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Studying the Effect of Adding Natural Sand on the Mechanical Properties of Asphalt Mixture

دراسة تأثير إضافة الرمل الطبيعي على الخواص الميكانيكية للخليط الأسفلتي

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إقـــــــرار

أنا الموقع أدناه مقدم الرسالة التي تحمل العنوان:

Studying the Effect of Adding Natural Sand on the Mechanical Properties of Asphalt Mixture

دراسة تأثير إضافة الرمل الطبيعي على الخواص الميكانيكية للخليط الأسفلتي

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دراسة تأثير إضافة الرمل الطبيعي على الخواص الميكانيكية للخليط الأسفلتي

Studying the Effect of Adding Natural Sand on the Mechanical Properties of the Asphalt Mixture

وبعد المناقشة التي تمت اليوم السبت 12 جمادي الثانية 1438هـ، الموافق 2017/03/11م الساعة الحادية عشر صباحاً، اجتمعت لجنة الحكم على الأطروحة والمكونة من:

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واللجنـة إذ تمنحـه هـذه الدرجـة فإنهـا توصـيه بتقـوى الله ولـزوم طاعتـه وأن يسـخر علمـه فـي خدمـة دينـه ووطنـه.

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نائب الرئيس لشئون البحث العلمي والدراسات العليا

أ.د. عبدالرؤوف علي المناعمة

DEDICATION

To my father, my mother…
To my wife, who I hold most dear…
To my brothers, and my sisters…
To my friend, who gave his life for Palestine, Khalid Sahmoud, may he rest in peace
To all of you, and for your unbounded support and love … I dedicate this thesis.

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Moreover, I would like to thank my colleague from the Material and Soil Laboratory at the Islamic university **Ahmad Alkord**, who helped me gathering the resources and literature materials.

LIST OF ABBREVIATION

APA	Asphalt Pavement Analyzer
CEI	Construction Energy Index
DMA	Dynamic Mechanical Analyzer
E	Dynamic Modulus
HMA	Hot-Mix Asphalt
IDT	Indirect Tensile Test
RCA	Recycled Aggregate Concrete
S.G.	Specific Gravity
SMA	Stone-Matrix Asphalt
SSD	Saturated Surface Dry
TSR	Tensile Strength Ratio
V.T.M	Air Voids Of Total Mix
V_a	Air Voids Content
V_A	Virgin Aggregates
V_B	Percent Bitumen Volume
VFB	Voids Filled With Bitumen
VMA	Voids Mineral Aggregate

ABSTRACT

Asphalt mixture is the most widely used material in roads and highways construction. It is composed of mineral aggregates, asphalt binder and filler. Properties of these materials and their interactions determine the mechanical behavior of asphalt mixtures, and consequently the durability of resultant asphalt pavements over time. Thus, adequate selection of materials is required to obtain correct asphalt pavement performance.

This study aims to determine the optimum ratio of natural sand to be introduced to the asphalt mixture while maintaining or improving the mechanical properties of the mixture, at the same or lower cost per unit. To this reason, several material properties must be assessed and compared to control specimens. Those parameters are Stability, Density, Flow, Voids Mineral Aggregate (*VMA*), Air Voids Content (*Va*) and Voids Filled with Bitumen (*VFB*) in asphalt mixtures.

Before conducting the experimental works, the material properties for all aggregates to be used in the experimental program were evaluated, such as physical properties and sieve analysis for the aggregates and bitumen-related properties such as penetration, specific gravity, ductility, flash point and softening point tests. Additionally, an aggregate blending procedure was implemented to properly select the various ratios of each aggregate in the asphalt mixture. The experimental program consisted of three phases. Phase (A) to determine the optimum bitumen content (OBC) without adding natural sand. Results from Phase (A) were considered as control data to be compared with when adding the natural sand at various amounts. The Following phase is Phase (B) were natural sand replaced Trabia by various amounts, starting from 2.50% until 15%, which is the maximum Trabia content based on the aggregate blending procedure. Aggregate blends with various percentage of natural sand were blended as closely as possible to same gradation. While phase (C) aimed to re-evaluate the bitumen content after obtaining the optimum sand content.

Results from Phase (A) indicated that a bitumen content of 5.00% would yield the most optimum results in terms of stability, bulk density and air voids. Based on this result, Phase (B) was implemented with bitumen content of 5.00%, in which, a natural sand content of 7.5% yielded the optimum results in terms of the same properties, i.e., stability, bulk density and air voids. Results from Phase (C) indicated that for asphalt mixture with natural sand content of 7.50%, the optimum bitumen content would be 4.60%. Based on the findings of this research, it is recommend to use asphalt mixture with embedded natural sand content (Optimum: 7.50%) in real-life application to assess its long term behavior.

الملخص

يعتبر الخليط الأسفلتي المادة الأكثر استعمالا في رصف الطرقات والطرق السريعة. ويتكون الخليط الأسفلتي من الحصويات غير العضوية، طبقات الربط والمواد المالئة. وتحدد خواص هذه المواد وطريقة التفاعل بينها الخواص الميكانيكية للخليط الأسفلتي، وبالتالي متانة طبقة الرصف خلال المدى العمري لها. ولهذا السبب، فإنه من الأهمية بمكان اختيار هذه المواد بشكل مناسب للحصول على الأداء المناسب لطبقة الرصف المطلوبة.

تهدف هذه الدراسة إلى تحديد نسبة الرمل الطبيعي المُثلى التي يمكن إضافتها للخليط الاسفلتي مع الإبقاء على أو تحسين المواصفات الميكانيكية للخليط، بنفس سعر التكلفة أو بتكلفة أقل. ولهذا السبب، فإنه يجب تقييم مجموعة من الخواص الخاصة بالخليط الاسفلتي المحتوي على الرمل الطبيعي ومقارنتها بخليط اسفلتي قياسي لا يحتوي عليه، مثل قيمة الثبات، الكثافة، الانسياب، الفراغات الكلية، نسبة الفراغات الهوائية، نسبة الفراغات المملوءة بالبيتومين.

قبل الشروع في البرنامج التجريبي للدراسة، تمت دراسة وتقييم خواص كافة الحصويات المنوي استعمالها في التجارب، كالخواص الميكانيكية واختبار التدرج الحبيبي، بالإضافة إلى الخواص الخاصة بالبيتومين مثل نقطة الغرز، الكثافة النوعية، الممطولية، نقطة الاشتعال ونقطة التميع. كما تم القيام بدراسة لتحديد نسبة الحصويات المنوي استعمالها في تحضير الخليط الأسفلتي.

تم إجراء البرنامج التجريبي للدراسة على ثلاث مراحل متتابعة. المرحلة الأولى هدفت إلى تحديد المحتوى البيتوميني الأمثل (OBC) بدون إضافة محتوى رملي للخليط، وتم اعتبار نتائج هذه المرحلة كنتائج قياسية للمقارنة بها عند إضافة الرمل الطبيعي للخليط. المرحلة التالية تمت بإضافة الرمل الطبيعي إلى الخليط الاسفلتي وخصم ما يكافئ نسبة الرمل من نسبة الترابية، بدءاً من 2.5% رمل طبيعي وصولا إلى 15.0%، وهي ذات القيمة التي تم الحصول عليها من تجربة إعداد الخليط الحصوي. المرحلة الثالثة والأخيرة هدفت إلى إعادة تحديد المحتوى البيتوميني الأمثل بعد إضافة الرمل الطبيعي للخليط.

أظهرت النتائج أن المحتوى البيتوميني الأمثل للخليط الاسفلتي بدون إضافة الرمل الطبيعي هي 5.0% بمراعاة قيم الثبات، الكثافة ونسبة الفراغات الهوائية. وبناء على هذه القيمة، تمت إضافة الرمل بنسب تبدأ من 2.5% وصولاً إلى 15.0% مع خصم ذات القيمة من الترابية مع ثبات قيمة البيتومين عند 5.0%. وأظهرت النتائج أن أفضل خليط اسفلتي بالنظر لكل من قيم الثبات والكثافة ونسبة الفراغات الهوائية ذاك المحتوي على 7.50% من الرمل الطبيعي. أما نتائج المرحلة الثالثة فأظهرت أن إضافة الرمل الطبيعي للخليط الاسفلتي ستغير قيمة البيتومين المُثلى من 5.0% إلى 4.6%.

بناء على النتائج التي تم التوصل إليها، فإننا نوصي بإضافة الرمل الطبيعي إلى الخلطات الاسفلتية (7.50%) لاستعمالها في التطبيقات الهندسية ومشاريع البنى التحتية.

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Introduction

CHAPTER 1: INTRODUCTION

1.1 Background

The modern use of asphalt for road and street construction began in the late 1800s and grew rapidly with the emerging automobile industry. Since that time, asphalt technology has made giant strides so that today the equipment and techniques used to build asphalt pavement structures are highly sophisticated. One rule that has remained constant throughout asphalt's long history in construction is: A pavement is only as good as the materials and workmanship that go into it. No amount of sophisticated equipment can make up for use of poor materials or poor construction practices.

Asphalt mixture is the most widely used material in roads and highways construction. It is composed of mineral aggregates, asphalt binder and filler. Properties of these materials and their interactions determine the mechanical behavior of asphalt mixtures, and consequently the durability of resultant asphalt pavements over time. Thus, adequate selection of materials is required to obtain correct asphalt pavement performance. In the context of road engineering, natural sand and crushed sand are considered individually as particles or elements that work together affecting mineral structure of a pavement (Kallas & Puzinauskas, 1961).

Aggregates are generally classified into two groups, fine and coarse, and normally constitute from 90 to 95 percent by weight of the total mixture. The asphalt is composed of a Performance Graded (PG) binder or some variation of PG binder, and ordinarily constitutes 5 to 10 percent by weight of the mixture. There are properties or characteristics of aggregate which influence the properties of resulting the mix such as composition, size and shape, surface texture, specific gravity, bulk density, voids, porosity and absorption. Aggregates are primarily responsible for the load supporting capacity of a pavement. Aggregate has been defined as any inert mineral material used for mixing in graduated particles or fragments. It includes gravel, crushed stone, slag, screenings, mineral filler and sand. Fine aggregates generally consist of natural sand and crushed sand, excessive natural sand contents can increase the susceptibility of asphalt concrete to permanent deformation-type distresses, natural sand contents to within approximately 5% of asphalt mixture. The components of an asphalt mixture play an important role in asphalt mixture behavior during service period (Asi, 2007).

From a local prospective, asphalt industry in Gaza Strip is faced with two dominant concerns: a) the disproportional increase in the prices of bitumen and high-quality aggregate and b) the rapidly increasing loads applied to the pavement. Additionally, with the limited supply of aggregate, both, fine and coarse, it's vital to use local available materials wherever it fits.

