and fine fractions make excellent aggregates for building roads. However, Sakesar limestone-derived aggregates should be used in ordinary Portland cement concrete, furthermore In terms of strength, durability, and other related testing, the coarse and fine fractions of gravel from Katha-Saghral and Jabbi-Warchha pass the requirements. They are advised for usage in building projects. The greywackies in Jabbi-Warchha gravel, however, have the potential to cause a deleterious alkali-silica reaction.

(Gondal et al., 2008) Geotechnical and petrographic evaluations were done on samples taken from two new regions as well as two old ones. as a potential supply of aggregate for cement concrete and asphalt. These aggregates decrease expenses while improving the performance life of roads, buildings, barrages, and bridges. The regions of Kaha/Khalgari, Pitok, and Zungi are additional sources of high-quality aggregate for base courses and subbases for roads.

(Bjarnason et al., 2002) This study has primarily compared various test methodologies and levels of material quality. However, it's critical to keep in mind that the regression analysis and component analysis are founded on findings from the testing of Icelandic aggregates, which are primarily basaltic. Testing materials from various nations and origins, such as sedimentary rock, plutonic rock, or metamorphic rock aggregates, may produce varied findings. The findings provided here have made it feasible to propose requirements for Icelandic aggregates for certain end uses in road construction (surface layer, basecourses etc).

2.6 Rutting in HMA:

Rutting is the development of tiny quantities of irrecoverable strains as a result of loading on pavements (Ahmed & Ahmed, 2014). Rutting also describes a steady buildup of minor, permanent deformations brought on by stress.

Rutting, which causes asphalt pavements to permanently distort, is a key factor in pavement distress. Due to the significant rise in truck pressure over the past few decades, rutting has emerged as the primary flexible pavement failure mode. Rutting in any pavement is primarily caused by the accumulation of persistent deformation that takes place at various levels and parts of layers. When studded tyres are used on pavement, rutting may also happen.

In the presence of a longitudinal irregularity, rutting produces roughness. Ruts along roadways decrease skid resistance and raise the possibility of hydroplaning, which severely restricts sight due to accumulated water. Ruts gradually cause pavement cracks, which ultimately cause pavements to crumble or disintegrate. Road maintenance and repair expenses related to these problems are quite significant. According to (Garba.R, 2002) average vehicle gross weight has risen and average axle loads are getting close to their maximum levels. In nations with loose restrictions on axle loads, trucks' axle load limits are breached, exceeding the legal limit. When driving on flexible pavements, the higher axle load and tyre pressure produce significant stresses owing to the increased tire-to-pavement contact area, which results in rutting in the wheel track. Therefore, rutting is more common on flexible pavements exposed to high tyre pressures due to significant axle loads of heavy vehicles. Thus, rutting is described as a longitudinal depression in the top layer that occurs along the wheel path and causes damage to the pavement's edges. Rutting endangers vehicle safety by leading to severe structural breakdowns and hydroplaning. Every layer of a pavement can develop ruts due to lateral side densification and deformation.

2.6.1 Types of Rutting:

Asphalt mixes that have a low shear strength are typically to responsible for rutting in flexible pavements because they are unable to withstand the repeated severe axel stresses that a pavement must withstand.

2.6.2 Rutting caused by weak asphalt layer - Instability Rutting:

Due to high temperatures, which often occur in the summer when pavement temperatures are high, rutting is frequently brought on by asphalt mixtures that are too weak (Hussain & Yanjun, 2012). Shear deformation can be distortional, or it can happen without volume variation. Additionally, while under load, asphalt concrete has the potential to expand and increase volume. Shear flow or plastic flow are terms used by certain authors to describe expansion-related deformation. These sorts of deformation can also lead to the degradation of pavements. They may cause the aggregate and binder aggregate to separate or disintegrate. I it is important to consider the shearing and dilatant behavior of mixtures when assessing their resistance to rutting, since viscosity rises with shear rate.

2.6.3 Rutting from weak subgrade - Structural Rutting:

Along with rutting in the asphalt layer, rutting may also be brought on by repetitive loads in the base, subbase, and subgrade layers underneath the asphalt layer. Numerous times, the thickness of the top layers on subgrade and the asphalt layers is insufficient to reduce the deflections of the structure put on by applied loads. It is believed that a structural rutting is more closely connected to structural issues than material issues.

however, the subgrade may also get weaker as a result of moisture getting through. The subgrade is where structural rutting is most likely to experience permanent deformation.

2.6.4 Previous Research findings on Rutting Behavior:

In this study, (Garba.R, 2002) highlights the need of using high-quality materials for paving lines since improper handling of material structures makes it impossible to lessen the effects of rutting. Understanding the impact of the mixture's composition and the characteristics of the components is key to producing mixtures that are sufficiently resistant to rutting. It is difficult to exclude rutting for this purpose, no matter how much layer is supplied or how well the construction is done.

(Mallick et al., n.d.) In his study, he detailed how HMA mixes with strong interlocking aggregate structures and a tight bond may greatly lessen the pavements' susceptibility to rut. Large aggregates with a strong binder, according to studies, are more resistive to mixes with high aggregate and high binder concentrations. Rutting eventually occurs in HMA roads with an increase in the quantity of loads applied.

(Sousa, n.d.) 1991 According to this study, proper aggregate gradations should be used to lessen the effect of rutting on asphaltic concrete layers. When aggregates mixed appropriately, a blend with dense aggregate and continuous aggregate has less vacant space and more points of contact between the aggregates than an open or gap mixture. Mixtures made of angular aggregates may be more stable than those made of circular compounds, and low viscosity tar makes the blend less difficult and hence more rut prone. This study came to the conclusion that the amount of binder used in the mix affected how the mix rutted; specimens rutted more when a larger binder percentage was utilized.

(Sousa, n.d.) 1887 examined the rutting in the asphalt surface using a wheel tracking system. They measured the average rut depth and the volume of material displaced using this technology. They discovered that the initial stage of the rut's growth was caused by traffic compaction, or, to put it another way, that it was its primary cause. After the first phase, the volume under the tyres decreases approximately to the same extent as the volume in the immediate area increases. Additional deformation is brought on by excessive compaction under traffic due to shear aging. They find that shear deformation is the primary cause of rutting after a thorough investigation.

2.7 Moisture damage of Asphalt Pavement:

Moisture damage, which (Ahmed & Ahmed, 2014) defines as the loss of stability and strength of asphalt mixtures, is a consequence of the moisture impact. If the fine aggregate and asphalt binder don't have the necessary binding strength to maintain their bond integrity, moisture degradation may develop in asphalt mixtures. Moisture forms a layer over the aggregate, weakening the binding between the binder and the aggregate in the mix and making the asphalt mixture more vulnerable to moisture during cyclic loading.

According to (Mallick et al., n.d.), moisture degradation occurs when moisture in air voids negatively impacts the HMA's strength and durability. Cohesive failure and adhesive failure are two categories under which moisture damage can be categorized. Cohesive failure occurs when the glue between the aggregate and binder fails, whereas moisture affects the strength of the binder in adhesive failure.

2.8 Method for Moisture susceptibility of Asphalt Mix:

Hot mix asphalt (HMA) tensile strength is essential because it acts as a reliable indicator of how likely the HMA mixture is to fracture. when the mixture has a high tensile strength, it means that The HMA has a greater chance of resisting against cracking and can withstand larger stresses.

By loading the compacted cylindrical sample diagonally over its vertical diameter plane at a standard rate of distortion (50 mm/min) and at a temperature of 25 °C in accordance with ASTM standard (D6931), indirect tensile strength (ITS) of HMA mixture is determined.

Importance of ITS testing to assess bituminous mixture resistance to rutting and cracking. The specimen separates When even the highest pressure is parallel to the active load and perpendicular to the diametrically opposite plane (Mallick et al., n.d.).

The loading procedure applies equal thickness pressure perpendicular to the working load and close to the plane of parapedicular diameter. ITS testing leads to the splitting of the HMA sample. The indirect tensile strength (ITS) is calculated by applying a constant rate of ram movement to failure, in accordance with ASSHTO TP9-96. By using the equation 1, the tensile strength is calculated.

$$S_t = 2P/\Pi tD \qquad (1)$$

Where:

St = tensile strength. (psi)

P = maximum load. (lbs)

t = sample thickness (inches)

D = sample diameter (inches)

The Indirect Tensile Strength (ITS) test reveals the characteristics that may be used to illustrate how much moisture is exposed to hot mix asphalt (HMA). Tensile Strength Ratio is an extremely significant feature (TSR).

$$\mathrm{UTS} = \mathrm{T2}/\mathrm{T1} \quad (2)$$

Where:

TSR = tensile strength ratio

S1 = average tensile strength of unconditioned samples

S2 = average tensile strength of conditioned sample

The TSR number reflects the likelihood that the HMA may peel off or weaken in a wet environment. Tensile dry strength and tensile wet strength were divided into two smaller groups of samples for the purpose of determining moisture susceptibility. To determine the tensile strength ratio, wet tensile strength samples are compared to dry tensile strength specimens (TSR). TSR value of 80% was used as the cutoff point for the criterion, and TSR values above 80% indicated that the tested mix is less susceptible to moisture damage and mixes with TSR values below 80% is more vulnerable to damage due to moisture. Under situations of dampness, a mix will likely perform poorly if the TSR value is less. The cracking tendency in HMA may also be determined using the TSR. The cracking tendency in HMA may also be determined using the TSR. Damage from moisture is a prevalent problem that is being addressed and studied globally.

2.8.1 Previous Research findings on Moisture susceptibility:

(Zhao et al., 2013) explained that one might estimate asphalt mixtures' sensitivity to moisture by taking dynamic modulus findings and contact angle into account. Which proved to be the best option for determining moisture damage to HMA.

(Mallick et al., n.d.) said that a specimen is loaded diametrically in an ITS test until it fails; a mix with a high strain at failure suggests that it will resist breaking. In accordance with the Superpave technique, which the Maine DOT approved in 1998, the TSR value for both damp and dry circumstances is the most accurate approach to measure moisture damage. With the addition of moisture, the resistance to deformation reduced, but the conditioned mixtures are all the same.

According to (Sousa, n.d.) the phrase "moisture damage" refers to the overall degradation of a hot mix asphalt mixture's strength and durability. Numerous elements influence moisture-related issues, but the two most important ones are cohesive and adhesive failure. When adhesive failure is assessed, the bituminous coating on the aggregate surface has been damaged by moisture. While a failure is referred to be a cohesiveness failure if there is a loss of mixture stiffness. The interactions between the aggregate, bitumen, and the aforementioned two failures are closely related.

The ITS test is another technique that is frequently employed in the pavement business to assess moisture damage, according to the Washington State Department of Transportation. By analyzing mix samples with and without moisture conditioning, moisture susceptibility of the mixture may be determined.

2.9 Summary

This chapter gives a brief overview of granitic rocks, HMA and appropriate aggregate characteristics utilized in HMA, and past research on various aggregate sources. The majority of earlier research on aggregate sources examine aggregate by identifying its physical and mechanical characteristics. It also covered the several forms of rutting that occurs in flexible pavements, as well as DWTD and ITS tests for rutting and moisture damage to HMA mix. Review of studies done on rutting susceptibility and moisture damage testing of asphalt mix designs.

Chapter 3: Research Methodology

3.1 Introduction:

In this Chapter, a detailed discussion of the methodology to be followed is discussed to fulfill the objectives of this study. Methodology Includes Material acquisition, conditioning, and testing of specimens. Aggregates to be tested were attained from District upper Dir Wari area and the Parco of grade 60/70 that was employed to prepare the Asphalt samples. For finding the Optimum Bitumen Content (OBC), Design used was Marshal Mix Design. Using the MS-2 Manual all the desired Volumetric properties were estimated, this includes Va, VFA, Flow, VMA, and stability of the sample. For performance testing of the prepared samples, Superpave Gyratory Compactor was used. Moreover, to evaluate the Rutting, the Hamburg wheel tracking method was used for which the samples were cut using the saw, and lastly, for the estimation of Moisture Susceptibility of the study samples, a Marshal compactor was used during the sample preparation.

3.2 Methodology Framework:

The methodology framework for this study is shown in *Figure 3.1*.The conceptual framework includes the material acquisition, sample preparation, testing, Analysis and results, and conclusion from the acquired results.

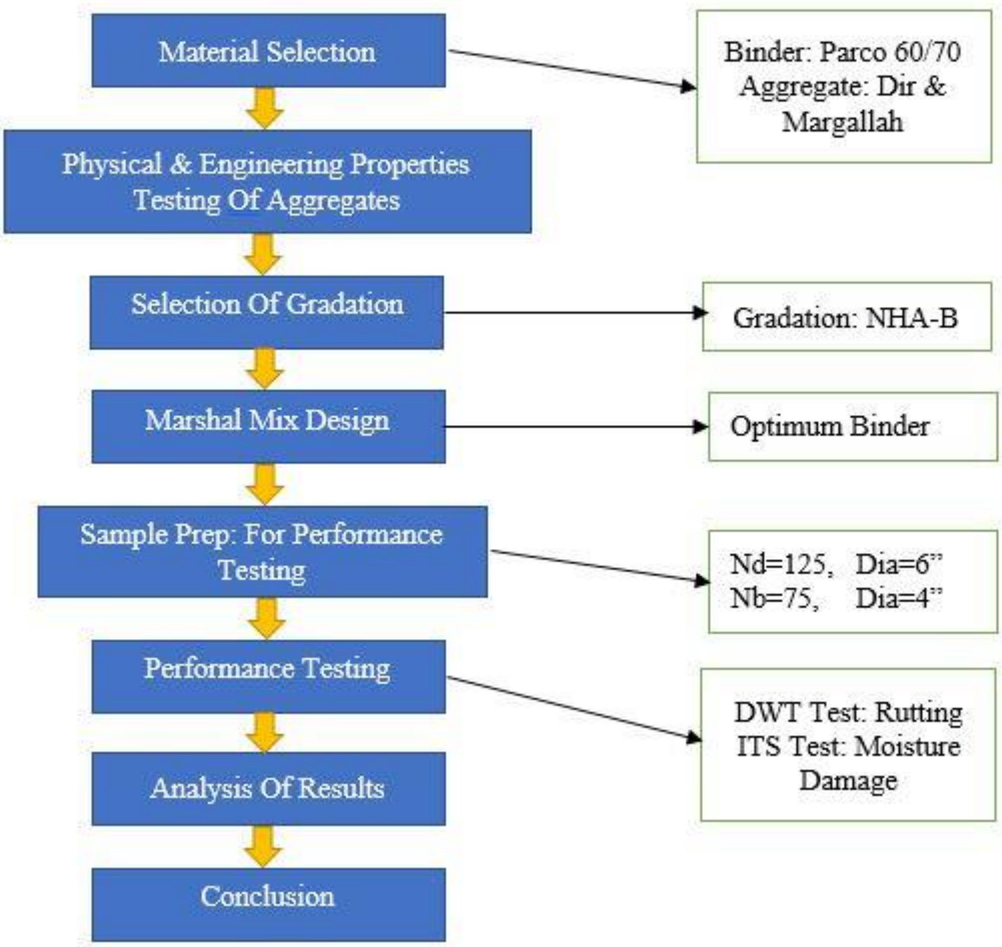

Figure 3.1 *Methodology Framework of study*

3.2.1 Material Selection and Acquisition:

Aggregates (Coarse and fine) were selected from upper Dir Wari area and Margallah and the sample binder material with the grade 60/70 was taken from Parco to prepare test samples. As Pakistan have moderate climate so 60/70 grade is more commonly used as binder.

The aggregates consist of fillers, fine aggregates, and coarse aggregates, which were gathered and further crushed with mechanical crusher in PCSIR Lab Peshawar for desire gradation ***Figure 3.2***.

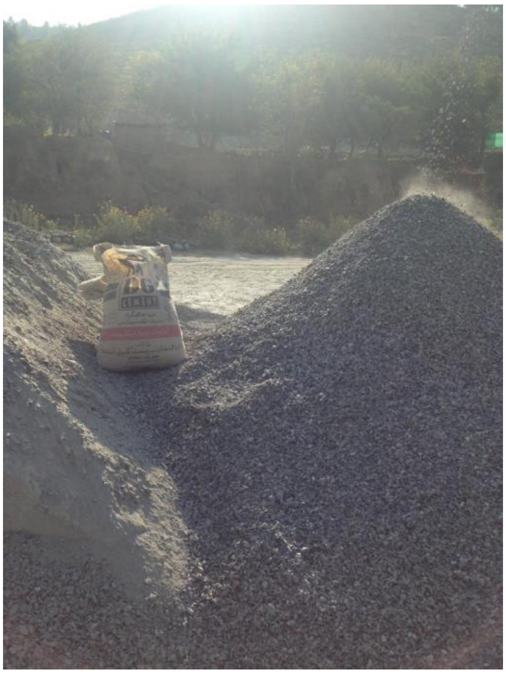

Figure 3.3 *Crush plant of Dir granitic rocks*

Figure 3.2 *Jaw Crusher in PCSIR Lab Peshawar*

3.3 Material's Laboratory Characterization:

About 95% of the permanent deformation resistance of a mixture is due to the structure of aggregates present in the material and remaining 5% is offered by the type of asphalt binder used in the mixture. In order to resist the repeated / fatigue load that causes the damage to the aggregates present, the material used must have a strong solid skeleton. When it comes to properties of HMA, it is strongly influenced by properties of aggregates this includes physical texture, Particles sizes and shapes. Shear strength varies according to shape of aggregate, Shear strength is greater in angular and rough textured aggregates in comparison to that of the round and smooth textured aggregates.

For characterizing aggregates according to ASTM and BS Standard, the tests were carried out.

3.4 Testing of Aggregates: Classification and Characteristics Tests:

Testing on the aggregate's samples were carried out to find all the required engineering properties. For the resistance to fatigue loads the stone skeleton is required to have a well-built up structure. For the fundamental properties of the aggregate samples, tests like water absorption, durability, and specific gravity tests were carried out on each sample stockpile.

3.4.1 Test No 1: Shape Test

For the prevention of particle damage during traffic flow a criterion is set, with particle size of coarse aggregates more than that of 4.75mm with percentage of flaky and elongated particles with the min to max dimension ratio should be greater than 5. The Standard procedure used for this test is ASTM-D4791 and results are shown in *Table 4-2*.

Figure 3.4 *Shows Flakiness index Apparatus*

3.4.2 Test No. 2: LOS Angles Abrasion Test

For Road Construction aggregate hardness test is carried out, as it is of great importance that the aggregate is hard enough so that it can be wear resistant due to traffic loading. For this test apparatus consisted of Los Angeles Abrasion machine, Sieve set, steel balls and balance. Gradation was done with aggregates retained on ½" and 1/8" sieve was used in the test. And around W_1 5000grams of aggregates were taken with 11 balls in the test machine. The machine was rotated with 5000 rotations at 30 to 33 rotations per minute. After this the sample was then sieves out through 1.7mm sieve. W_2 was the sample weight that was passed through the sieve. The value of abrasion was found using the following equation.

$$\left(\frac{W2}{W1}\right) * 100 \qquad (3)$$

For good quality mixtures, it is important to carry out test in order to determine the aggregate specifications and behaviors, this can be done using AASHTIO Standard T 96-87. The tests were conducted on aggregate samples taken from Upper Dir Wari area granite and Margallah. *Table 4-2* shows the results of these tests.

Figure 3.5 *Tested Aggregate Sample in LA Apparatus*

Figure 3.6 *LOS Angeles Abrasion Machine*

3.4.3 Test No 3: Impact Value Test of Aggregates

This test is used to compare the various strengths of aggregates using various impact loads. Due to heavy traffic loads the road structure is said to be under impact loading. Impact loading can cause aggregate stones to be crushed into much smaller sizes as a result of continuous pounding. Thus, it is important for aggregates to be tough enough to resist the damages causing breakage during impact loading, Standard BS 812 and IS 383 was used to find the impact values.

Figure 3.7 *Apparatus Of Impact Value Test*

3.4.4 Test No 4: Absorption Value and Specific Gravity:

Absorption and specific gravity tests were conducted on the aggregate sample. The specific gravity of a material is calculated by dividing the density of any substance by the density of water at 23 °C. Any substance that has a specific gravity of 1.0 has the same density as water. ASTM C-127 [33] and ASTM C 128 tests were carried out to establish the specific gravity and water absorption value of aggregate from both sources.

Figure 3.8 *Shows Saturated sample and Test Apparatus*

3.4.5 Test No. 5: Crushing Value Test:

Aggregate must be able to sustain large traffic loads in order to construct a pavement with a high level of quality strength. Open-ended steel slander, base plate, 150mm piston, rod for lifting the cylinder, cylindrical measure balance, tamping rod, and compressive testing equipment were all used. The aggregates were pass through a series of sieves, and those that retained 3/8" and passed through 12" were chosen. The aggregate sample (W1) was placed in three layers to the cylindrical measure after being washed, oven dried, and weighed. Each layer was then tamped 25 times. The aggregate sample (W1) was placed in three layers to the cylindrical measure after being washed, oven dried, and weighed. Each layer was then tamped 25 times. The sample was moved to the steel cylinder and inserted with the plunger after being embedded in three layers of

Figure 3.9 *Shows Compressive Testing Machine And Steel Cylinder*

the foundation plate for the steel cylinder. Then, we put it in a compressing machine for crushing tests and applied a steady load of 4 tones per minute until it reached 40 tones. Crushed material was removed from the steel cylinder and put through a 2.36 mm sieve. Materials collected and weighed after passing through this filter (W2). Calculate the aggregate crushing value by multiplying W2/W1 by 100.

3.4.6 Test No 6: Soundness Test

This test is used to gauge an aggregate's resistance to deterioration brought on by weathering. We repeatedly immerse the aggregate sample in the sodium sulphate solution to test soundness. After five cycles, aggregate samples are washed and sieved into separate size ranges to calculate each sample's mass loss separately. A weighted average of the mass loss for each size range makes up the final reported loss value. According to ASTM C-88, this test technique is carried out.

Figure 3.10 *Shows Sample For Soundness Test*

3.5 Testing of Bitumen: Classification and Characterization:

The Asphalt Institute MS-4 guidebook recommends the following for use in construction or engineering objectives: A binder must possess uniformity, safety, and purity in order to be successful. The consistency of asphalt binder varies with temperature. Therefore, it is necessary to compare asphalt binder consistency at a constant temperature. Penetration testing may be used to determine bitumen consistency (Asphalt Institute MS-4, 2003). Bitumen underwent further tests, such as the softening point test and the ductility test of binder, to learn more about its consistency and binding qualities. Therefore, a variety of laboratory studies were carried out to define more asphalt binders.

- Flash and Fire Point test of Bitumen.
- Penetration Grade test of Bitumen.
- Softening Point test of Bitumen.
- Ductility test of Bitumen.

3.5.1 Grade Penetration

One technique for determining the penetration of asphaltic materials is a penetration test. Containers containing needles and specimens are utilised in the penetration test. With a soft binder, penetration levels are higher. As per ASTM D5-06, three Parco 60/70 specimens were used, and five values from each specimen were collected after completing penetration tests. The temperature was held at 25°C, the load was 100 grams, and the test period was 5 seconds. The outcomes were entirely in line with the penetration testing requirements. *Table **4-1*** displays the results of the penetration test.

Figure 3.11 *Shows Penetration Test Apparatus*

3.5.2 Softening Point:

Although bitumen has viscoelastic qualities, as temperature increases, the viscosity decreases and the substance softens. The softening point of bitumen is the temperature at which a sample of standard size can no longer hold the weight of 3.5 g steel balls. The bitumen's softening point is therefore the average temperature at which it softens

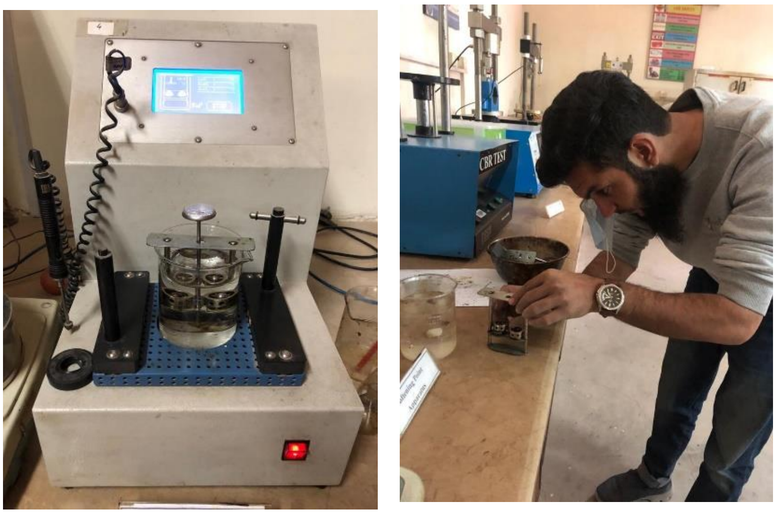

Figure 3.12 *Shows Test Apparatus For Softening Point*

just enough to let steel balls fall 25 mm. By employing a ring and ball apparatus, the softening point of biner bitumen was ascertained in accordance with ASTM D36-95. The findings of the softening point test are shown in ***Table 4-1***.

3.5.3 Ductility Test:

The primary characteristic and crucial element of bitumen binder that might affect the effectiveness of an asphalt mixture is ductility. The ductility test can demonstrate how variations in temperature affect bitumen's properties. Simply said, the definition is "Maximum lengthening of binder sample at particular temperature and definite speed without breaking or drooping away in water bath when force is applied on sample from both ends in accordance with standard (ASTM D113-07). The typical circumstances and outcomes for bitumen ductility testing are shown in ***Table 4-1***. Each specimen met the minimum 100 cm ductility requirement.

Figure 3.13 *Shows Sample Preparation For Ductility Test And Test Apparatus*

3.5.4 Flash and Fire Point Test of Bitumen:

The flash and fire point of the binder is discovered to enable the safe heating of the mix in the field without it catching fire. Therefore, it is crucial to

Figure 3.14 *Flash Point Test Apparatus*

plan ahead for the asphalt's safe working temperature for mixing and compaction. To determine the necessary temperatures for the ASTM standard D-92-05 bituminous Flash point and Fire point test.

3.6 Selection Of Aggregate Gradation:

After determining the necessary aggregate qualities from each selected source, NHA Class B gradation was chosen for densely graded, wearing course surfaces. The selected gradation is displayed in *Table 3-1* and *Figure 3.15* where orange and blue lines indicate the upper and lower limits established by NHA and a grey line displays the selected gradations. A nominal maximum aggregate size of 12.5 mm was chosen for the class B gradation for wearing coarse.

Table 3-1 *Gradation For Marshal*

Sr. No	Sieve size	Passing Range			Our Selection	
		Lower Limit	Upper Limit	0.45	Passing %	Retain %
1	25					0
2	19	100	100	3.7621761	100	0
3	12.5	75	90	3.1160865	82.5	17.5
4	9.5	60	80	2.7540741	70	12.5
5	4.75	40	60	2.0161003	50	20
6	2.38	20	40	1.4772692	30	20
7	1.18	5	15	1.0773254	10	20
8	0.075	3	8	0.3117293	5.5	4.5
	0					5.5

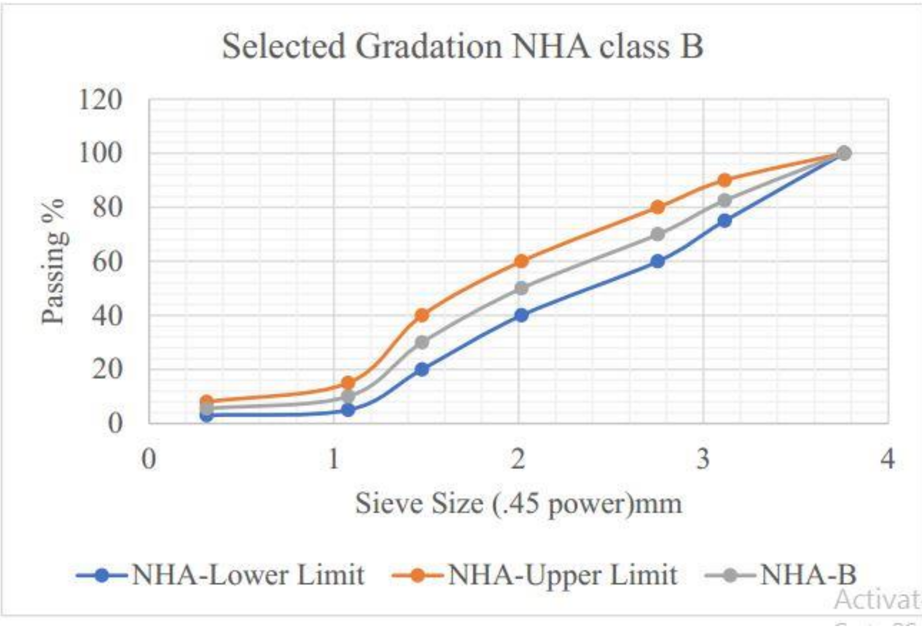

Figure 3.15 *Mid Gradation Selected For Testing*

3.7 Preparation Of Asphalt Mixtures:

In this study, two asphalt mixtures were made, one from widely used Margallah aggregate and the other from Dir Granitic rocks aggregate. Marshal Mix designs process is used to produce samples in the lab to determine OBC for each aggregate source. Samples were compacted to their OBC at predetermined air voids in order to assess the performance of the mix. Below is a detailed discussion of laboratory samples that were prepared in accordance with ASTM guidelines.