From this point, it is aimed to investigate the effects of adding natural sand to the asphalt mixture, in order to decrease the cost per unit, while maintaining if not improving the mechanical properties of the asphalt mixture.

1.2 Problem Statement

After conducting an extensive literature review, it is found out that there is almost no study addressing the allowable content of natural sand within the asphalt mixture in Gaza strip. And hence, this study addresses the problem of determining the ratio of natural sand that is permitted to be used within the asphalt mixture while maintaining or improving the mechanical properties of the mixture.

1.3 Research Aims

This study aims to determine the optimum ratio of natural sand – in Gaza strip – to be introduced to the asphalt mixture while maintaining or improving the mechanical properties of the mixture, at the same or lower cost per unit.

1.4 Research Objectives

The main objectives of the researches are:

1. To investigate the effect of adding natural sand with different ratio on the mechanical properties of asphalt mixtures;
2. To study the effect of optimal ratio of natural sand on Stability, Density, Flow, Voids Mineral Aggregate (*VMA*), Air Voids Content (*Va*) and Voids Filled with Bitumen (*VFB*) in asphalt mixtures.

1.5 Research Importance

The importance of this research comes from the fact that the use of Gaza natural natural sand would properly lead to a significant decrease in the cost of the asphalt mixture per unit. However, limited number of research were conducted in this area, and that’s why it is vital to carry on this study, locally. The research will mainly focus on the following:

1. Determining the effect of adding different ratio of natural sand on the Stability, Density, Flow, Voids Mineral Aggregate (*VMA*), Air Voids Content (*Va*) and Voids Filled with Bitumen (*VFB*) of asphalt mixture,
2. Helping local asphalt industry to make decision for determining the optimum content of natural sand to the asphalt mixture.

1.6 Research Scope

The research will focus mainly on determining the optimum natural sand to be introduced to the asphalt mixture while maintaining or improving the mechanical behavior of the asphalt mixture. The factors to be investigated are as mentioned in the research objectives. No other factors will be included in the research.

1.7 Research Methodology

To achieve the objectives of this study, the following methodology will be implemented:

1. Reviewing previous studies regarding the effect ratio of natural sand on Stability, Density, Flow, Voids Mineral Aggregate (*VMA*), Air Voids Content (*Va*) and Voids Filled with Bitumen (*VFB*) of the asphalt mixture;
2. Studying the asphalt mix design;
3. Studying the specifications such as identifying optimum natural sand content using Marshal Mix design procedure. six percentages of natural sand will be examined to determine the best percentage of natural sand and as shown in **Table (**1.1**)**. A 15% natural sand content is specified as the upper limit to be tested, which represent the percentage of the Trabia content to be replaced. The value of the Trabia content is determined based on a preliminary aggregate blending study as shown in the following chapters;
4. Implementing a compacted asphalt mixes at different ratio of natural sand with a fixed temperature at 145°C;
5. Analyzing the test results, and
6. Conducting conclusion and recommendations.

- *Table (1.1): Ratio of natural sand to be investigated*

Natural sand	0	2.5	5	7.5	10	15

1.8 Research Structure

This research will be divided into five chapters. The first chapter summaries the aims, objectives, importance and methodology of the research. The second chapter includes a detailed background and literature review regarding asphalt mix design, components of natural sand and similar previous works. The third chapter discusses methodology of the materials in terms of mechanical and physical properties, samples in terms of numbers and variations and the testing procedures to be implemented throughout this research.

Chapter four presents the results of the testing program. A discussion of those results are also included, as well as a comparison between the results and similar results obtained by different international regulations regarding the natural sand content. Chapter five contains the conclusion of the study and the recommendations.

The chapters will be contains the following order:

1. Chapter 1: Introduction,
2. Chapter 2: Literature Review,
3. Chapter 3: Materials and testing program,
4. Chapter 4: Results and data analysis,
5. Chapter 5: Conclusion and Recommendations,
6. List of References, and
7. Appendices

Chapter 2

Background

and Literature Review

CHAPTER 2: BACKGROUND AND LITERATURE REVIEW

2.1 Introduction

The term "hot-mix asphalt"(HMA) is used generically to include many different types of mixtures of aggregate and asphalt cement that are produced at an elevated temperature in an asphalt plant. Most commonly HMA is divided into three different types of mix—dense-graded, open-graded, and gap-graded—primarily according to the gradation of the aggregate used in the mix as shown in Table (2.1). The dense-graded type is further subdivided into continuously graded or conventional HMA, large-stone mix, and sand asphalt mix. The open-graded type includes the subtypes open-graded friction course and asphalt-treated permeable base. The gap-graded type encompasses both gap-graded asphalt concrete mixes and stone-matrix asphalt mixes. Pavement designers specify different mixture types to satisfy different pavement performance demands and to accommodate variability in the nature and cost of available aggregates and asphalt cement supplies (Federal Aviation Administration, 2013).

Table (2.1): Types of Hot-Mix Asphalt

Dense-Graded	Open-Graded	Gap-Graded
Conventional Nominal maximum aggregate size usually 12.5 to 19 mm (0.5 to 0.75 in.)	Porous friction course	Conventional gap-graded
Large-stone Nominal maximum aggregate size usually between 25 and 37.5 mm (1 and 1.5 in.)	Asphalt-treated permeable base	Stone-matrix asphalt (SMA)
Sand asphalt Nominal maximum aggregate size less than 9.5 mm (0.375 in.)		

2.2 Types of Asphalt Mixtures

2.2.1 Dense-Graded Hot-Mix Asphalt

Dense-graded HMA is composed of an asphalt cement binder and a well or continuously graded aggregate. Conventional HMA consists of mixes with a nominal maximum aggregate size in the range of 12.5 mm (0.5 in.) to 19 mm (0.75 in.). This material makes up the bulk of HMA used around the globe. Large-stone mixes contain coarse aggregate with a nominal maximum size larger than 25 mm (1 in.). these mixes have a higher percentage of coarse aggregate than the conventional mixes [larger than the 4.75-mm (No. 4) sieve]. Sand asphalt – sometimes called sheet asphalt – is composed of aggregate that passes the 9.5-mm (0.375-in.) sieve, the all type of Dense-graded HMA as shown in Figure (3.7) . The binder content of the mix is higher than that of conventional HMA because of the increased voids in the mineral aggregate in the mixture. Unless manufactured sand or a rough-textured natural sand is used in the mix, the rut resistance of this type of mix is typically very low (Ahmad, Abdul Rahman, & Hainin, 2011).

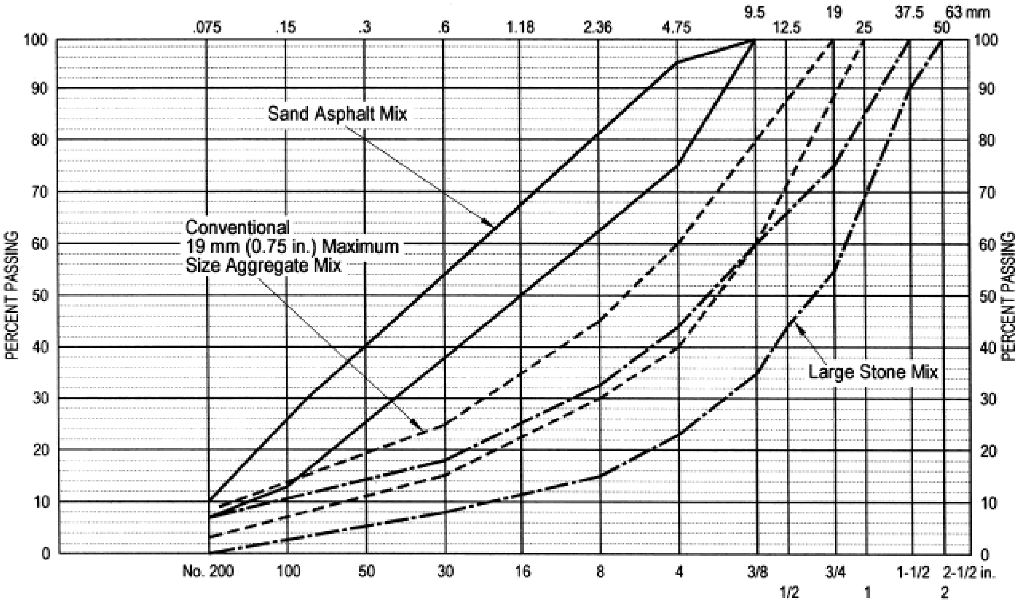

Figure (2.1): Representative gradations for Dense-Graded Hot-Mix Asphalt (Ahmad, Abdul Rahman, & Hainin, 2011).

2.2.2 Open-Graded Mixes

Open-graded mixes consist of an aggregate with relatively uniform grading and an asphalt cement or modified binder. The primary purpose of these mixes is to serve as a drainage layer, either at the pavement surface or within the structural pavement section.

As noted, there are two types of open-graded mixes. The first comprises mixes used as a surface course to provide a free-draining surface in order to prevent hydroplaning, reduce tire splash, and reduce tire noise; this type of mix is frequently termed an open-graded friction course. The second type, termed asphalt-treated permeable base, comprises a uniformly graded aggregate of larger nominal maximum size than that used for open-graded friction course—19 mm (0.75 in.) to 25 mm (1.0 in.)—and is used to drain water that enters the structural pavement section from either the surface or subsurface, Figure (3.7) shown all type of Open-Graded Mixes (Ongel, Harvey, & Kohl, 2007).