3.7.1 Bituminous Mixes Preparation For Marshall Mix Design:

The bituminous mixes were prepared according to ASTM D-6926, which was followed for the fabrication of bituminous specimens utilizing Marshall apparatus. Prior to determining OBCs, we first measured the volumetric parameters of the mix, followed by checks on flow, stability, and Marshall Mix criterion verification. Marshall Mix design was completed using the below-discussed steps.

3.7.2 Preparation Of Aggregates and Bitumen for Mix Design:

Aggregates were sieved in accordance with the chosen gradation before being heated in an oven at 105°C to 110°C until consistent weight was achieved. A compacted sample with a diameter of 4 inches was prepared using 1200 grammes of aggregate using the Marshall Mix design technique (ASTM D6926). Each specimen's required amount of asphalt cement is determined as a percentage of the mix's overall weight using the formula in eq 4 below.

$$MT = MA + MB \qquad (4)$$

$$MB = X/100(MT)$$

Here,

MT = Mass of the Total mix

MA = Aggregate’s mass in mix

MB = Bitumen’s mass in mix

X = Bitumen’s Percentage in mix

Figure 3.16 *Sieving Of Aggregates And Oven Dried Sample*

3.7.3 Aggregates and Asphalt Cement Mixing:

The heated bitumen and aggregates were poured right into the mixing pan after being taken out of the oven. The schematic diagram for manual aggregate mixing is shown in *Figure 3.17* The mixing temperature range in Pakistan for the preparation of HMA mixes is between 160°C and 165°C, as per NHA requirements.

Figure 3.17 *Asphalt Mixer*

3.7.4 Specimens Compaction:

After conditioning at 135°C, the Marshall Compactor compressed the mixture. The mould assembly also includes a baseplate and an extension collar in addition to the mould cylinder. A mould cylinder is roughly 3 inches tall with an interior diameter of 4 inches. In order to allow for the changeover of the collar and base plate, it is made to be compatible with either end of the mould. The mixture was put into the mould using a spatula. Before the mould was packed, a piece of filter paper with a diameter equal to that of the mould was placed there. Before packing, the mould was cleaned and heated to 135°C in the oven. As soon as a batch has been distributed uniformly throughout a mould. To prevent any sticking with the hammer, a filter paper with a diameter equivalent to the diameter of the mould was put over it.

30 million ESALs were chosen for this investigation based on the criteria of significant traffic for dense graded wearing course. On each end, 75 strikes were delivered to simulate heavy traffic. The mould assembly was mounted onto a mould holder on a compaction pedestal in order to compact (deliver blows). The hammer hit the mould assembly 75 times, mechanically blasting the specimens. After the blows on one side were finished, the mould assembly was withdrawn from the holder, the specimen was turned over, the mould was reassembled, and the same number of blows were delivered on the opposite side.

Figure 3.18 *Automatic Compactor for samples*

3.7.5 Specimens Extraction from Mould:

After mechanical hammer compression, the mould was removed and split. Sample was given some time to cool. To extract the sample from the mould, use an extraction jack. The prepared specimens

3.7.6 Specimens for Each Job Mix Formula:

For each mix of asphalt cement and aggregates, three specimens were prepared. There were 15 specimens created for each type, with a total of 30 specimens. To prepare the samples, five different binder contents were utilized (3.5, 4.0, 4.5, 5.0 and 5.5 percent). Five trial mixes were chosen in order to discover the combination with the best performance at 4 percent air voids.

Figure 3.19 *Prepared Samples for Tests*

3.8 Determination Of Volumetric properties, Stability and Flow:

Marshall samples were prepared, and their volumetric characteristics and stability values were computed. Voids in Mineral Aggregates (VMA), Voids filled with asphalt (VFA), Air Voids (Va), and unit weight are among the volumetric characteristics of the mixtures. The equipment used to determine the bulk specific gravity and theoretical specific gravities for Marshal samples is shown in *Table 4-4* and *Table 4-5*. The Gmm and Gmb of bituminous paving mixes are computed using ASTM D2041 and D2726.The determination of the prepared samples' bulk specific gravity (Gmb) and theoretical maximum specific gravity (Gmm), formulae were used to determine their volumetric parameters. The Marshall Mix design criterion is displayed in *Table 3-1*.

After the Gmb determination was completed in a water bath for one hour at 60°C, the samples were evaluated for stability and flow in apparatus, as shown in *Figure 3.21*.

Every sample was deformed at a rate of five millimeters per minute until failure was reached. The entire maximum load in KN is known as Marshall Stability. The overall deformation under the highest load was measured as a flow number of mm. Marshall mix design guidelines state that for a densely graded wearing course surface, specimen stability should not be less than 8.006 KN and flow value must be between 2-3.5.


Figure 3.20 *Apparatus For Gmm And Prepared Samples For Gmm*

According to Marshall Mix design, the specimen's stability must meet the minimum passing requirements of not being less than 8.006 KN and having a flow number between 2 and 3. (MS-2). Prior to testing for flow and stability, the specimens were immersed in a water bath set at 60 degrees Celsius. Marshall machine was then used to test stability and flow, as shown in *Figure 3.22*.

Figure 3.21 *Gmb Test Apparatus And Prepared Samples In Water Bath*

Figure 3.22 *Marshal Compression Machine*

3.9 Preparation of Sample For Performance Testing:

Superpave mix was used to prepare the specimens for testing with wheel trackers and assessing for moisture damage with UTM. After sieving, the aggregates were heated to

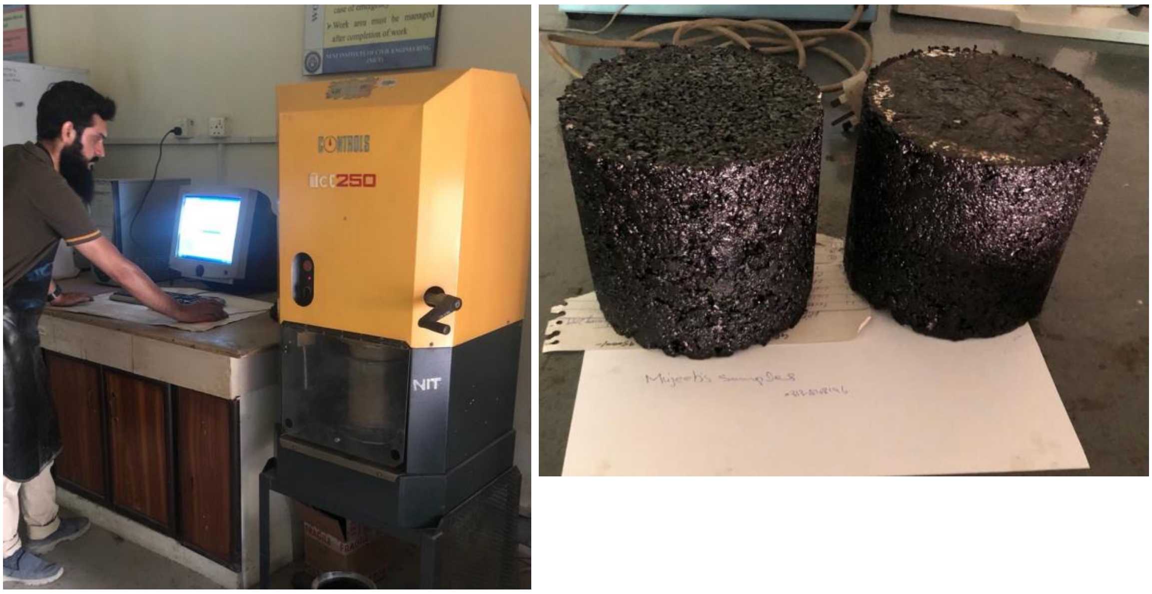

Figure 3.23 *Gyratory compactor and Prepared Samples for performance tests*

105°C to 110°C in order to maintain a steady weight. For HMA mix, temperatures of 160 C for mixing and 135 C for compacting are employed. 6000gm of material were needed to create gyratory compacted specimens with a six-inch diameter. The specimens underwent 125 spins with a 1.16o gyratory angle and 600kpa pressure applied to compress them.

For every source of the aggregate, two replicas were created. A saw cutter was used to cut each specimen into dimensions of a 6-inch diameter and 1.5-inch height in order to generate a standard sample for wheel tracker testing. Each specimen was cut into a 6-inch diameter and a 1.5-inch height using a saw cutter.

Figure 3.24 *Saw Cutter And Samples For DWT*

On UTM, samples measuring 4 inch diameter were prepared for moisture susceptibility.

3.9.1 Rutting Test on Sample Using DWT:

Rutting, one of the most frequent permanent deformations of pavement, is caused by cyclic traffic loads and is the accumulation of minor deformations in the pavement materials that appear as longitudinal depressions along the pavement's wheel tracks. Using a double wheel tracker, the specimens were put to the test to see how resistant they were to permanent deformation for the research of rutting susceptibility. A 203mm diameter and 50mm width tyre can be rotated across a 230mm distance using the electrically driven DWT. The steel wheel is under 700 N of stress, and it generates pressure equivalent to that of a double axle's rear tyres. As rut depth increases, the contact area grows and as a result, the contact stresses change. Moving forward and backward over the specimen is the steel wheel. About 60 passes on the sample must be made by the HWTD steel wheel every minute. The center of the sample is where the wheel travels over the specimen at a speed of almost 1 foot per second. In a dual wheel

Figure 3.25 *DWT for Rutting test*

tracker, testing may be done in either a dry or an wet environment. This inquiry used a dry mood test on the specimen. The instrument assesses the effects of rutting by rolling a steel wheel across the specimen surface. Rutting tests are carried out using a double wheel-tracking equipment, as shown in *Figure 3.25*. Before conducting the test, the sample was saw cut in accordance with the necessary size of the mould, which was 63mmthick and 150mm in diameter.

Free places were filled with bits of plastic or wood after the specimen was placed in the mould so that the sample wouldn't move while the wheel rotated, as seen in *Figure 3.26*. For fastening, the steel tray was adjusted and positioned just beneath the wheel.

Figure 3.26 *Sample in DWT Tray*

The wheel tracking device was turned on when the steel tray with the sample was fixed securely. Basic data of samples, including the code, dia, weight, and height, were entered into the laptop that was coupled to the device. The speed of the wheels moving was set at 60 ppm (passes per minute). For the purpose of determining the rutting potential of asphalt mixtures, a fixed 10,000 pass number was used. The wheel tracker was utilized in dry mode.

The test was finally conducted, with wheel movement indicating test progress. On the LCD of the system connected to the machine, the number of passes was displayed. The wheel's whole back and forth motion was counted as two passes. The LVDT (Linear Variable Differential Transformer) simultaneously monitors the wheel motion and the impact of the rut in unit of millimeters. When the desired number of passes were completed, the machine automatically shut down. The outcomes were kept for further use.

3.9.2 Moisture Susceptibility Testing using UTM:

The tests were carried out in line with ASTM D 6931-07, (Resistance of Compacted Hot-Mix Asphalt to Moisture Induced Damage), to determine moisture susceptibility. Three samples from each blend were evaluated in an unconditioned manner. Prior to testing at 25*1°C (77*1.8°F), the unconditioned specimens were placed in a water bath for one hour. Additionally, three samples of each blend were conditionally examined. Sample conditioning was done in accordance with ALDOT-361; that is, saturated specimens were first put in a water bath at 60°C (140°F) for 24 hours, then for an hour in a water bath at 25°C (77°1.8°m/minF). Each specimen was positioned in the UTM machine so that the load would transfer into the sample in both the unconditioned and conditioned states at a rate of 50 mm/minute per specimen, as illustrated in *Figure 3.27*.

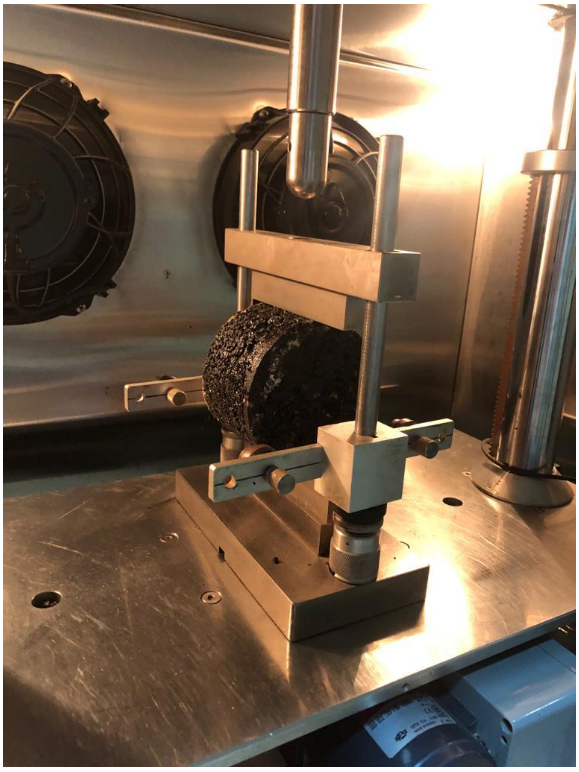

Figure 3.27 *Sample In UTM*

Following that, the tensile strength was determined using the specimen's measurements and failure loads. We divided the average conditioned tensile strength by the average unconditioned tensile strength to arrive at tensile strength ratios. An acceptable tensile strength ratio was defined as 80 percent (minimum).

Figure 3.28 *Prepared Unconditioned Sample for UTM*

Each sample's tensile strength is determined using Equation 5 below

$$St = 2000P/\pi Dt \qquad (5)$$

Where:

St = Tensile. Strength of sample (kPa)

P = Maximum load Applied on sample (N)

t = Specimen height before tensile test (mm)

D = Specimen diameter of sample (mm)

Tensile strength ratio (TSR), a measure of the impact of moisture damage, is the ratio of the tensile strength of the conditioned samples to that of the unconditioned samples. Equation 6 is used to compute the TSR for each blend.

$$TSR = [S2/S1] \qquad (6)$$

Where:

S1 = Tensile strength of dry subset (Average)

S2 = Tensile strength of conditioned subset (Average)

3.10 Summary:

This chapter illustrates how bitumen and aggregates from two separate sources are characterized in a lab in order to create bituminous paving mixtures. For the preparation of the bituminous mix, materials that met the required standards were employed. OBC was determined after volumetric properties of bituminous mix were calculated. It has been discussed how the ITS test for moisture susceptibility and the permanent deformation testing of bituminous mix specimens were conducted.

Chapter:4 Results and Analysis

4.1 Introduction

This study is focused on using two distinct sources of aggregate and comparing their fundamental engineering and mechanical properties as well as assessing the sensitivity of HMA mixes to moisture susceptibility and rutting. The new aggregate utilized in this investigation was obtained from a granite quarry in Dir Upper, and control samples were made in a lab following the calculation of OBC using Margalla aggregate with an NHA Class B gradation. Previous studies on various aggregate sources in Pakistan, rutting susceptibility, and moisture damage to mix have already been explained in detail in the Literature Review, while all evaluations and performance tests, as well as the procedures and equipment used, have been described in detail in Chapter 3 (Research and Testing Methodology). The most prevalent pavement distress in Pakistan is rutting, which is mostly brought on by high temperatures paired with heavy loads. Therefore, it is both technically feasible and practically acceptable to examine rutting susceptibility using the Hamburg Wheel tracker test. Moisture works as a destructor that causes pavement to collapse earlier than rutting alone, and the simplest way to check for moisture damage is with a UTM. This chapter includes a thorough examination of data collected from various experimental tests as well as detailed test findings derived from the data.

4.2 Bitumen Conventional tests Result:

This investigation made use of bitumen of the Parco 60/70 pen grade. To describe the binder, conventional tests were conducted. *Table 4-1* lists the typical characteristics of binder. Satisfactory findings from result columns can be seen, demonstrating that its use in asphalt pavements is a suitable option.

4.3 Aggregates Physical Testing Results:

Margalla Quarry Aggregates conducted physical testing (in accordance with ASTM/BS standard protocols) to ensure their use in the wearing course of asphaltic pavements. The results column has demonstrated that all values fall within the given ranges.

Table 4-2 lists the overall tests that were run.

Table 4-1 *Results Of Basic Bitumen Tests*

S.NO	Description of test	Specification standards	Results	Specification limit
1	Penetration Test (25°C)	ASTM D 5	62.00	60-70
2	Ductility Test (cm)	ASTM D 113	above 100	≥100
3	Softening Point Test (°C)	ASTM D 36	50.00	49-56
4	Flash Point (°C)	ASTM D 92	358.00	250min
5	Fire Point (°C)	ASTM D 92	386	>250
6	Specific gravity of Bitumen	ASTM D 3289	1.01	1.01-1.06

Table 4-2 *Physical Test Results of Both Aggregates (Dir & Margallah)*

S.NO	Description of test	Specification standards	Dir Granite	Margallah	Specification limit
1	Elongation Index %	ASTM D 4791-95	11.45	11.3	≤ 15%
2	Flakiness index %	ASTM D 4791-95	14.50	13.6	≤ 15%
3	Los Angles Abrasion %	ASTM C 131	26.30	21.7	≤ 40%
4	Impact value %	BS 812	24.95	18.3	≤ 30%
5	Soundness Test %	ASTM C 88	2.84	2.01	<12%
6	Crushing Value %	BS 812	25	18.6	WC ≤ 30%
					BC ≤ 45%
7	Water absorption %	ASTM C 127	0.74	0.53	≤ 5%
8	Specific gravity	ASTM C 127	2.651	2.71	≤ 3

4.3.1 Flakiness & Elongation index:

If flakiness and elongation values are high, these particles may break down or present a challenge during the compaction process. In *Figure 4.1*, the FI and EI values of the aggregates from Upper Dir & Margallah are displayed. After comparing numbers visually, it was discovered that Dir's flakiness and elongation index is higher than the aggregate for Margallah.

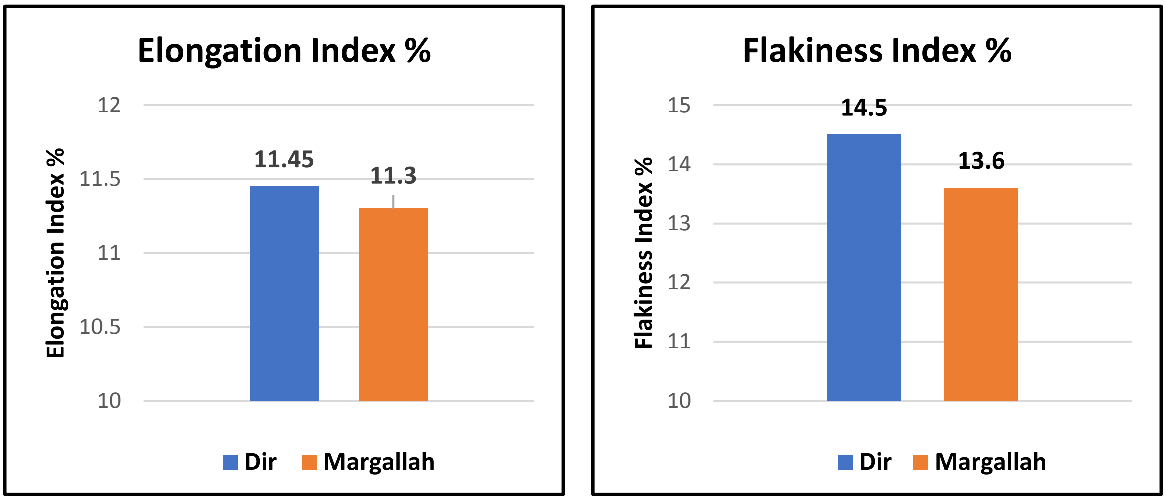

Figure 4.1 *flakiness & Elongation index of Dir & Margallah Aggregates*

4.3.2 Loss Angeles Abrasion

Figure 4.2 compares the abrasion values of the aggregates from Margallah and Upper Dir; it is evident from this comparison that Dir aggregate has 4.6 percent less resistance to abrasion than Margallah aggregate. Materials value of Los Angeles test is likewise under NHA's acceptable limits which is 30 percent for wearing courses.

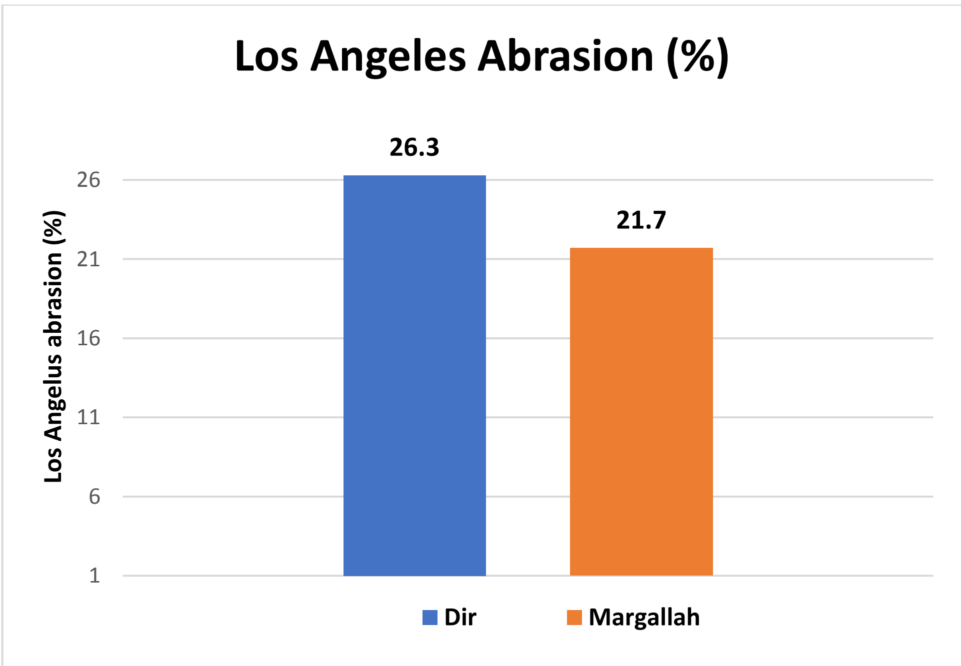

Figure 4.2 *LOS Angeles abrasion values of Dir & Margallah Aggregates*

4.3.3 Aggregate Impact Value

Figure 4.3 displays the AIV of Upper Dir crush aggregates in comparison to Margalla. It is clear that Upper Dir aggregates have a higher AIV than Margallah aggregates. The aggregate loses strength under impact loads as impact value increases. In comparison to Margallah aggregate, Upper Dir aggregate will demonstrate reduced strength under impact load circumstances, because of this 6.65% difference in AIV. Furthermore, values of this test should be less than 30%, values of both sources are within acceptable limits.

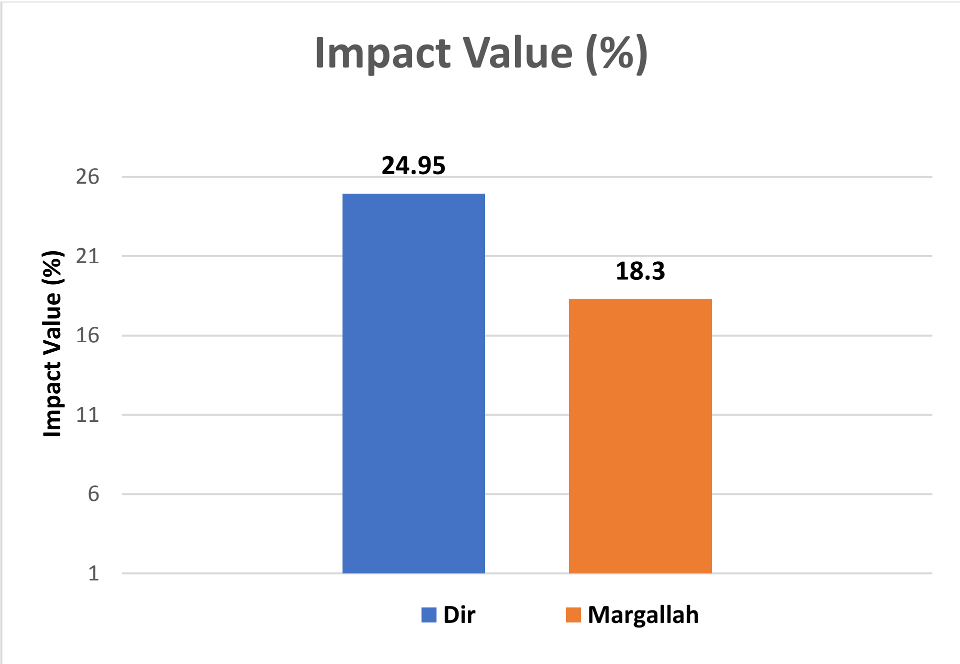

Figure 4.3 *Impact Values of Dir & Margallah Aggregates*

4.3.4 Soundness Value

Figure 4.4 compares the soundness values of the aggregates from the sources Margallah and Dir and reveals that the Dir granitic rocks aggregate source has a higher soundness value than the Margallah aggregate source. It indicates that the Margallah aggregate is more sound than the Dir aggregate, although both values fall within the limits allowed by the NHA. According to the results both aggregates are durable and less prone to disintegrate in the field.

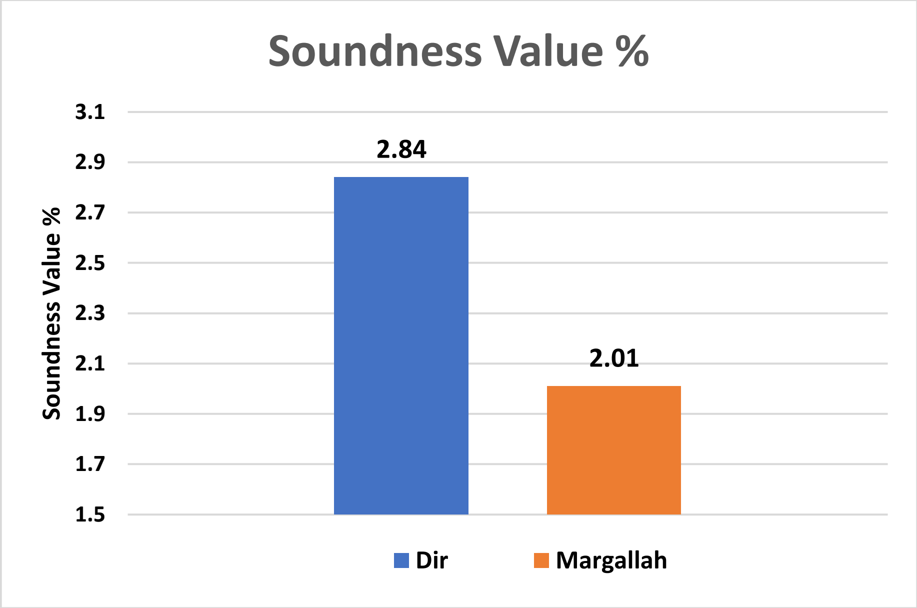

Figure 4.4 *Soundness values of Dir and Margallah Aggregates*

4.3.5 Crushing Value of Aggregate

Less than 30% of an aggregate crushing value is allowed. If the crushing value is lower, the aggregates will be stronger. The figure shows that Margalla aggregates are the most effective from Dir Aggregate, with a minimum crushing value of 18.6%. The crushing value of Dir aggregate is 25% which is in acceptable limit.

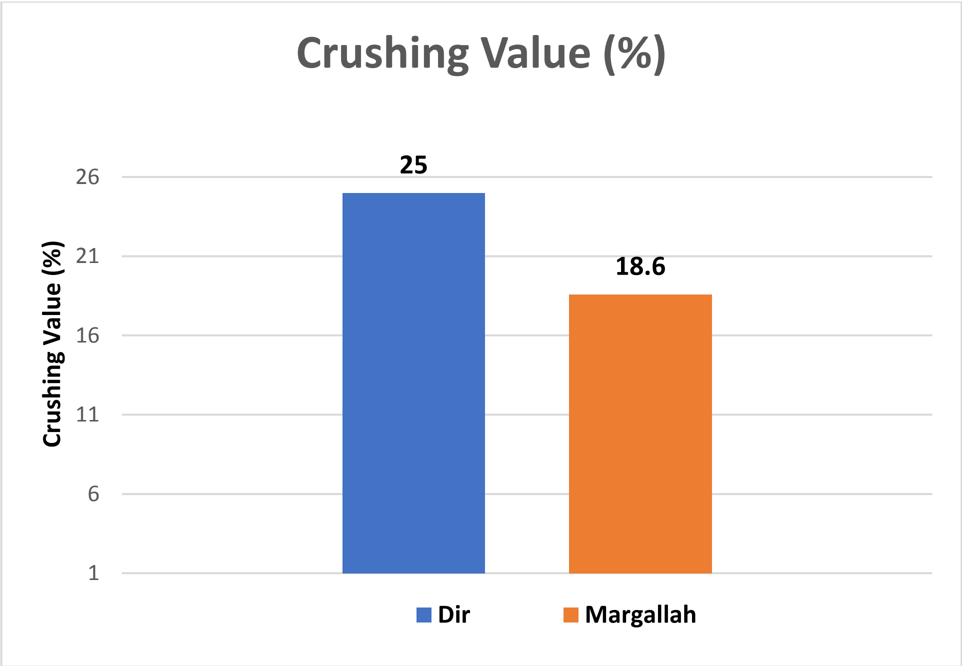

Figure 4.5 *Crushing Values of Dir & Margallah Aggregates*

4.3.6 Water Absorption

The results of both aggregate sample’s water absorption are demonstrated in the following *Figure 4.6.* Water absorption serves as an indirect indicator of aggregate porosity. It also denotes resistance to destruction from frost. Larger porosity in aggregates causes significant durability issues since they absorb more water. Margalla aggregates have the lowest water absorption (0.53 percent), whereas Dir coarse aggregates have the highest, according to the graph (0.74 percent). Margalla aggregates have a higher water absorption value than Dir aggregates. This shows that, in terms of porosity and durability, both Dir and Margalla aggregates are acceptable for use in construction.