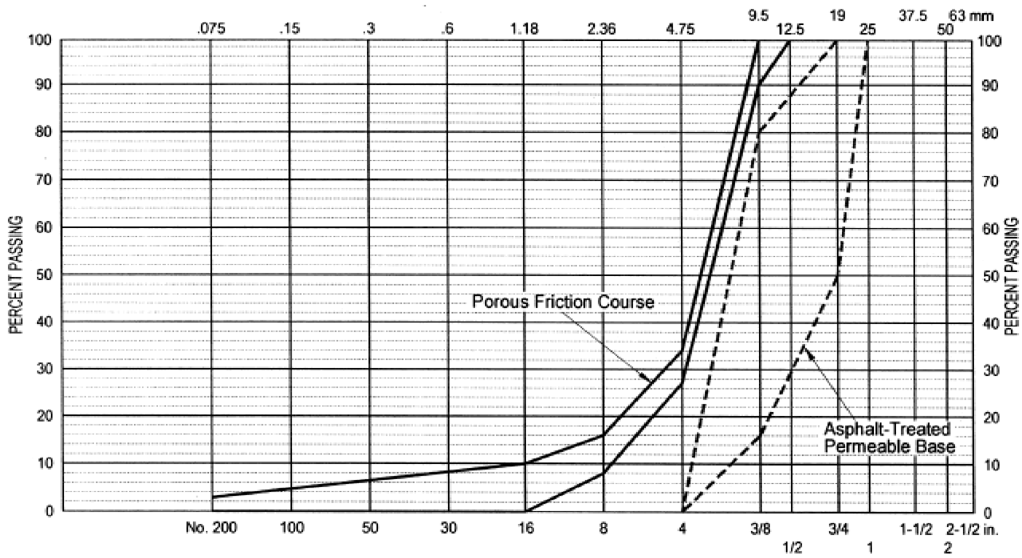

Figure (2.2): Representative gradations for Open-Graded Mixes (Ongel, Harvey, & Kohl, 2007)

2.2.3 Gap-Graded Mixes

Gap-graded mixes are similar in function to dense-graded mixes in that they provide dense impervious layers when properly compacted. Conventional gap-graded mixes have been in use for many years. Their aggregates range in size from coarse to fine, with some intermediate sizes missing or present in small amounts. The second type of gap-graded mix is stone-matrix asphalt (SMA) mix, Figure (3.7) shown all type of Gap-Graded Mixes (Federal Highway Administration, 2001).

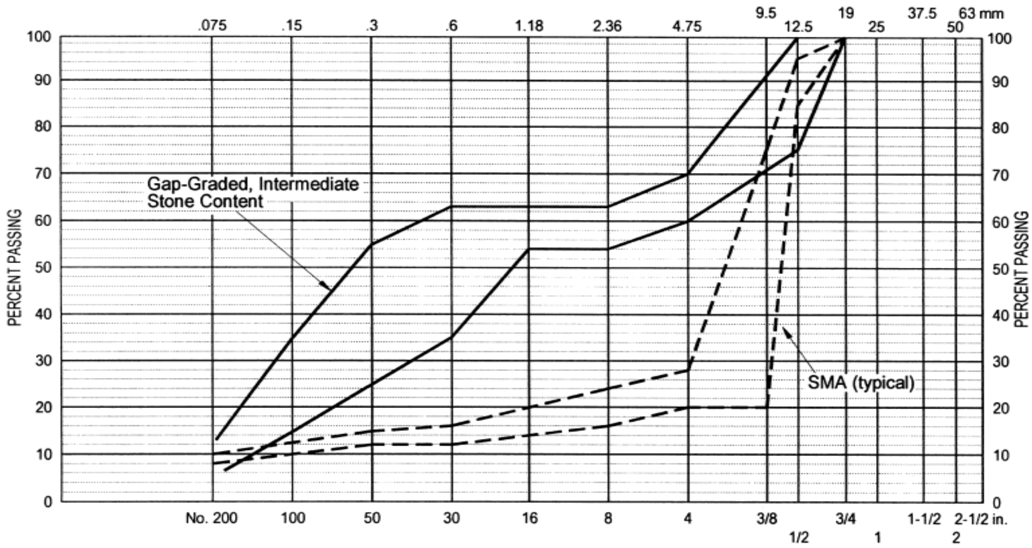

Figure (2.3): Representative gradations for Gap-Graded Mixes (Federal Highway Administration, 2001)

2.3 Aggregate Characteristics and Properties

The characteristics of aggregates influence their properties and, in turn, affect the performance of HMA. These characteristics influence the amount of binder required for satisfactory performance and can have an effect on construction, particularly placement of HMA (Transportation Research Board, 2011).

2.3.1 Surface Texture and Shape

The aggregate's surface texture is the most important factor contributing to its frictional resistance. This characteristic also strongly influences the resistance of a mix to rutting. The rougher the texture of the aggregate, the better will be the rutting resistance of the mix. During construction, however, an HMA containing an aggregate with a rough texture will necessitate a greater compactive effort to achieve the required density than an HMA containing a smooth-textured aggregate. The shape of the aggregate also influences the rutting resistance of a mix, with angular aggregate producing greater resistance than more rounded material. The improved resistance to rutting of angular aggregates likely results from increased surface roughness produced by crushing and to some extent from aggregate interlock. As with surface texture, the more angular the aggregate, the greater will be the compaction effort required to produce a mix with a specified degree of density (Transportation Research Board, 2011).

2.3.2 Particle Size Distribution (Gradation)

One of the important properties of aggregates for use in pavements is the distribution of particle sizes, or gradation. Aggregates having different maximum particle sizes can have different degrees of workability. Typically, the larger the maximum size of aggregate in a given mix type in relation to the layer thickness and the greater the amount of large aggregate in the mix, the more difficult it is to compact the mix. Further, if the nominal maximum aggregate size exceeds one-third of the compacted thickness of the pavement layer, the surface texture of the mix can be affected, and the degree of density of the mix obtained by compaction may be reduced. To improve the resistance of HMA to rutting, both the proportion of coarse aggregate [retained on the 4.75-mm (No. 4) sieve] and the maximum particle size may be increased (Federal Highway Administration, 2001).

2.3.4 Absorption

The amount of asphalt cement that is absorbed by the aggregate can significantly affect the properties of the asphalt mixture. If the aggregate particles have high asphalt absorption, the asphalt content in the mix must be increased to compensate for binder material that is drawn into the pores of the aggregate and is unavailable as part of the film thickness around those particles. If that asphalt content adjustment is not made, the mix can be dry and stiff, the amount of compactive effort needed to achieve density in the mix will need to be increased, and the mix will have a tendency to ravel under traffic. If absorptive aggregates that have a high water content are used, extra time will be required in the production of HMA to ensure that the moisture in the pores can evaporate. Otherwise, the asphalt may not be properly absorbed, leading to compaction difficulties (Kandhal & Khatri, 1991).

2.3.5 Clay Content

The presence of clay in the fine aggregate [material passing the 4.75-mm (No. 4) sieve] can have a detrimental effect on the water sensitivity of an asphalt concrete mix. For example, clay minerals coating aggregates can prevent asphalt binders from thoroughly bonding to the surface of aggregate particles, increasing the potential for water damage to the paving mixture. The sand equivalent test is used to limit the presence of clay material in the aggregate (Lu, Cong, & Zheng, 2006).

2.4 Mix Design

To produce an asphalt mix design, asphalt binder and aggregate are blended together in different proportions in the laboratory. The resulting mixes are evaluated using a standard set of criteria to permit selection of an appropriate binder content. The type and grading of the aggregate and the stiffness and amount of the asphalt binder influence the physical properties of the mix. The design (or optimum) binder content is selected to ensure a balance between the long-term durability of the mix and its resistance to rutting (stability).

Mix design is performed in the laboratory, generally using one of three methods. Until the late 1990s, the most common mix design method was the Marshall method. A second method is the Hveem method. While the third method is the Superpave method (Federal Aviation Administration, 2013).

2.4.1 Marshall Method

The Marshall method resulted from developments by the U.S. Army Corps of Engineers (USACE) for a mix design procedure for airfield pavements during World War II and subsequent modifications (Highway Research Board , 1949). This test procedure is used in designing and evaluating bituminous paving mixes and is extensively used in routine test programmes for the paving jobs. There are two major features of the Marshall method of designing mixes namely, density – voids analysis and stability – flow test. Strength is measured in terms of the 'Marshall's Stability' of the mix following the specification ASTM D 1559 (2004) (American Society for Testing and Materials (ASTM), 2004), which is defined as the maximum load carried by a compacted specimen at a standard test temperature of 60°C. In this test compressive loading was applied on the specimen at the rate of 50.8 mm/min till it was broken. The temperature 60°C represents the weakest condition for a bituminous pavement.

The flexibility is measured in terms of the 'flow value' which is measured by the change in diameter of the sample in the direction of load application between the start of loading and at the time of maximum load. During the loading, an attached dial gauge measures the specimen's plastic flow (deformation) due to the loading. The associated plastic flow of specimen at material failure is called flow value. The density- voids analysis is done using the volumetric properties of the mix, which will be described in the following sub sections (Federal Aviation Administration, 2013).

2.4.2 Hveem Method

This method, developed by F. N. Hveem of the California Division of Highways, has been used by that organization since the early 1940s.

As is the case with the Marshall method, actual design criteria vary among organizations using this method, although the equipment for mix evaluation is essentially the same. The design philosophy embodied in this procedure is as follows:

- Stability is a function primarily of the surface texture of the aggregate,
- Optimum asphalt content is dependent on the surface area, surface texture and porosity of the aggregate, and asphalt stiffness, and
- If required, the design asphalt content is adjusted to leave a minimum of 4 percent calculated air voids to avoid bleeding or possible loss of stability.

Kneading compaction (ASTM D1561) is used to prepare specimens for laboratory testing over a range of asphalt contents. The compactive effort was established to produce densities considered representative of those obtained under traffic soon after construction (Hveem, 1938).

2.4.3 Superpave Method

This method included both a volumetric design procedure and performance tests on the resulting mix or mixes obtained from the volumetric design.

The volumetric mix design is accomplished in four steps:

- Selection of component materials,
- Selection of design aggregate structure,
- Selection of design asphalt content, and
- Evaluation of moisture susceptibility.

Selection of the component materials includes selection of the appropriate binder performance grade and aggregate with requisite characteristics for the traffic applied. As noted earlier, both the high temperature and low temperature at the pavement site establish the binder grade to be used. Aggregate characteristics include coarse aggregate angularity, fine aggregate angularity, flat and elongated particles, and clay content. Design requirements for the aggregate increase as the traffic increases (TRB, 2005).

2.5 Detailed Literature Review

Asphalt concrete is composed primarily of aggregate and asphalt binder. Aggregate typically makes up about 95% of a Hot-Mix Asphalt (HMA) mixture by weight, whereas asphalt binder makes up the remaining 5%. By volume, a typical HMA mixture is about 85% aggregate, 10% asphalt binder, and 5% air voids. Small amounts of additives and admixtures are added to many HMA mixtures to enhance their performance or workability. These additives include fibers, crumb rubber, and anti-strip additives (European Asphalt Pavement Association, 2008).

Because HMA mixtures are mostly aggregate, aggregates used in HMA must be of good quality to ensure the resulting pavement will perform as expected. Aggregates used in HMA mixtures may be either crushed stone or crushed gravel. In either case, the material must be thoroughly crushed, and the resulting particles should be cubical rather than flat or elongated. Aggregates should be free of dust, dirt, clay, and other deleterious materials. Because aggregate particles carry most of the load in HMA pavements, aggregates should be tough and abrasion resistant (Transportation Research Board, 2011).