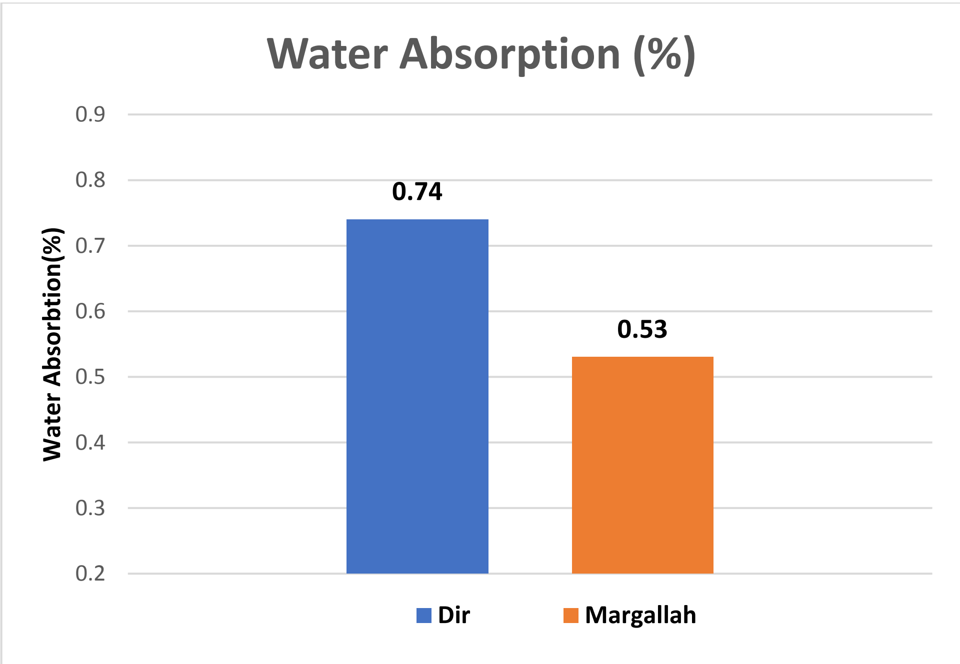

Figure 4.6 *Water Absorption of Dir & Margallah Aggregates*

4.3.7 Specific Gravity:

Specific gravity results from two separate sources are displayed in *Table 4-2*. The results below show that the specific gravity of aggregates derived from the Upper Dir is somewhat lower than that of aggregates from Margallah. For coarse aggregate, Margallah aggregate has a higher specific gravity value than Upper Dir Aggregate by 2.2% percent. This indicates that Margallah aggregate is stronger than Dir aggregate. However, there is not much of a difference.

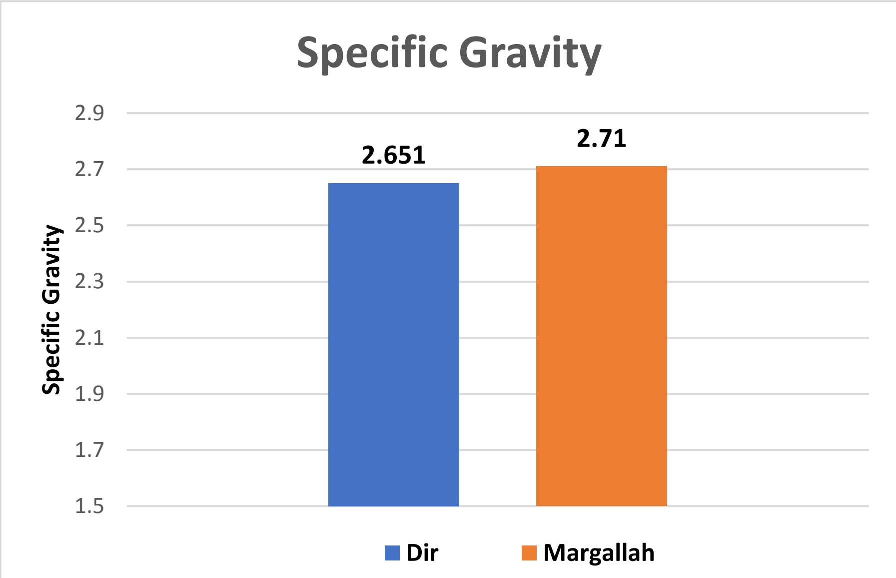

Figure 4.7 *Specific Gravity of Dir & Margallah Aggregates*

4.4 Volumetric Properties of Aggregate's mix

4.4.1 *Margallah Aggregate's mix Volumetric Properties*

The mix that contains Margallah aggregate has the volumetric properties, stability, and flow as stated in the *Table 4-3*.

Table 4-3 *Volumetric Properties of Margallah Aggregate Mix*

AC %	Gmm	Gmb	Air voids%	Vma%	Vfa%	Flow (mm)	Stability (KN)
3.5	2.4511	2.3034	5.9771	15.597	61.661	2.5612	9.3196
4	2.4435	2.3082	5.3434	15.409	65.057	2.7436	9.6313
4.5	2.4223	2.3254	4.2017	15.414	72.743	3.3416	9.945
5	2.4134	2.3582	3.8577	16.029	75.935	3.4276	9.4236
5.5	2.3967	2.0399	3.447	16.897	79.597	4.2746	9.3698

According to the MS-2 manual, graphs relating asphalt contents and volumetric properties, stability, and flow were developed to determine the OBC of mixes including Margallah Aggregate *Figure 4.8*.

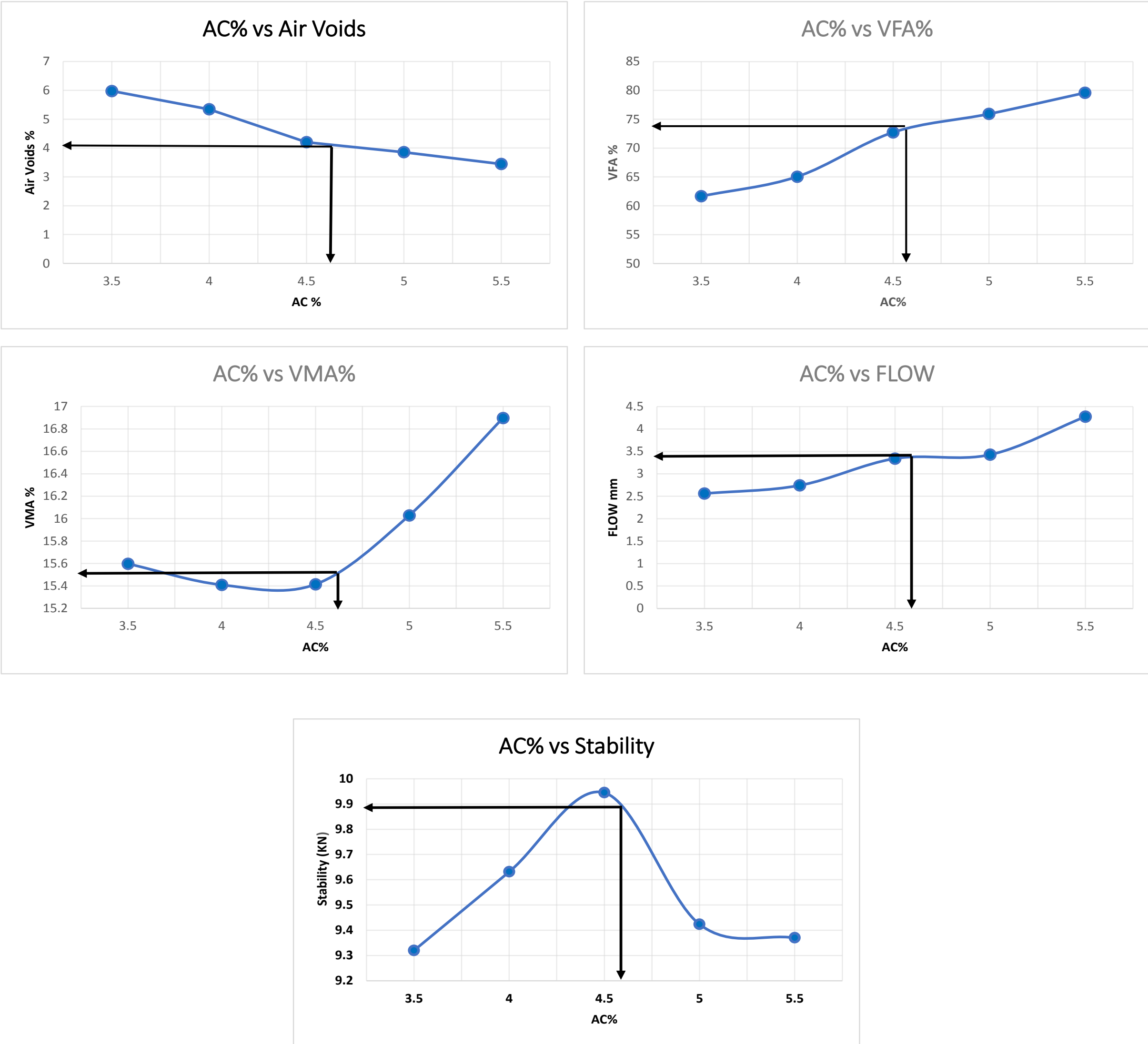

Figure 4.8 *Shows Volumetric Properties Flow and Stability of Margallah Aggregate Mix*

OBC is the term used to describe the amount of asphalt content at 4% air voids in the mix. OBC in the mixture with Margallah aggregate is 4.56 percent. The plots were then used to determine the volumetric properties, stability, and flow values according to OBC. The job mix formula for a mix including Margallah aggregate is shown in *Table 4-5*. The table clearly shows that all of the volumetric characteristics, stability, and flow satisfy the standard requirements. The VMA should not be less than 13 percent when there are 4% design air voids, however in this case, it was 15.5 percent. VFA should be between 65 and 75, and its computed value of 74 percent falls within this range. According to the standards, the stability value should not be less than 8.006 KN, however in this case, it was 9.86 KN. The measured flow number was 3.4mm, which is within the acceptable limit.

4.4.2 Dir Aggregate's mix Volumetric Properties

The following *Table 4-4* lists the volumetric characteristics, stability, and flow of the mix that contain Dir aggregate.

Table 4-4 *Volumetric Properties of Dir Aggregate Mix*

AC %	Gmm	Gmb	Air Voids %	VMA	VFA	Flow	Stability (KN)
3.5	2.53	2.28	9.54	16.83803	42.99	2.3185	12.171
4	2.51	2.30	8.28	16.71703	49.57	2.502	14.069
4.5	2.49	2.33	6.53	16.21083	61.75	2.8055	13.2755
5	2.43	2.34	3.72	16.32283	78.93	3.1855	12.3035
5.5	2.4	2.34	2.52	16.4596	87.32	3.352	9.7715

The graphs between asphalt contents and volumetric attributes, stability, and flow were drawn in accordance with the MS-2 handbook to determine the OBC of mixes including Dir granitic rock Aggregate **Figure 4.9**.

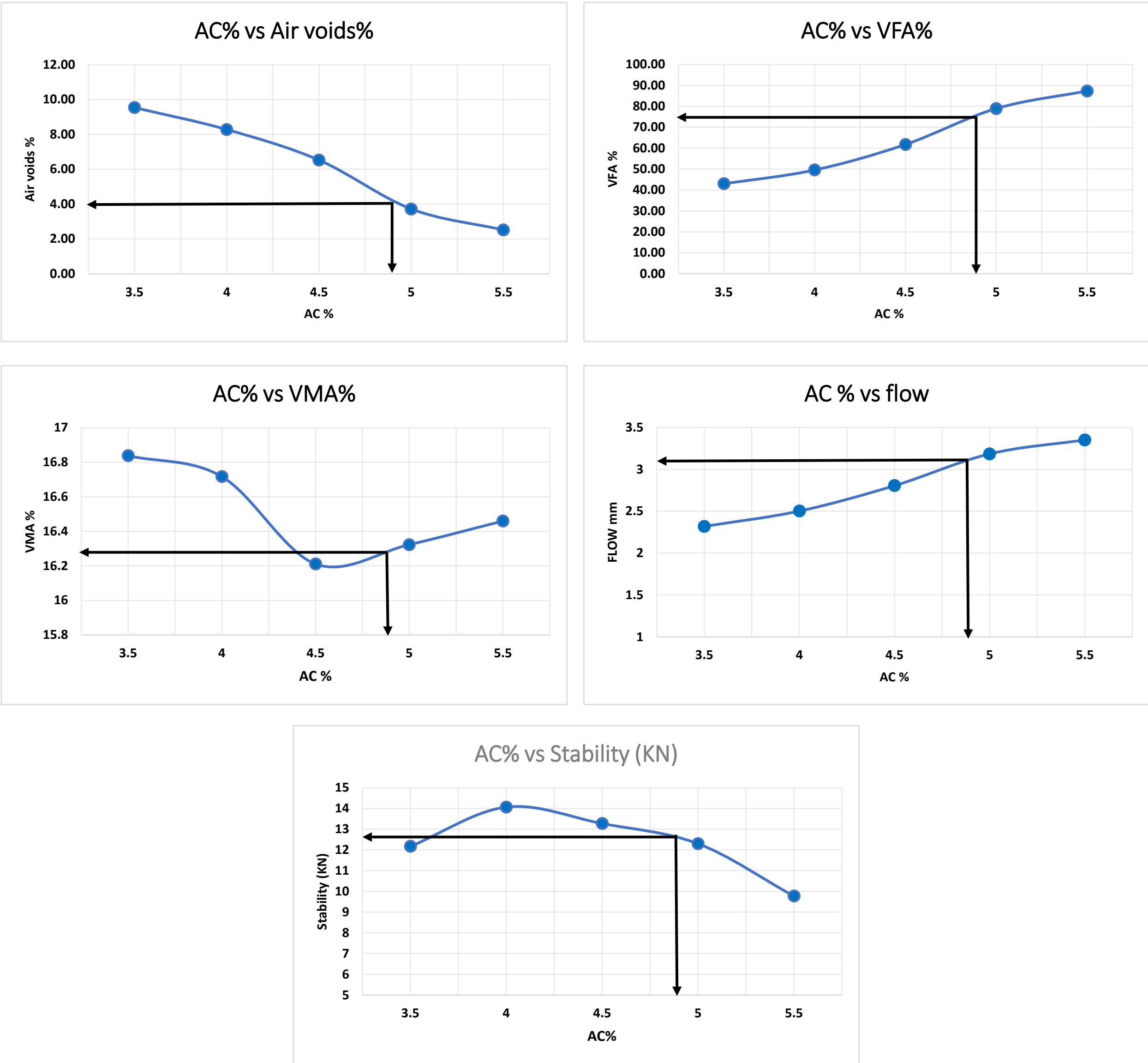

Figure 4.9 *Shows Volumetric Properties Flow and Stability of Dir Aggregate Mix*

OBC is the term used to describe the amount of asphalt content at 4% air voids in the mix. OBC for the mix including Dir's granitic rock aggregate is 4.8 percent. The plots were then used to determine the volumetric characteristics, stability, and flow values according to OBC. The job mix formula for a mix including Dir aggregate is shown in Table 4.8. The table clearly shows that all of the volumetric properties, stability, and flow satisfy the requirements. When there are 4% design air voids, the VMA shouldn't be less than 13%; nonetheless, in this situation, it was 16.3%. VFA should be between 65 and 75, and its computed value of 74 percent falls within this range. According to the criterion, the stability value couldn't be less than 8.006KN, however in this case it was 12.8KN. The measured flow number was 3.1 mm, which is within the acceptable limit.

Table 4-5 *Job mix formula with Dir & Margallah Aggregate Mix*

Property	Dir	Margallah	Criteria	Remarks
Optimum Binder Content	4.8	4.61	-	----
Air Voids %	4	4	3-5	Pass
Voids in Minerals %	16.3%	15.5	Min 13	Pass
Voids Filled with Asphalt %	74	74	65-75	Pass
Marshall Stability (KN)	12.8	9.86	8	Pass
Flow (mm)	3.1	3.4	2-3.5	Pass

4.5 Performance Test Results

4.5.1 Rutting Test Result (DWT *Result*)

In order to evaluate permanent deformation, a research compared the resistance of control specimens to rutting with samples prepared from Dir's granitic rock aggregate. Gyratory compacted specimens for the control sample and the sample containing Dir's granitic rock aggregate were made using an NHA class B for wearing course. We tested rutting on test specimens in dry condition using a double wheel tracker. Four samples were created as described above utilizing two aggregate sources. These samples were saw-cut to assess their rutting ability using wheel trackers. Comparatively, controlled specimens made with Dir's granitic rock aggregate demonstrated stronger resistance to rutting than specimens made with Margallah material. The HMA mix's rutting potential test results demonstrate that samples made with Dir's granitic rock aggregate are 24% less resistant to rutting than Margallah samples. However, all of the specimens' rutting values met the 12.5 mm requirement of the wheel tracker test.

Table 4-6 *DWT test results of both sources*

Aggregate Source	Avg Rutt Depth (mm)
Dir Aggregate	2.18
Margallah Aggregate	1.65

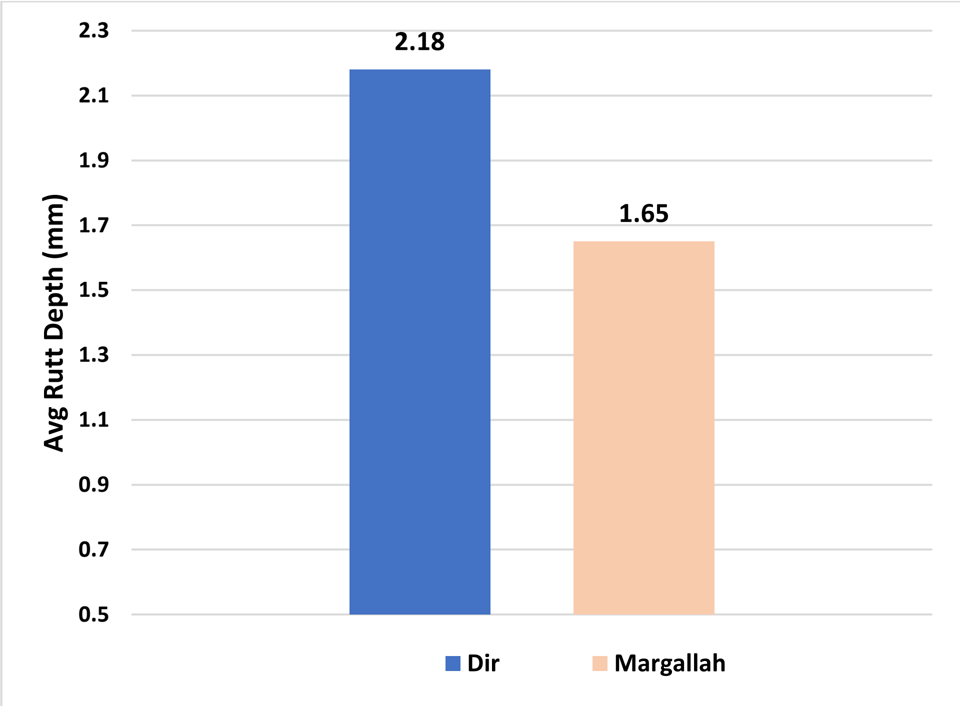

Figure 4.10 *Average rutt depth of Dir and Margallah aggregate sample*

4.5.2 Moisture Susceptibility (ITS test Result)

The mixes were evaluated for moisture susceptibility in accordance with ASTM D 6931-07 once mix design was complete. The samples were preconditioned with ALDOT 361. 12 Marshall samples were subjected to the ITS test with 4% air voids (four samples were preconditioned and four samples were unconditioned). four samples were created in the Marshall compactor at 4% air voids for each aggregate source. Two of the samples were analyzed without conditioning, while the remaining two specimens underwent a 24-hour 60°C warm-water soaking cycle after a one-hour conditioning period at 25°C before being examined for ITS. *Table 4-7* displays the values for both conditioning and unconditioning strength for each blend. The findings indicate that Margallah has stronger tensile strength than Dir Granitic rock aggregates.

Results for moisture sensitivity are shown in Table 4-7, and values for tensile strength are shown individually for each sample in Table 4-7. However, every sample meets the required minimum of 80%. The average TSR value for the combination of granitic rock aggregates from Margallah and Dir is shown in Figure 4.11. TSR value of 83% for Dir granitic rock aggregates and 91% for Margallah. Comparing Dir aggregate to Margallah aggregate, moisture resistance is 8 percent lower in Dir aggregate. TSR must meet criteria with a minimum of 80%. We can observe that the HMA mix created from Dir aggregate behaves in a way that meets the required standards.

Table 4-7 *ITS test results for both sources Dir & Margallah*

SOURCE	Conditioned T Strength (kpa) S2	Unconditioned T Strength (kpa) S1	TSR S2/S1	Avg TSR %
Dir	329.0117213	417.7659798	79%	83%
Dir	361.1817563	417.9459737	86%	
Margallah	409.3421	449.6151	91%	91%
Margallah	411.6181	455.1381	90%	

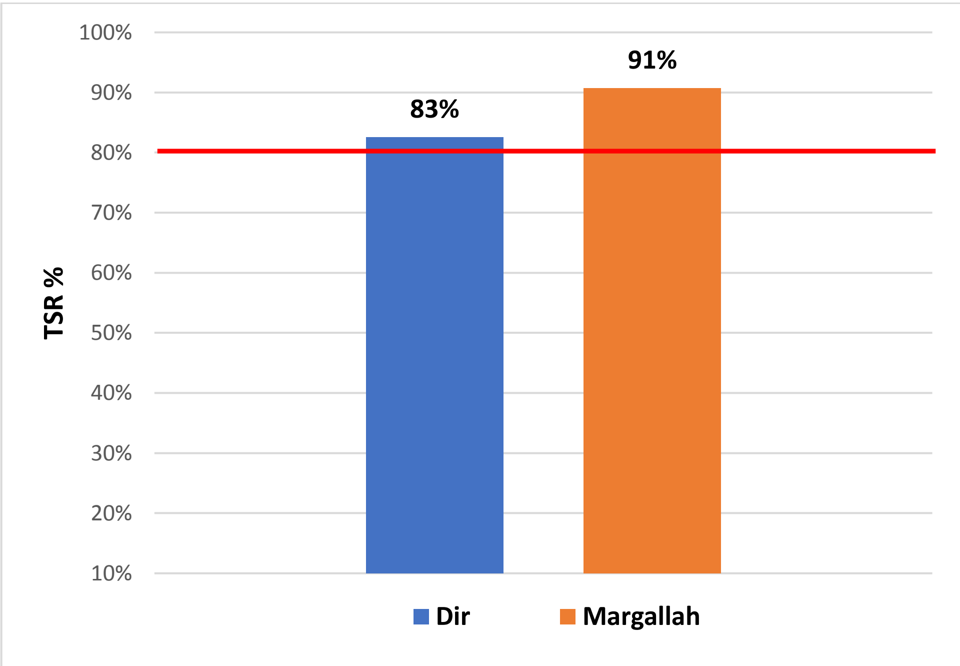

Figure 4.11 *ITS results of Dir & Margalla Aggregate mix (TSR)*

4.6 Cost Comparison Of Local Aggregate With Aggregates From Margallah

For wearing courses, a cost analysis is conducted. To evaluate the costs of two different aggregate sources, a road segment with a length of 1 km, a lane width of 3.6 m, and a thickness of 50 mm asphalt concrete was used. It is estimated that the compacted portion has a density of 2360 kg/m3. The material rates are obtained from the local suppliers and the bitumen rate was taken from PARCO Islamabad.

Table 4-8 *Cost Calculation & Comparison of Dir & Margallah Aggregates*

Margallah Aggregate Cost Calculations	Dir Aggregate Cost Calculations
Volume of Mixture=1000*3.6*0.05= **180m³**	Volume of Mixture=1000*3.6*0.05= **180m³**
Density Assumed= **2360kg/m³**	Density Assumed= **2360kg/m³**
Total weight of mix for 1km road **424.8tons**	Total weight of mix for 1km road **424.8tons**
OBC = **4.61%**	OBC = **4.85%**
Bitumen required = **19.37tons**	Bitumen required = **20.60tons**
Cost calculation for 100tons of HMA production	***Cost calculation for 100tons of HMA production***
OBC= **4.61%**	OBC= **4.85%**
Weight of bitumen in mix= **4.61tons**	Weight of bitumen in mix= **4.85tons**
Weight of aggregate in mix= **95.39tons**	Weight of aggregate in mix= **95.15tons**
• **Cost of bitumen @PKR 141000/ton:** 141000*4.61=650010 PKR	• **Cost of bitumen @PKR 141000/ton:** 141000*4.85=683850 PKR
• **Cost of Aggregate @PKR 2465.7/ton:** 2465.7*95.39=235208 PKR	• **Cost of Aggregate @PKR 835/ton:** 835*95.15=79450.25 PKR
• **Combined cost of asphalt plant/equipment of 100 tons of HMA**: =300,000PKR	• **Combined cost of asphalt plant/equipment of 100 tons of HMA**: =300,000PKR
• **Total cost of 100tones HMA:** 650010+235208+300000=1185218 PKR	• **Total cost of 100 tons HMA:** 683850+79450.25+300000=1063300.25 PKR
• **Cost of HMA per ton**: 1152236/100=11852.18 PKR	• **Cost of HMA per ton**: 1063300.25 /100=10633 PKR
Total cost of HMA for 1 km road section 11852.18 *424.8= 5034807 PKR	***Total cost of HMA for 1 km road section*** 10633*424.8=4516899 PKR
Total Cost in Million = 5.03M	**Total Cost in Million = 4.51M**

Table 4-9 Separate Cost Analysis for Asphalt mix Material

	Margallah			Dir			
Description	**Weight in Tons for 1KM road**	**Price/ton**	**Total Price for 1 km**	**Weight in Tons for 1KM road**	**Price/ton**	**Total Price for 1 km**	**Percent Difference**
	4.61%			4.85%			
AC	19.58328	141000	2761242	20.6028	141000	2904995	-5%
Aggregates	405.2167	958.9041	388564	404.1972	698.6301	282384.3	27%
Transportation	405.216	1506.849	610599.5	404.197	136.9863	55369.45	91%
Plant cost	1	1284000	1284000	1	1284000	1284000	0%
Cumulative Cost			5044406			4526749	10%

Overall and separate Cost analysis have been done for asphalt mix which is shown in ***Table 4-8*** and ***Table 4-9*** respectively for one kilometer road section.

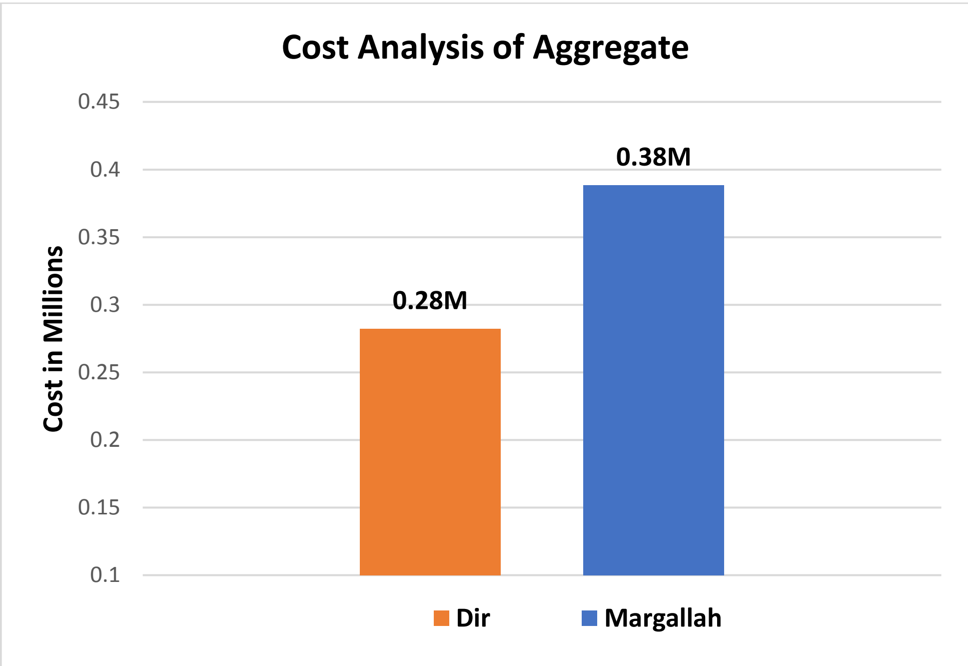

Figure 4.12 *Cost analysis for aggregate*

In **Figure *4.12*** the cost analysis comparison are shown which shows that Dir aggregate is 27% economical as compared to the Margallah aggregate quarries.