Since about 85% of the volume of dense-graded HMA is made up of aggregates, HMA pavement performance is greatly influenced by the characteristics of the aggregates. Aggregates in HMA can be divided into three types according to their size: coarse aggregates,

fine aggregates, and mineral filler. Coarse aggregates are generally defined as those retained on the 2.36-mm sieve. Fine aggregates are those that pass through the 2.36-mm sieve and are retained on the 0.075-mm sieve. Mineral filler is defined as that portion of the aggregate passing the 0.075-mm sieve. Mineral filler is a very fine material with the consistency of flour and is also referred to as mineral dust or rock dust (European Asphalt Pavement Association, 2008).

The Geotechnical Laboratory for the United States air force conduct a detailed laboratory research to determine the optimum natural sand content and to evaluate its impact on the engineering properties of the mix at various amounts. The study revealed that the optimum asphalt content decreased as the percentage of natural sand increased. The stability values were also affected by the percentage of natural sand; the stability values decreased as the percentage of natural sand increased. Another relationship that was observed was a decrease in voids in mineral aggregate as the percentage of natural sand increased. The general observation conducted from the laboratory tests is that asphalt concrete mixtures with all crushed aggregates had higher strength properties and would resist potential rutting better than mixtures containing natural sand materials. Asphalt concrete mixtures containing more than 20 percent natural sand appeared to have tremendous potential to deform under severe loads (Randy, 1991).

(Lee, White, & West, 1999) studied the effect of fine aggregate angularity on asphalt mixture performance. Among the research parameters was the amount of natural sand to be introduced to enhance the mechanical behavior of the asphalt mixture. This study consisted of two phases. In the first phase, individual mix designs were conducted for each fine aggregate combination. In addition, mixtures were evaluated with blends of natural sand and crushed gravel sand. In the second phase of the study, different approaches were adopted to redesign the two mixtures that had poor rutting performance in the first phase. The two mixtures were a slag sand mix and a stone sand mix with an S-shaped gradation. The modifications included adding mineral filler, replacing part of the original sand with natural sand, and changing gradation of the aggregate blend.

Results indicated that adding natural sand and mineral filler did not improve the rutting performance of the S-shaped limestone sand mixture. The reason is that the gradation remained S-shaped after adding either natural sand or mineral filler. The only means to improve the rutting performance was to change the gradation. By straightening the S-shaped gradation curve, the VMA and associated asphalt demand were greatly reduced. With lower asphalt content and denser mineral aggregate structure, the rutting performance was also improved.

(Vagner , Bismak , Diego , & Ricardo , 2014) compared the mechanical performance of asphaltic mixtures made with natural aggregates and concrete recycled aggregates for surface course of pavements. The materials were collected in an asphalt mixing plant and in a construction and demolition solid waste recycling plant. The Marshall asphalt mix design was chosen to determine optimum asphalt content and evaluate mechanical performance of asphaltic mixtures. The asphalt mixtures specimens were composed of natural aggregates, and afterwards of recycled aggregates with percent contents of 25, 50 and 100. It was concluded that the replacement of natural aggregates with 25% recycled concrete aggregates in asphalt mixtures can be technically viable to build asphalt surface course on pavements, besides lowering pavement costs and decreasing environmental impacts.

(You & Mills-Beale, 2010) studied the mechanical properties of asphalt mixtures with recycled concrete aggregates. The objective of this study is to characterize the mechanical properties of asphalt mixtures with recycled concrete aggregates for low volume roads. In this study, the RCA is substituted for Michigan traprock virgin aggregates (VA) in a light traffic volume HMA (control mix) at the rate of 25, 35, 50 and 75. The rutting potential using Asphalt Pavement Analyzer (APA), Dynamic Modulus (E), Tensile Strength Ratio (TSR) for moisture susceptibility, Indirect Tensile Test (IDT) resilient modulus and the Construction Energy Index (CEI) are determined to evaluate the field performance suitability or otherwise of the mix. Results indicated that the master curves for the hybrid mixes showed that the dynamic stiffness of the hybrid mixes were less than that of the control mix, and it decreased when the RCA increased in the mix. In terms of moisture susceptibility, the tensile strength ratio increased with decreasing RCA; with only the 75% of RCA in the mix failing to meet the specification criterion. The compaction energy index proved that using RCA would save some amount of compaction energy. It is recommended that a certain amount of RCA in HMA is acceptable for low volume roads.

(Ahmed & Mohiuddin, 2016) studied the effect of natural sand percentages on fatigue life of asphalt concrete mixture. In this study, two types of fine aggregate were used, natural sand (desert sand) and crushed sand. The crushed sand was replaced by natural sand (desert sand) with different percentages (0%, 25%, 75% and 100%) by the weight of the sand (passing sieve No.8 and retained on sieve No.200) and one type of binder (40/50) penetration. The experimental tests showed that the best proportions of natural sand to be used in an asphaltic concrete mixture is (0% and 25%) by weight of fraction (passing No.8 and retained on No.200) sieves.

(Niazi & Mohammadi, 2003) studied the effect of using natural sand on the properties and behavior of asphalt paving mixes. The research devoted to investigate the effect of using natural sand, particularity in a soiled state, on the properties of asphalt concrete, and also to evaluate the sufficiency of the current method of design and control of asphalt mixes in this relation. Four types of aggregate blends with the same grading and a 60/70 penetration grade asphalt were used in the study to produce asphalt mixes. Aggregate blends were prepared using constant coarse and different fine fractions. Fine aggregates which their shape and surface texture characteristics were determined by following standard laboratory procedures include one type of crushed sand, one type of natural river sand and a sand type consisting of a blend of the crushed sand and the natural sand. Results obtained from Marshall Method of Mix Design indicates that this design method does not comprise the sensitivity required to indicate the maximum allowable percentage of natural sand in asphalt mixes and so, further relevant complementary tests are needed. Results obtained from mix design tests, and also from unconfined compressive strength tests indicate that using natural sand particularly in a soiled state causes a reduction in the bearing and energy absorption capacity of the asphalt mixture, and intensifies the risk of occurrence of permanent deformation and bleeding in the asphalt concrete surfaces.

(Sánchez, Caro, & Caicedo, 2012) aimed to characterize the material properties of the sand-asphalt mixture and its constitutive phases, and to evaluate the possibilities of using this material in road infrastructure projects. In this research the linear viscoelastic material properties and the deterioration characteristics of the mixtures when subjected to dynamic loading were evaluated by means of the Dynamic Mechanical Analyzer (DMA) test. The results obtained of the study have shown a high variability in material properties among the sand-asphalt samples. Besides, the asphalt binder was observed to have high penetration values, low complex moduli and high phase angle values. The results also suggest that the compaction temperature of the sand-asphalt mixtures strongly impacts the resistance of the material (e.g., a difference of 92% in complex modulus was observed between the samples compacted at room temperature and those compacted at 140ºC, all samples were tested at room temperature). The mechanical properties of this natural bituminous material and the high variability in its material properties seem to limit the possibility of its extensive use in high-volume road infrastructure projects. However, the results suggest that the material could be used for base or subbase stabilization, and they confirm the convenience of its use as asphalt courses in low-volume roads.

2.6 Summary and conclusions

By far, the vast majority of the studies it is reviewed does not investigate the effect of adding natural sand to the asphalt mixture in the first place so to investigate the effect of natural sand on various factors like the stability, density, flow, voids mineral aggregate (*VMA*), air voids content (*Va*) and voids filled with bitumen (*VFB*) in the asphalt mixture.

Hence, it is imperative to carry out this research in order fill Gap in this researching domain, and provide a guideline on the feasibility and practically of using natural sand in hot-mix asphalts. The results of this study is assumed to leave a major impact among the local asphalt industry and help minimizing the cost of asphalt production.

Chapter 3

Experimental Program

CHAPTER 3: EXPERIMENTAL PROGRAM

3.1 Introduction

This chapter includes a detailed description of the experimental program, i.e., the materials physical and mechanical, the testing standards and the testing procedures, the findings as a raw data and other related information. Throughout the experimental program, the following materials were used: a) bitumen, b) aggregates, c) filler material, and d) natural sand. Following a brief description regarding each of the aforementioned materials and their physical and mechanical properties.

3.2 Bitumen

For the experimental program, an asphalt binder (Bitumen) with 60/70 penetration grade was used to conduct all the experimental samples.

3.2.1 Bitumen Physical Properties

The physical properties of the Bitumen were conducted using the following standards:

- Penetration: ASTM D5\ Standard Test Method for Penetration of Bituminous Materials
- Ductility: ASTM D113\ Standard Test Method for Ductility of Bituminous Materials
- Flash Point: ASTM D3134\ Standard Practice for Establishing Color and Gloss Tolerances
- Softening Point: ASTM D36\ Standard Test Method for Softening Point of Bitumen

Table (3.1) summarizes the physical properties to be obtained of the asphalt binder that have been used throughout the experimental program:

Table (3.1): Physical Properties to be obtained of the Asphalt Binder (Bitumen)

Physical Properties	ASTM Standard	Specification
Penetration [(1/10 mm) – 25 ^{o}C]	D5	60-70
Ductility (cm)	D113	Min 100
Flash Point (^{o}C)	D92	Min 230
Softening Point (^{o}C)	D36	48-56

3.3 Aggregates

Aggregates goes into the asphalt mixes are fine and coarse aggregates. Those aggregates are distinguished from each other based on the particles size, as following in Table (3.2).

Table (3.2): Sizes of used aggregates

	Aggregate Type	Particle Size (mm)
Coarse	Folia	0/19.0
	Adasia	0/12.5
	Simsimia	0/9.50
Fine	Trabia	0/4.75
	Sand	0/0.60

3.3.1 Aggregates Physical Properties

Laboratory tests were carried out to determine the physical properties of the aggregates, i.e., bulk dry density S.G., bulk SSD S.G., Apparent S.G., Effective S.G., Absorption and Abrasion value. Table (3.3) summarizes the physical properties of the aggregates used in the experimental works.

Table (3.3): Aggregates' Physical Properties

Test	ASTM Specification	Folia	Adasia	Simsimia	Trabia	Sand	Limits
Bulk Dry S. G.	C127	2.53	2.60	2.52	2.63	2.58	-
Bulk SSD S. G.		2.59	2.64	2.58	2.69	2.60	
Apparent S. G.		2.68	2.71	2.67	2.79	2.63	
Effective S. G.		2.60	2.65	2.60	2.71	2.61	
Absorption (%)	C128	2.18	1.56	2.19	2.27	0.75	<5
Abrasion (%)	C131	19.2	X	X	X	X	<40

3.3.2 Aggregates Sieve Analysis

A sieve analysis (or gradation test) is a practice or procedure used to assess the particle size distribution of a granular material.

The size distribution is often of critical importance to the way the material performs in use. A sieve analysis can be performed on any type of non-organic or organic granular materials including sands, crushed rock, clays, granite, feldspars, coal, soil, a wide range of manufactured powders, grain and seeds, down to a minimum size depending on the exact method. Being such a simple technique of particle sizing, it is probably the most common (Mcglinchey, 2005).

A sieve analysis (gradation test) was carried out in accordance with ASTIM C 136 Specification. The results of the sieve analysis are listed below in Table (3.4). Figures (3.1),(3.2),(3.3),(3.4),(3.5),(3.6) expressing those results are presented.

Table (3.4): Aggregates Sieve Analysis Results

Sieve #	Opening	FOLYIA (0/19.0)	ADASIA (0/12.5)	SIMSIMIA (0/9.50)	TRABIA (0/4.75)	SAND (0/0.6)
1"	**25.00**	100.00	100.00	100.00	100.00	100.00
3/4''	**19.00**	97.50	99.16	100.00	100.00	100.00
1/2"	**12.50**	21.16	53.34	100.00	100.00	100.00
3/8''	**9.50**	14.16	17.18	100.00	100.00	100.00
#4	**4.75**	4.23	1.11	43.38	95.04	100.00
#8	**2.36**	0.59	1.09	5.86	76.70	99.78
#16	**1.18**	0.32	1.08	2.82	56.49	99.78
#20	**0.85**	0.25	1.06	2.31	39.56	99.78
#30	**0.60**	0.25	1.06	2.30	23.27	99.78
#40	**0.43**	0.25	1.06	2.30	23.27	62.04
#50	**0.30**	0.25	1.06	2.30	23.27	62.04
#80	**0.18**	0.25	1.03	2.16	11.62	2.56
#100	**0.15**	0.25	0.98	1.90	7.77	2.56
#200	**0.08**	0.25	0.98	1.90	7.77	0.76
PAN		0.00	0.00	0.00	0.00	0.00