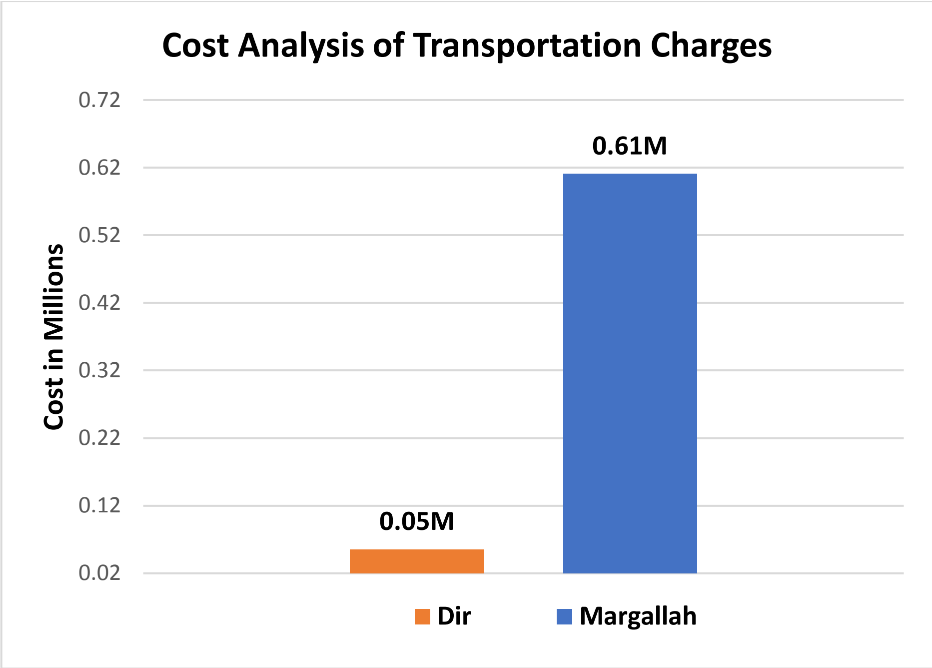

Figure 4.13 *Transport Cost analysis of aggregates*

The Dir aggregate saves 91% cost incurred for transportation of aggregates as compared to Margallah aggregate as shown in **Figure *4.13***.

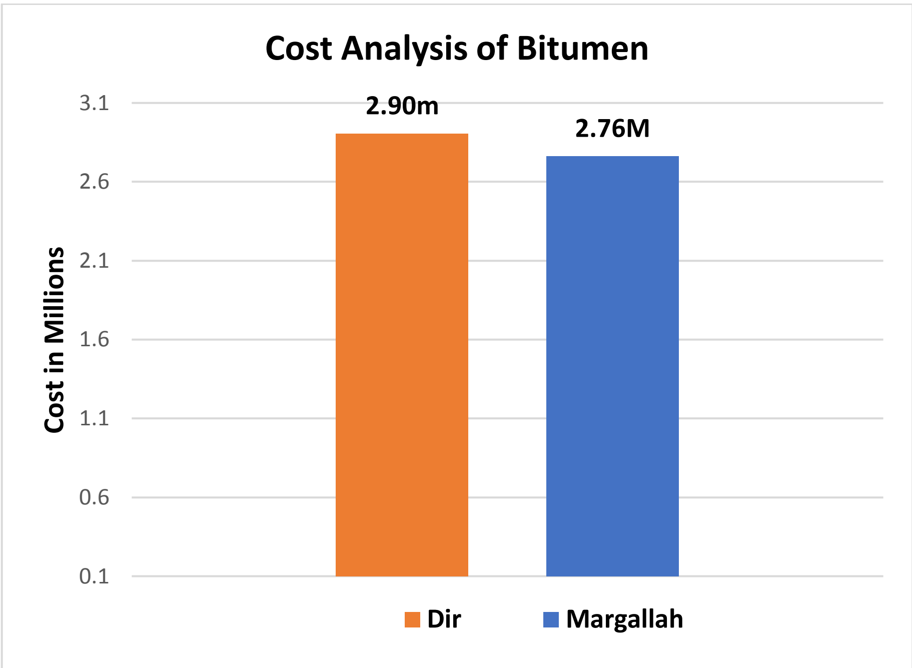

Figure 4.14 Cost Comparison of bitumen

In *Figure 4.14* shows that the Dir Aggregates required 5% more cost for the bitumen content because of its high OBC as compared to Margallah aggregates.

The cumulative cost comparison between Margallah and Dir aggregate source is shown

Figure 4.15. When compared to locally available granitic rocks aggregates, Margallah aggregate is nearly 10% more expensive. Therefore, using local aggregate rather than acquiring aggregates materials from outside can save us a lot of money.

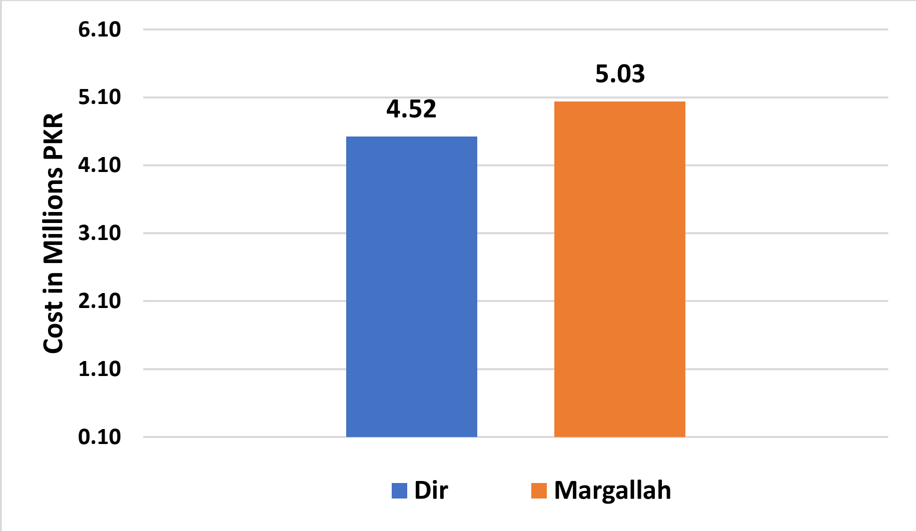

Figure 4.15 *Cost Comparison of Dir & Margallah aggregate*

4.7 Summary:

This chapter has described the thorough study of the outcomes of laboratory tests. Double wheel tracker and UTM findings from material performance characterization are described in depth. Tables and graphs are used to display the results of the data analysis. The volumetric properties of both mixes are elaborated in detail with the help of graph and tables. The results of the ITS test and the wheel tracker test, for Margallah aggregates and the Dir granitic rock aggregate specimen are displayed as bar charts. To determine if a new source was appropriate, the findings from each source were compared (Dir granitic rocks Aggregate & Margallah aggregate). Dir granitic rocks Aggregate have nearly same mechanical properties to Margallah, according to laboratory results that we compared. Additionally, according to the results of performance testing, Dir granitic rocks aggregate behaves better than Margallah aggregate in terms of resistance to rutting, whereas ITS testing reveals that Margallah aggregate is 8 percent more resistant to moisture damage than Dir aggregate. To assess the economic impact of utilizing local aggregate, cost comparison is also done. Based on the findings discussed in this chapter, it is safe to suggest utilizing Dir aggregate in place of Margallah aggregate for building roads.

Chapter: 5 Conclusion & Recommendations

5.1 Background

The major goal of this study was to evaluate the effectiveness and suitability of Dir Granitic rocks as aggregate for paving. Flexible pavement surfaces are more susceptible to rutting and moisture damage. The Hamburg wheel tracker and ITS test is the quickest and most accurate way to identify whether or not asphalt mixes are moisture damaged and rutt resistant. It evaluates the long-term performance of an asphalt mixture.

For the mix preparations, NHA Class-B gradation was chosen, bitumen with penetration grade 60/70 purchased from PARCO, and aggregate acquired from Margalla & Dir were all used in the tests. Material from Dir Upper was brought in for analysis in the Nust Laboratory. Following the procedures at OBC specimens were created for the Dir Aggregate Mix and Margallah Aggregate Mix, OBC was assessed using the Marshall Mix design technique.

Gyratory Compactor (SGC) specimens were prepared for checking rutting susceptibility in air conditions in Double Wheel Tracker Device. And Marshall sample were prepared to find TSR for checking moisture damage. The key findings for physical and mechanical properties of aggregate, HWTD testing, UTM testing, and their results are concluded as under.

5.2 Conclusion

The analysis and discussion of all tests and experiments conducted allowed us to reach the conclusion listed below.

1. According to the physical and mechanical characteristics of the aggregates from the Dir Granitic rocks quarry, that they can be utilized locally in Dir to produce asphalt with the desired properties.

2. The results of this study show that Dir Granitic rocks Quarry can generate subbase, base, and surface materials for roads.
3. The rutting potential of HMA mixes containing Dir aggregates decreases by 24% as compared to Margallah aggregate.
4. When compared to Margallah Aggregate, Mix with Dir Aggregate has an 8 percent lower resistance to moisture damage, although the resistance value is still within acceptable limits.
5. The Dir aggregates is 27% cheaper as compared to Margallah's aggregate and its Transportation cost is 91% less than the cost incurred by transportation for Margallah aggregates

5.3 Recommendations

The region has the potential to produce huge volumes of aggregates for pavement construction. Government departments should consider these aggregate in the BOQ of road projects to encourage the mining and usage of these aggregates.

Only two performance tests, the moisture damage and the rutting susceptibility test, were conducted for the HMA mix in this study, using HWTD and UTM, respectively. Additional performance tests, such as the dynamic modulus, creep test, fatigue analysis, and others, should be conducted to learn more about the behavior of HMA-containing mixes with Dir Aggregate.

Although Dir has several sources for aggregate, more sources are required in order to assess their suitability as potential road aggregate.

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APPENDICES

APPENDIX 1: PHYSICAL & MECHANICAL PROPERTIES OF AGGREGATE

APPENDIX 1

EI & FI of Dir Aggregate						
Pass	Retain	Ret wt. (g)	Flaky wt	EL wt	FI %	EL %
1"	3/4"	500	82	62	14.4	13.5
3/4"	1/2"	1500	225	220		
3/5"	3/8"	1500	195	186		
3/6"	#4	1500	218	207		
∑		5000	720	675		

EI & FI of Dir Margallah						
Pass	Retain	Ret wt. (g)	Flaky wt	EL wt	FI %	EL %
1"	3/4"	259	54	0	13.56981	11.33223
3/4"	1/2"	1968.5	284	57		
3/5"	3/8"	1268	147	198.5		
3/6"	#4	1353.5	173	294		
∑		4849	658	549.5		

CRUSHING VALUE TEST of Dir Aggregate					
S/NO	Sample weight kg	Passing W	Retained W	Crushing V	
1	2.762	0.697	2.065	25%	25%
2	2.8	0.7	2.1	25%	
3	2.9	0.75	2.15	26%	

CRUSHING VALUE TEST of Margallah Aggregate					
S/NO	Sample weight kg	Passing W	Retained W	Crushing V	
1	3.12	0.414	2.065	13%	18%
2	2.82	0.602	2.218	21%	
3	2.96	0.545	2.415	18%	

LOS ANGELES ABRASION VALUE of Dir Aggregate					
S/NO	Sample weight g	Passing W	Retained W	LA Value	Avg V
1	5002.5	1283	3719.5	26%	26%
2	5002.5	1351	3651.5	27%	
3	5000	1290	3710	26%	

LOS ANGELES ABRASION VALUE of Margallah Aggregate					
S/NO	Sample weight g	Passing W	Retained W	LA Value	Avg V
1	5000	908.2	3719.5	18%	18%
2	5000	853	3651.5	17%	
3	5000	952	4048	19%	

IMPACT VALUE OF Dir AGGREGATES					
S/NO	Sample weight g	Passing W	Retained W	Impact V	Avg V
1	311.9	73.8	238	24%	25%
2	314.1	82.7	231.6	26%	
3	313	77	236	25%	

IMPACT VALUE OF Margallah AGGREGATES					
S/NO	Sample weight g	Passing W	Retained W	Impact V	Avg V
1	321.6	60.8	238	19%	19%
2	323.3	58	231.6	18%	
3	314.2	64.4	249.8	20%	

APPENDIX-II: MARSHAL MIX DESIGN REPORT

Aggregate weight calculation for Marshal sample / mid gradation

Sieve sizes	Specification Range %	Mid Gradation Passing	Retained %
3/4	100	100	0
1/2	75-90	82.5	17.5
3/8	60-80	70	12.5
#4	40-60	50	20
#8	20-40	30	20
#16	5-15	10	20
#200	3-8	5.5	4.5
Pan			5.5

Binder	3.5% of 1200gm	42gm Bitumen	1158gm Aggre
Sieve sizes	Retained	Retained in grams	
1/2	17.50 x 1158	202.65	
3/8	12.50 x 1158	144.75	
#4	20 x 1158	231.6	
#8	20 x 1158	231.6	
#16	20 x 1158	231.6	
#200	4.5 x 1158	52.11	
Pan	5.50 x 1158	63.691	
		1158 grams	

Binder	4% of 1200gm	48gm Bitumen	1152gm Agg
Sieve sizes	Retained	Retained in grams	
1/2	17.5% x 1152	201.6	
3/8	12.50% x 1152	144	
#4	20% x 1152	230.4	
#8	20 %x 1152	230.4	
#16	20 %x 1152	230.4	
#200	4.5% x 1152	51.84	
Pan	5.50% x 1152	63.36	
		1152 grams	

Binder	4.5% of 1200gm	54gm Bitumen	1146gm Agg
Sieve sizes	Retained	Retained in grams	
1/2	17.5% x 1146	200.5	
3/8	12.50% x 1146	143.25	
#4	20% x 1146	229.2	
#8	20 %x 1146	229.2	
#16	20 %x 1146	229.2	
#200	4.5% x 1146	51.57	
Pan	5.50% x 1146	63.03	
		1146 grams	