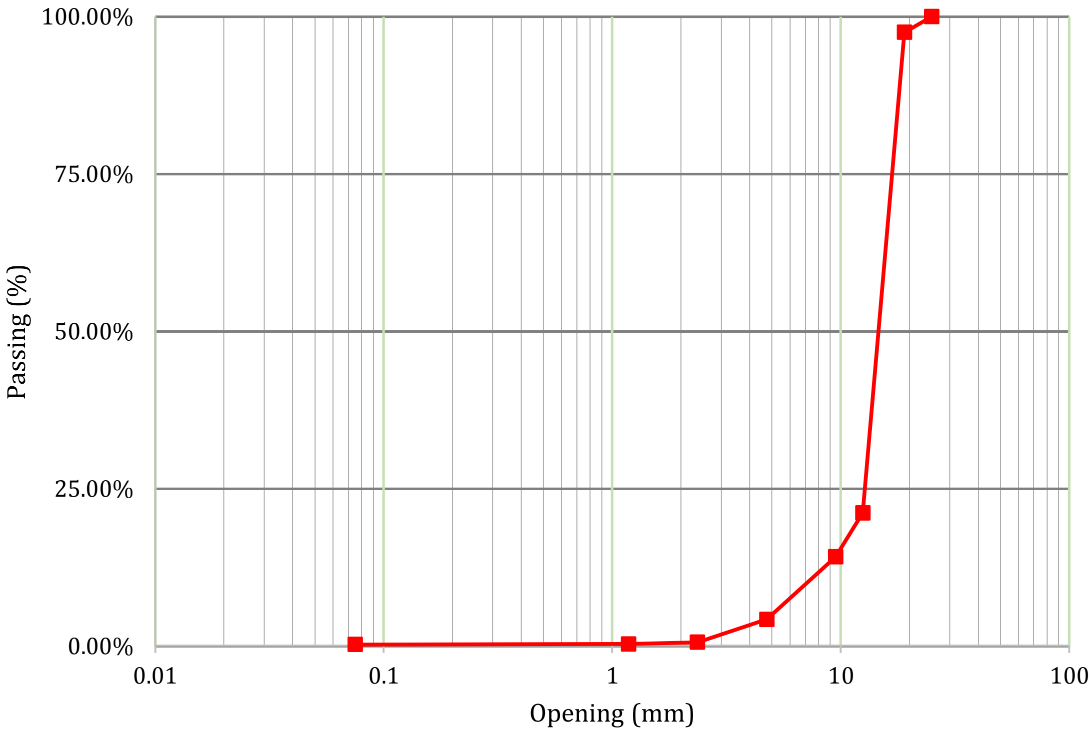

Figure (3.1):Gradation Curve for FOLIA (0/19.0) Aggregate

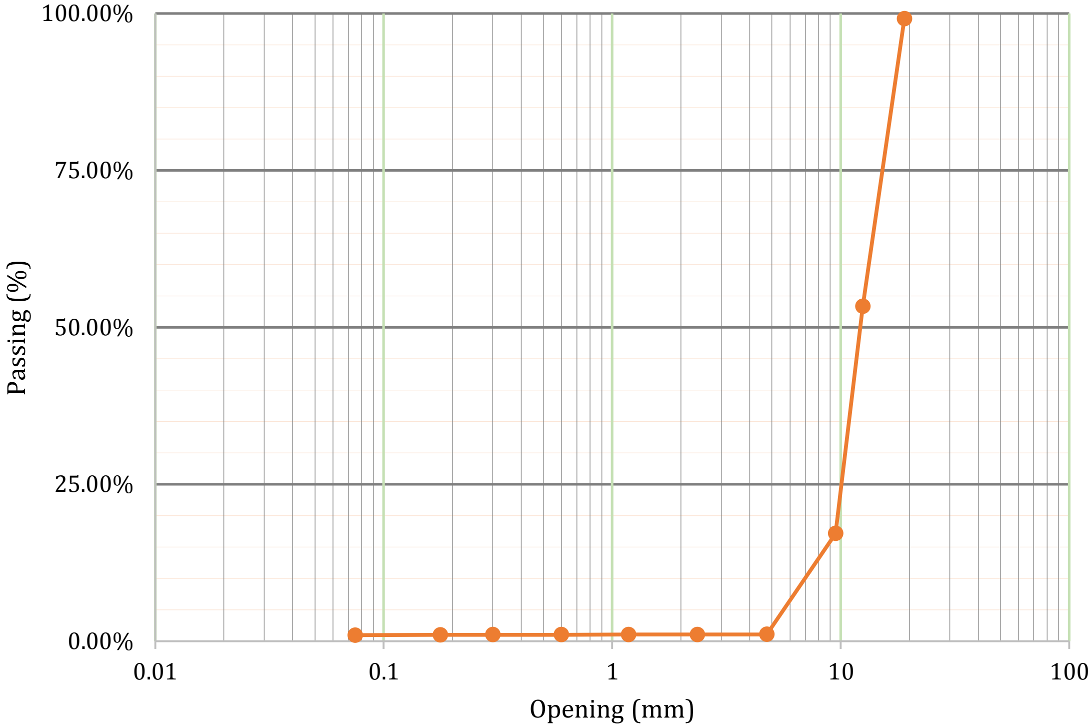

Figure (3.2): Gradation Curve for ADASIA (0/12.5) Aggregate

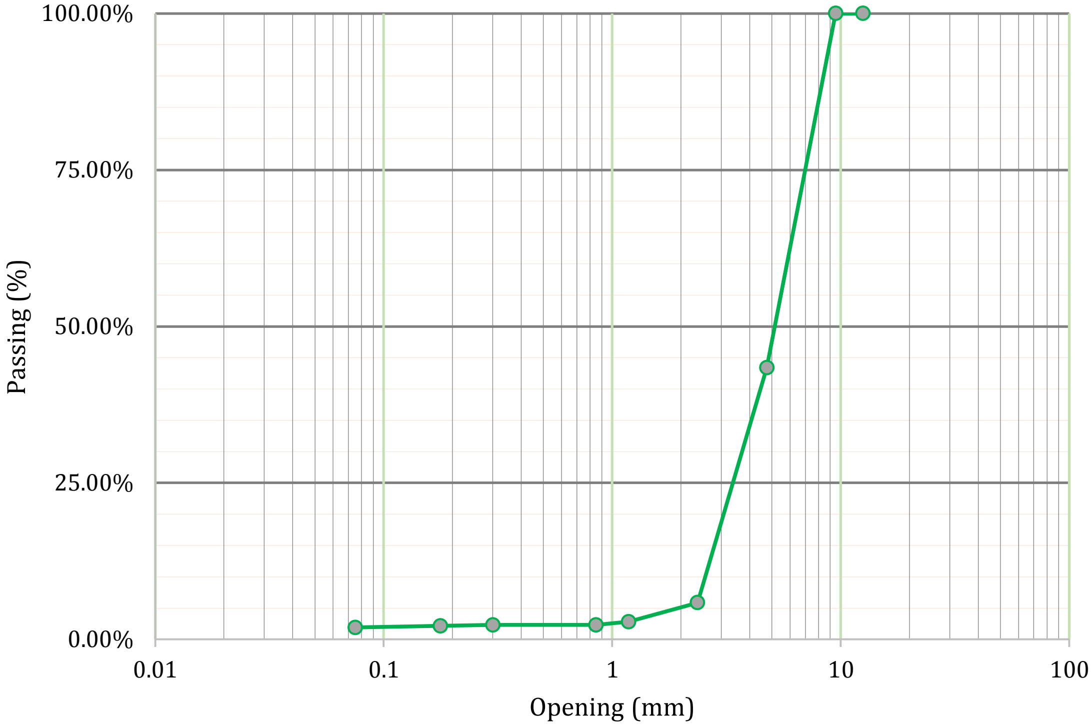

Figure (3.3): Gradation Curve for SIMSIMIA (0/9.50) Aggregate

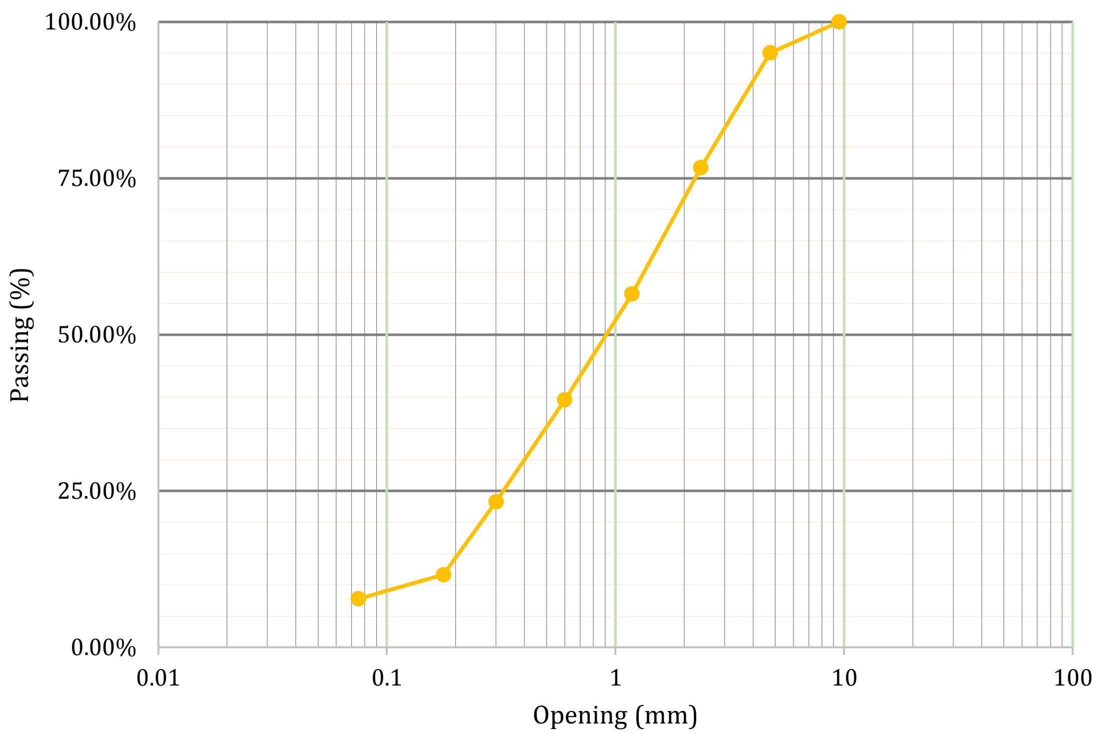

Figure (3.4): Gradation Curve for TRABIA (0/4.75) Aggregate

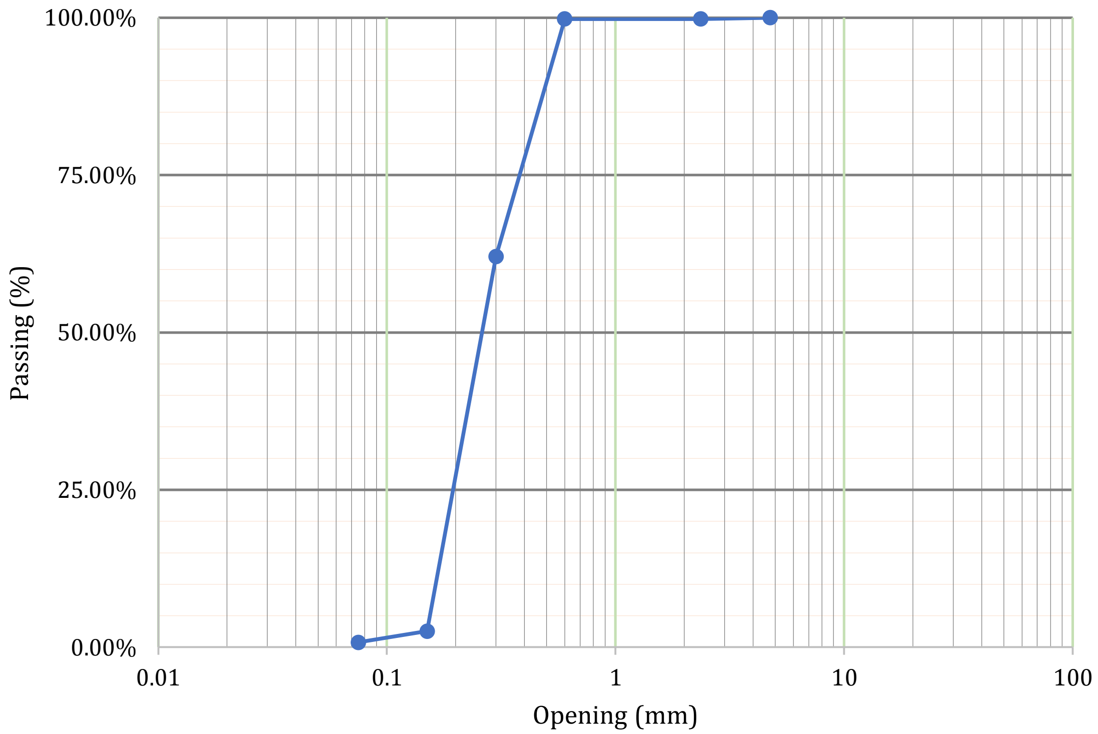

Figure (3.5): Gradation Curve for SAND (0/0.6)

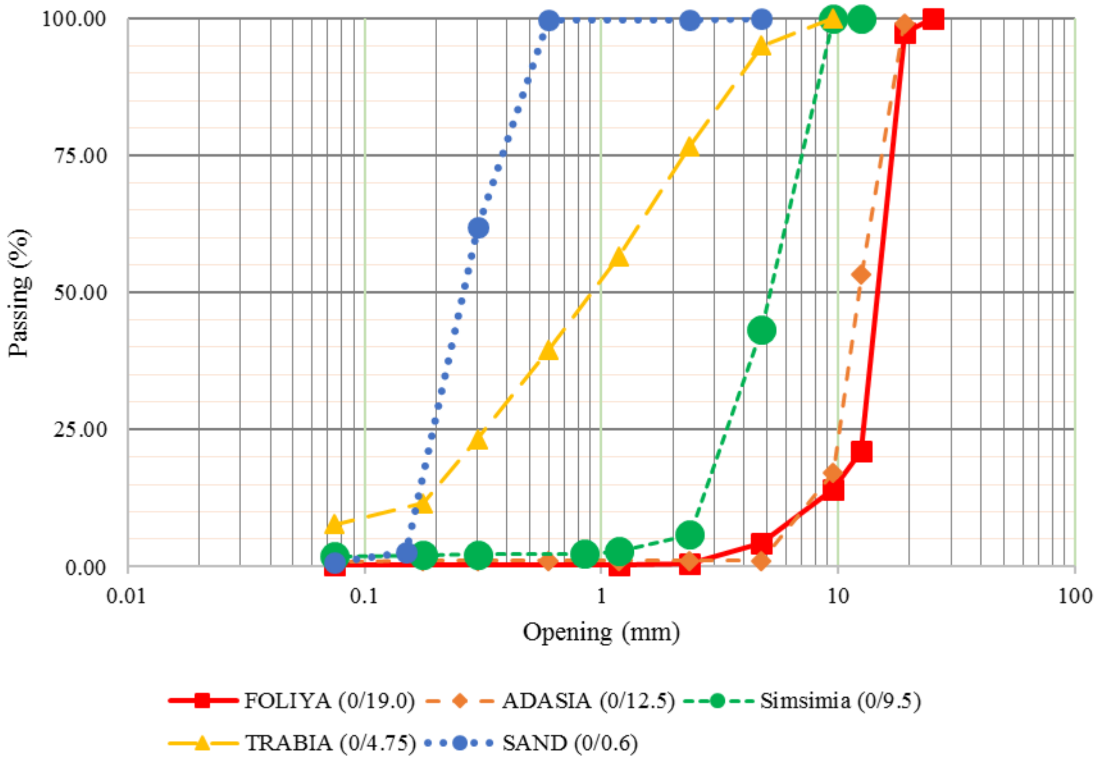

Figure (3.6): Gradation Curves of all aggregates types

3.4 The Experimental Program

To evaluate the feasibility of adding natural sand to the asphalt mixture and studying its effect on the mechanical properties on the asphalt mixture, an extensive and comprehensive experimental work was carried out.

At first, the physical properties of the materials to be used in the experimental work, i.e., bitumen, aggregates and sand, were evaluated and a gradation test were conducted. Then, a blending of aggregates was carried out to obtain the binder course gradation curve which has been used in the preparation of the asphalt mixture. Afterwards, different bitumen contents asphalt mixes were prepared to obtain the optimum bitumen content in accordance with the Marshal Test results. The optimum bitumen content is used to prepare the asphalt mixtures with various percentages of sand replacing the Trabia (Filler Material) fine aggregate. Marshal test was used to evaluate the properties of these mixes. And finally, laboratory tests were obtained and analyzed.

Following are the steps of the experimental works:

1. The materials to be used in the experimental work, i.e., the aggregates, bitumen and sand, were first procured and properly stored,
2. Experimental tests were conducted to evaluate the materials and obtain the physical properties, which includes:
   - Gradation tests (sieve analysis),
   - Specific gravity tests (S.G),
   - Unit weight tests,
   - Los Anglos test, and
   - Impact and Crush tests.

   Results of the aforementioned tests were nominal and within the limitation of the specifications,

   3. Blending of aggregates was carried out to obtain the binder course gradation curve which has been used in the preparation of the asphalt mixture in accordance with ASTM D3515 specification. A trial and error method was used to determine the percentage of each aggregate to be used. The following percentage were found to fit the ASTM D3515 limitations: Folia (0/19.0): 15.71%, Adasia (0/12.5): 25.65%, Simsimia (0/9.50): 15.71%, Trabia (0/0.6): 39.79%, Filler (0/0.075): 3.14%. Aggregate blending details are included in the appendices.

4. The blended mix of the aggregates where within the minimum and maximum limits of the binder course specifications (ASTM 3515), as shown in the Table (3.5) and Figure (3.7).

Table (3.5): ASTM D 3515 Dense Binder Gradation Results

SIEVE (NO.)	OPENING (mm)	Selected Gradation (PASSING %)	SPECIFICATION		15.00%	24.50%	15.00%	0.00%	38.00%	3.00%
					15.71%	25.65%	15.71%	0.00%	39.79%	3.14%
			MINIMUM	MAXIMUM	FOULIA (0/19.0)	ADASIA (0/12.5)	SIMSMIA (0/9.5)	SAND (0/4.75)	TRABIYA (0/0.6)	FILLER
1"	**25**	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
3/4''	**19**	99.39	70.00	100.00	97.50	99.16	100.00	100.00	100.00	100.00
1/2"	**12.5**	75.65	53.00	90.00	21.16	53.34	100.00	100.00	100.00	100.00
3/8''	**9.5**	65.27	40.00	80.00	14.16	17.18	100.00	100.00	100.00	100.00
#4	**4.75**	48.72	30.00	56.00	4.23	1.11	43.38	100.00	95.04	100.00
#8	**2.36**	34.95	23.00	49.00	0.59	1.09	5.86	99.78	76.70	100.00
#20	**0.85**	19.64	14.00	43.00	0.32	1.08	2.82	99.78	39.56	99.60
#50	**0.3**	13.02	5.00	19.00	0.25	1.06	2.30	62.04	23.27	98.25
#80	**0.177**	8.03	4.00	15.00	0.00	1.06	2.16	2.56	11.62	89.00
#200	**0.075**	6.04	2.00	8.00	0.00	0.98	1.90	0.76	7.77	76.55

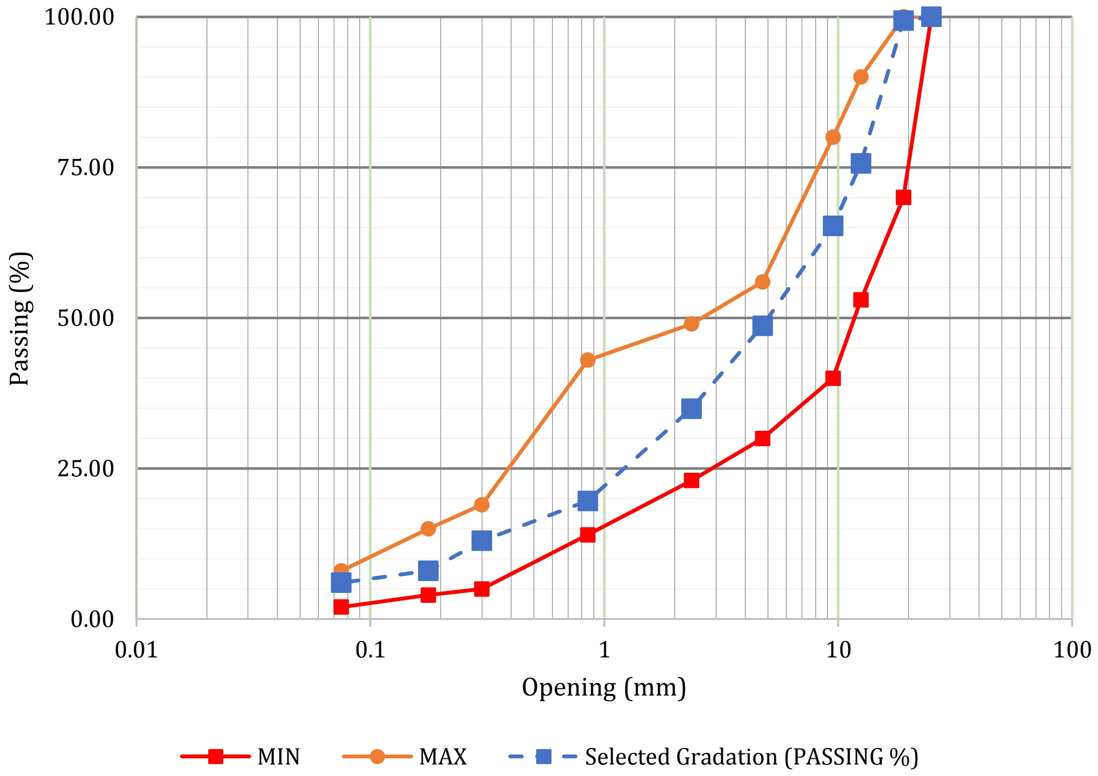

Figure (3.7): ASTM D 3515 Dense Binder Gradation Curves Limits and Aggregates Mixture Gradation Curve

5. Bitumen samples to be used in the experimental program were subjected to various testing in order to conduct its properties, as following:

- The Penetration Test in accordance with ASTM D5 Standards,
- The Ductility Test in accordance with ASTM D113 Standards,

- The Flash Point Test in accordance with the ASTM D3134 Standards,
- The Softening Point Test in accordance with the ASTM D36 Standards,

Table (3.1) list the aforementioned tests,

6. A Job mix was conducted to determine the optimum bitumen content. The content of the bitumen varied between 4-6%, such as, 4% – 4.5% – 5% – 5.5% and 6% bitumen content were used,
7. A Marshal Test were conducted on the control specimens, by testing 3 samples for each bitumen content,
8. Additional samples were prepared and used in the stability, density, flow, unit weight and specific gravity tests,
9. Since both Trabia and natural sand are the closest among other aggregates in terms of the grain size, and after determining the optimum bitumen content, a replacement took place for the Trabia (0/0.6) by natural sand, in the following order: 2.5%, 5%, 7.5%, 10% and 15%,
10. For the aforementioned percentage of replacement of Trabia by natural sand, a marshal test was carried out for each one, by testing three samples for results consistency. The tests aimed to investigate the stability, density, flow, unit weight and specific gravity tests,
11. Results were documented and analyzed,
12. Conclusions and recommendations were drawn afterwards.

3.6 Mixtures Preparation

According to ASTM specifications using mathematical trial method, aggregates are blended together in order to get a proper gradation. Mathematical trial method depends on suggesting different trial proportions for each type of aggregate. The percentage of each type of aggregates are computed and compared to specification limits. If the calculated percentages for, each type of aggregate, gradation is within the specifications limits, no further adjustments need to be made. If not, an adjustment in the proportions must be made till the percentage of each size of aggregate are within the specifications limits (Jendia, 2000). Figure (3.7) shows the envelope of ASTM D 3515-01 binder dense gradation and used aggregate gradation.

Each aggregate sample was blended for each specimen separately. Aggregate are first dried to constant weight at 110±5 ºC. The aggregates are then heated to a temperature of 135 ºC before mixing with asphalt cement. Asphalt was heated up to 145 ºC prior mixing. Pre-heated asphalt was avoided and excess heated asphalt was disposed of to avoid variability in the asphalt properties. The required content of asphalt was then added to the heated aggregate and mixed thoroughly for at least three minutes and until a homogenous mix is obtained. Standard Marshall molds were heated in an oven up to 130 ºC. The hot mix is placed in the mold and compacted with 75 blows for each face of specimen.

3.7 Determining the Optimum Values

Marshall Stability test is used in this study for both determining the Optimum Bitumen Content (OBC) and evaluation the specimens of were natural sand replaced Trabia. Marshall Method is essentially an empirical method and it is useful in comparing mixtures under specific conditions. This method covers the measurement of the resistance to plastic flow of cylindrical specimens of bituminous paving mixture loaded on the lateral surface by means of the Marshall apparatus according to ASTM D 1559-89. The prepared mixture was placed in preheated mold 4inch (101.6mm) in diameter by 2.5 inch (63.5mm) in height, and compacted with 75 blows for each face of specimen. The specimens were then left to cool at room temperature for 24 hours. Marshall stability, density, flow, unit weight and specific gravity tests were performed on each specimen, where the cylindrical specimen was placed in water path at 60 ºC for 30 to 40 minutes then compressed on the lateral surface at constant rate of 2 inch/min. (50.8mm/min.) until the maximum load (failure) is reached. Three specimens for each combination were prepared and the average results were reported. The bulk specific gravity, density, air voids in total mix, and voids filled with bitumen percentages are determined for each specimen.

3.7.1 Optimum Bitumen Content

Marshall Test has been used to determine the optimum binder content. Five percentages of bitumen were examined to determine the best percentage of bitumen for the aggregates used, which include 4, 4.5, 5, 5.5 and 6% by weight of the mix with three samples for each percentage. The optimum binder content is calculated as the average of binder content values that corresponding the maximum stability, maximum density and median percent of air voids (Jendia, 2000). The optimum binder content can be calculated according to the following formula:

$$(OBC)\% = \frac{Bitumen_{Max-Stability} + Bitumen_{Max-Density} + Bitumen_{MED-VA}}{3}$$

3.7.2 Optimum Sand Content

Laboratory tests were conducted to determine the properties of the asphalt mixture and the effect of adding natural sand using Marshall test. All tests were conducted based on the optimum bitumen content. Effect of five percentages of natural sand were investigated, three samples were prepared for each percentage to insure the results consistency.

Following are the procedures for investigating the effect of natural sand content:

1. Natural sand was first procured, cleaned from any debris and then sieved, and tested for unit weight and specific gravity,
2. Five percentage of natural sand were investigated, i.e., 2.5%, 5%, 7.5%, 10% and 15%. Sieve analysis for new mixtures with various sand content are as shown in Figure (3.8),
3. A replacement procedure took place between the natural sand and the Trabia, by adding sand with percentages from step 2 and removing Trabia with the same percentage. Three samples were prepared for each natural sand content,
4. The aggregates are then heated to a temperature of 135 ºC before mixing with bitumen,
5. Asphalt was heated up to 145 ºC prior mixing with aggregates. Pre-heated asphalt was avoided and excess heated asphalt was disposed in order to avoid variability in the asphalt properties,
6. The required amount of asphalt (Optimum content) were then added to the heated aggregate and mixed thoroughly for at least three minutes until a homogenous mix is obtained,

7. Standard Marshall molds were heated in an oven up to 135 ºC and then the hot mix is placed in the mold and compacted with 75 blows for each face of specimen, and finally
8. Specimens are prepared, compacted, and tested according to Marshall Method designated ASTM D 1559-89.

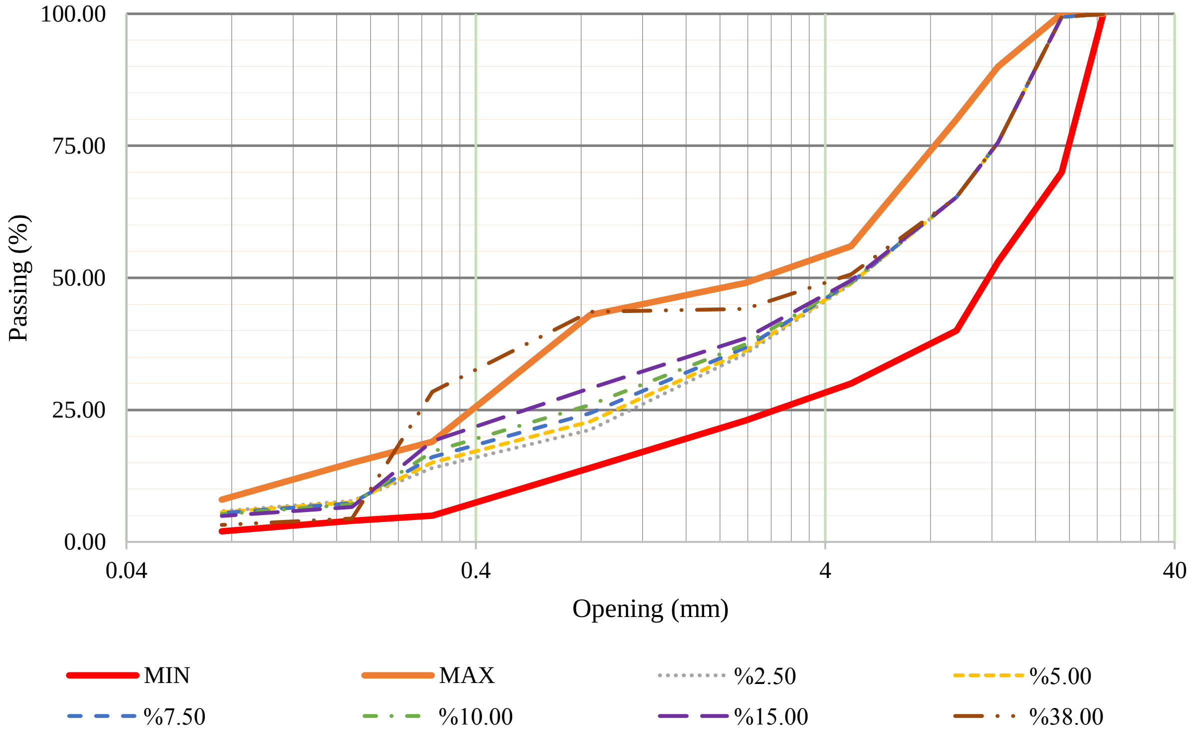

Figure (3.8): ASTM D 3515 Dense Binder Gradation Curves Limits and Aggregates Mixture Gradation Curve for Various Sand Content Replacement (2.50%-38.0%)