Binder	5% of 1200gm	60gm Bitumen	1140gm Agg
Sieve sizes	Retained	Retained in grams	
1/2	17.5% x 1140	199.5	
3/8	12.50% x 1140	142.5	
#4	20% x 1140	228	
#8	20 %x 1140	228	
#16	20 %x 1140	228	
#200	4.5% x 1140	51.3	
Pan	5.50% x 1140	62.7	
		1140	

Binder	5.5% of 1200gm	66gm Bitumen	1134gm Agg
Sieve sizes	Retained	Retained in grams	
1/2	17.5% x 1134	198.45	
3/8	12.50% x 1134	141.75	
#4	20% x 1134	226.8	
#8	20 %x 1134	226.8	
#16	20 %x 1134	226.8	
#200	4.5% x 1134	51.03	
Pan	5.50% x 1134	62.37	
		1134	

S.NO	Binder %age	A (Dry W)	B	C (Water W)	Gmm
1	3.5	1187	6328	7045	2.53
2	4	1181	6328	7038	2.51
3	4.5	1172	6328	7029	2.49
4	5	1186	6328	7025	2.43
5	5.5	1191	6328	7023	2.40

S.NO	Binder %age	W in air	W SSD	W in Water	Gmb
1	3.5	1184.1	1201.5	683.2	2.28
2	4	1179.35	1192.6	679.8	2.30
3	4.5	1191.8	1194.4	682	2.33
4	5	1190.4	1191.5	681.7	2.34
5	5.5	1195	1195.4	681.5	2.34

S.NO	Binder %age	Gmm	Gmb	Air Voids %
1	3.5	2.525532	2.28	9.54
2	4	2.507431	2.30	8.28
3	4.5	2.488323	2.33	6.53
4	5	2.425358	2.34	3.72
5	5.5	2.404121	2.34	2.52

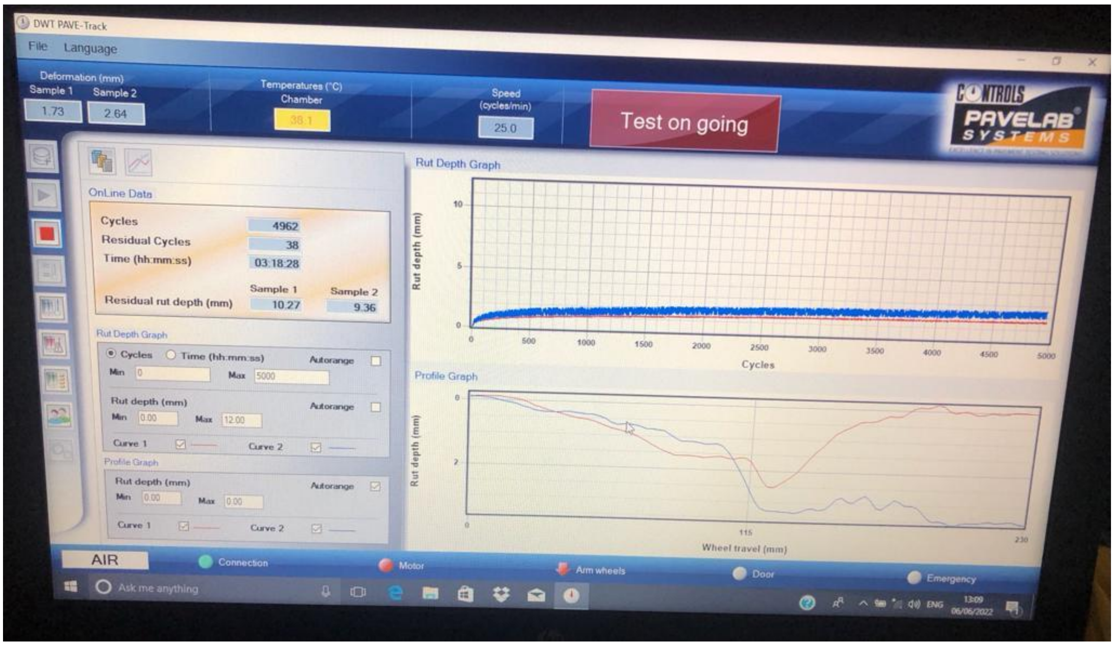
S.NO	Binder %age	Gmb	Aggregate %age	Gsb	VMA %
1	3.5	2.28	96.5	2.651	16.83803
2	4	2.30	96	2.651	16.71703
3	4.5	2.33	95.5	2.651	16.21083
4	5	2.34	95	2.651	16.32283
5	5.5	2.34	94.5	2.651	16.4596

S.NO	Binder %	VMA	Air Voids	VFA
1	3.5	16.83803	9.6	42.99
2	4	16.71703	8.43	49.57
3	4.5	16.21083	6.2	61.75
4	5	16.32283	3.44	78.93
5	5.5	17.10824	2.17	87.32

S.NO	Binder %age	Stability (KN)		AVG	Flow (mm)		AVG
		Sample 1	Sample 2		Sample 1	Sample 2	
1	3.5	12.132	12.21	12.171	2.29	2.347	2.3185
2	4	13.513	14.625	14.069	2.443	2.561	2.502
3	4.5	13.335	13.216	13.2755	2.821	2.79	2.8055
4	5	12.606	12.001	12.3035	3.251	3.12	3.1855
5	5.5	9.222	10.321	9.7715	3.342	3.362	3.352

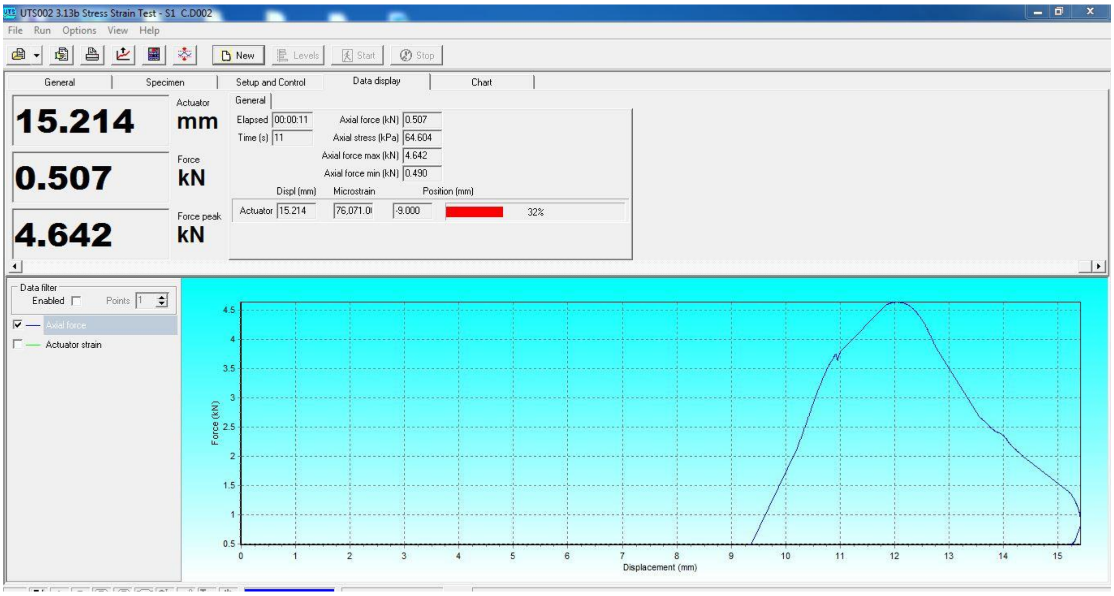
AC %	Gmm	Gmb	Air Voids %	VMA	VFA	Flow	Stability (KN)
3.5	2.53	2.28	9.54	16.83803	42.99	2.3185	12.171
4	2.51	2.30	8.28	16.71703	49.57	2.502	14.069
4.5	2.49	2.33	6.53	16.21083	61.75	2.8055	13.2755
5	2.43	2.34	3.72	16.32283	78.93	3.1855	12.3035
5.5	2.4	2.34	2.52	16.4596	87.32	3.352	9.7715

APPENDIX-III: DWTD TEST RESULTS

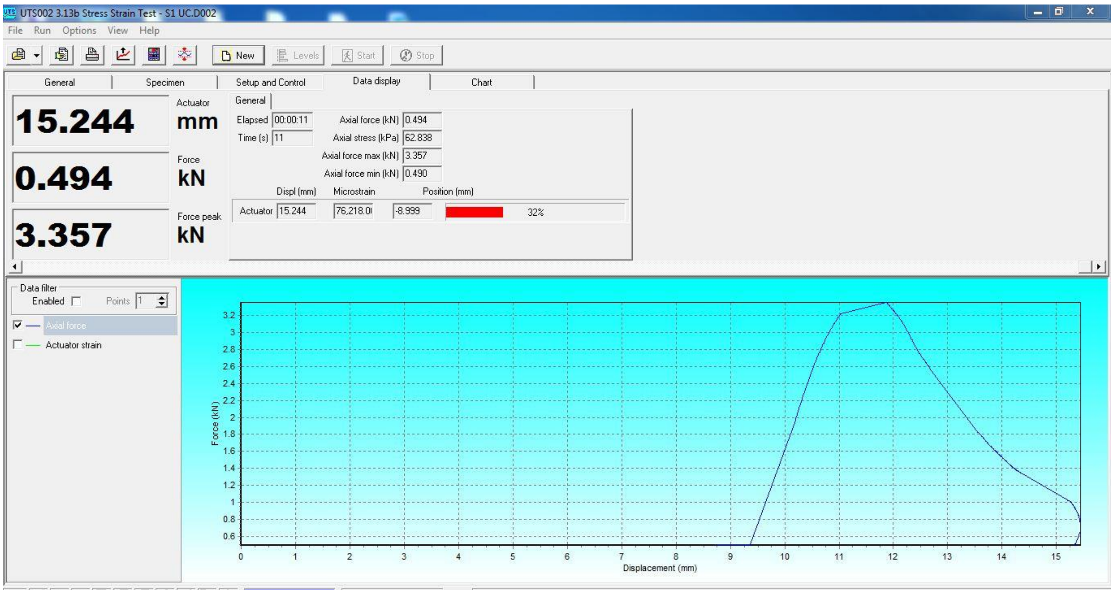


DWTD test result

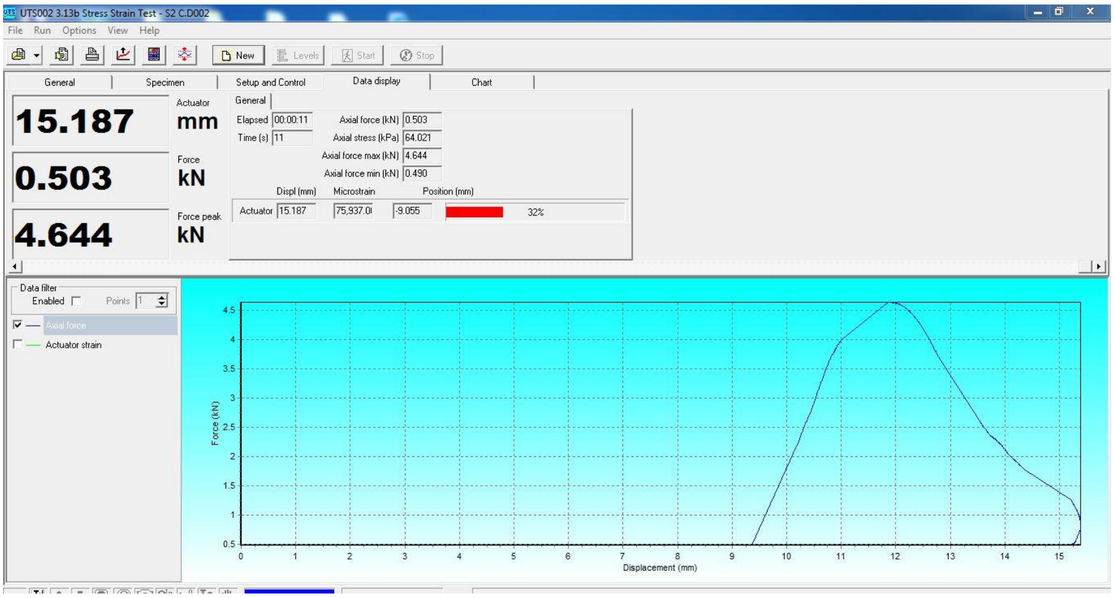
APPENDIX-IV: UTM-25 ITS TESR RESULT



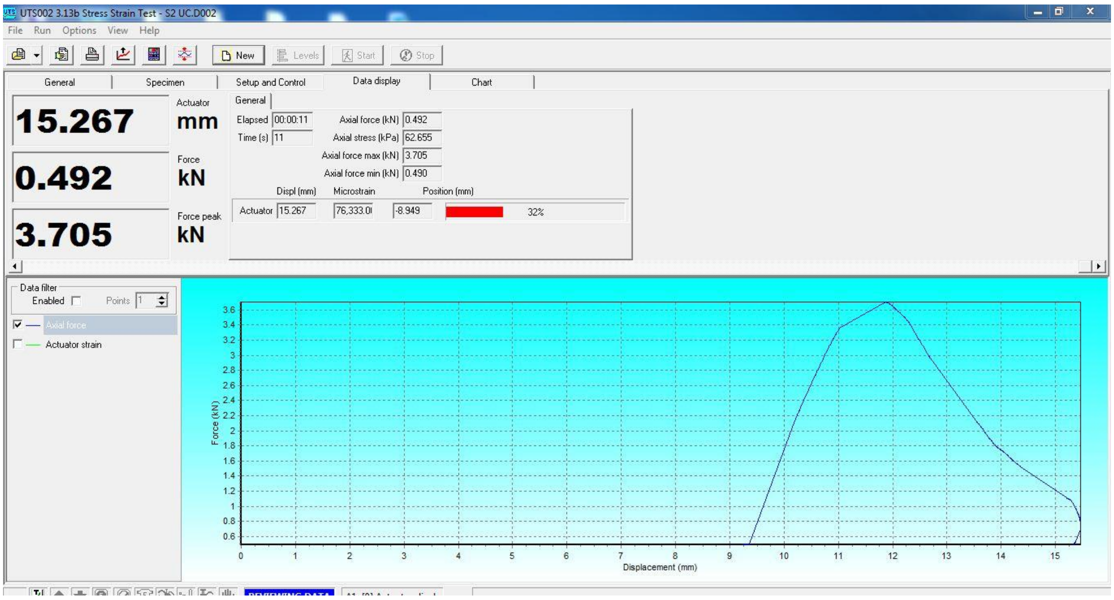
Sample 1 unconditioned



Sample 2 Conditioned



Sample 3 Unconditioned



Sample 4 Conditioned