The ratio of replacement for Trabia by natural sand was in ascending manner to investigate the effect of adding natural sand on the mechanical properties of asphalt mixtures, were the Trabia percentage was removed, and the same equivalent percentage of sand was introduced (38%). Finally, total replacement of Trabia by natural sand was implemented (38% replacement ratio) to fully investigate the effect of adding natural sand to asphalt mixture.

From this it is found a very distinctive hump is noticed at 38% sand content, this indicates that 38% sand is sensitive and tender (unstable). Aggregate Gradation with 38% sand and higher caused aggregate blending problems by showing definite hump at sieve #30.

Chapter 4

Results Analysis

CHAPTER 4: RESULTS ANALYSIS

4.1 Introduction

This chapter includes the results of the experimental works, which aimed to investigate the effect of adding natural sand to the asphalt mixture, study the mechanical properties of the new mixture and determine the optimum natural sand content. A thorough and detailed discussion for the results will be conducted, including Marshall method for designing asphalt mixtures and determining the optimum bitumen content. A comprehensive evaluation for the specimens were the natural sand were introduced as a replacement for the Trabia. An overall evaluation for the concept of replacing Trabia by natural sand was explained.

It is worth mentioning that the results of this study is only applicable to mixtures with similar material properties to those who have been used in this research.

4.2 Aggregate Mixtures

Both fine and coarse aggregates have been used to prepare the asphalt mixtures. The physical properties of aggregates are listed in Table (3.3). Aggregates were first sieved and gradation test was carried out for each type, separately. Then, a blended mixture containing all types of aggregates were prepared in accordance with the ASTM D3515 limitation to ensure good quality and smooth gradation of the mixture. Table (3.2) shows the particle size distribution for each aggregate that have been used throughout the experimental program, while Table (3.5) and Figure (3.7) shows the mixture gradation in accordance with ASTM limitations.

4.3 Bitumen Experiments Results

Bitumen used in the experimental program was subjected to various testing procedure to determine its physical properties. Those tests are the penetration, ductility, flash point and softening point.

4.3.1 Penetration Test

In accordance with ASTM D5-06, a penetration test was carried out of three samples, with a penetration value (0.1 mm). This test method covers determination of the penetration of semi-solid and solid bituminous materials. The results of the penetration test were within limits. The results are as following:

Table (4.1): Penetration Tests Results

	SAMPLE (1)			SAMPLE (2)			SAMPLE (3)		
Values	63	61	62	60	59	61	60	59	62
Samples Average	62			60			60.33		
Total Average	60.778								

Figure (4.1): Bitumen Samples through the Penetration Test

4.3.2 Specific Gravity test

Based on the ASTM D70 limitation and specifications, the specific gravity test for bitumen was conducted. Results were as following:

- Sample weight (gm) [A]: 145.19
- Weight of Pycnometer + water at 25ºC (gm) [B]: 1783.34
- Weight of Pycnometer + water at 25ºC + Sample (gm) [C]: 1786.92

The Specific Gravity: A/(A+B-C) = 1.03008 g/cm^3. For convenient, the S.G. will be considered to be 1.03 g/cm^3. The results of the specific gravity test were within limits.

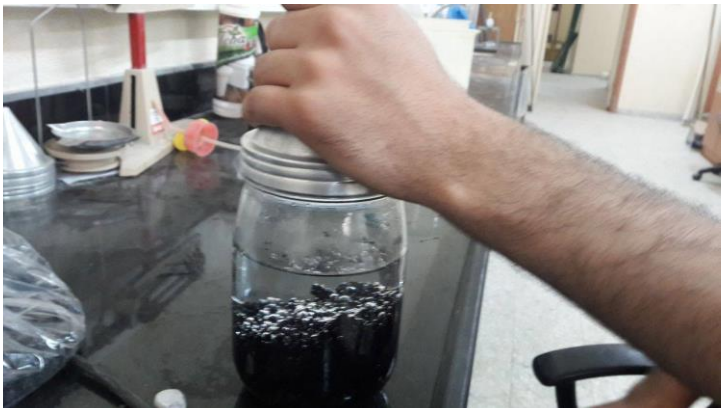

Figure (4.2): Bitumen Samples through the Specific Gravity Test

4.3.3 Ductility Test

In accordance with ASTM D113-86, a ductility test was carried out of three samples. This test method describes the procedure for determining the ductility of a bituminous material measured by the distance to which it will elongate before breaking when two ends of a briquette specimen of the material, are pulled apart at a specified speed and at a specified temperature. Unless otherwise specified, the test shall be made at a temperature of 25 ± 0.5°C and with a speed of 5 cm/min ± 5.0 %, figure (4.3) shown as the Ductility test. The results of the ductility test were within limits. The results are as following:

Table (4.2): Ductility Tests Results

SAMPLE	VALUE
(1)	144
(2)	143
(3)	142
Average	143

Figure (4.3): Bitumen Samples through the Ductility Test

4.3.4 Flash Point

In accordance with ASTM D92-90, a flash point test was carried out of one samples. The flash point is one measure of the tendency of the test specimen to form a flammable mixture with air under controlled laboratory conditions. It is only one of a number of properties that should be considered in assessing the overall flammability hazard of a material, figure (4.4) as shown the flash point test. The results revealed that the value of the flash point for bitumen under consideration is 306 oC. The results of the flash point test were within limits.

Figure (4.4): Bitumen Samples through the Flash Point Test

4.3.5 Softening Point Test

In accordance with ASTM D36-2002, a softening point test was carried out of two samples. This test method covers the determination of the softening point of bitumen in the range from 30 to 157°C (86 to 315°F) using the ring-and-ball apparatus immersed in distilled water (30 to 80°C), USP glycerin (above 80 to 157°C), or ethylene glycol (30 to 110°C), figure (4.5) as shown the softening point test. The results of the flash point test were within limits. The results are as following:

Table (4.3): Softening Point Tests Results

SAMPLE	VALUE
(1)	51.9
(2)	51.9
Average	51.9

Figure (4.5): Bitumen Samples through the Softening Point Test

The following Table summarizes the physical properties of the bitumen that has been used in the experimental program.

Table (4.4): Physical Properties of Bitumen used in the Experimental Program

		ASTM SPECIFICATIONS	
Physical Properties	**Sample**	**Limits**	**Designated**
Penetration [(1/10 mm) – 25 ^oC]	60.7	60-70	ASTM - D5
Ductility (cm)	143	Min 100	ASTM - D113
Flash Point (^oC)	306	Min 230	ASTM - D92
Softening Point (^oC)	51.9	48-56	ASTM - D36

4.4 Determination of Bitumen Optimum Content

Five percentage of bitumen were evaluated, e.g., 4%, 4.5%, 5%, 5.5% and 6%, in order to determine the optimum bitumen content. To do so, Marshall Test method was used.

4.4.1 Marshall Results

Marshall test was carried out on 15 control specimens with different bitumen content. The results are shown in Table (4.5). Results included the following: bulk density (ρA), air voids (%VA), percent volume of bitumen (%Vb), voids mineral aggregates (%VMA) and voids filled with bitumen (%VFB)

Table (4.5): Marshall Tests Results

Bitumen Content (% by total weight)	Sample NO.	Corrected Stability (KG)	Flow (mm)	ρA (KG/cm3)	VA (%)	Vb (%)	VMA (%)
4.0%	1	1925.85	2.60	2304.70	7.35%	8.95%	16.30%
	2	1917.34	2.50	2318.69	7.05%	9.00%	16.05%
	3	1927.77	2.40	2314.28	6.96%	8.99%	15.95%
	Average	1923.65	2.50	2312.56	7.12%	8.98%	16.10%
4.5%	1	1943.52	3.02	2320.68	5.78%	10.14%	15.92%
	2	1957.38	2.66	2328.32	5.47%	10.17%	15.64%
	3	1924.74	2.64	2325.27	5.60%	10.16%	15.76%
	Average	1941.88	2.77	2324.76	5.62%	10.16%	15.77%
5.0%	1	1972.63	3.33	2339.85	4.26%	11.36%	15.62%
	2	1975.54	2.83	2338.95	4.30%	11.35%	15.65%
	3	1976.87	3.10	2340.48	4.24%	11.36%	15.60%
	Average	1975.01	3.09	2339.76	4.27%	11.36%	15.62%
5.5%	1	1961.37	3.61	2324.89	2.70%	12.41%	15.11%
	2	1945.50	2.82	2332.21	2.67%	12.45%	15.12%
	3	1974.22	3.79	2329.96	2.90%	12.44%	15.34%
	Average	1960.36	3.41	2329.02	2.76%	12.44%	15.19%
6.0%	1	1938.69	3.45	2307.45	1.75%	13.44%	15.19%
	2	1942.21	3.47	2321.81	1.72%	13.53%	15.25%
	3	1933.57	3.48	2309.59	1.62%	13.45%	15.07%
	Average	1938.16	3.47	2312.95	1.70%	13.47%	15.17%
5% - VERIFICATION	1	1974.60	3.32	2342.19	4.29%	11.37%	15.66%
	2	1977.12	3.30	2341.29	4.24%	11.37%	15.61%
	3	1978.75	3.27	2342.82	4.30%	11.37%	15.67%
	Average	1976.82	3.30	2342.10	4.28%	11.37%	15.65%

Table (4.6) shows a summarization for the average values of the tested samples against the bitumen content.

Table (4.6): Average Values for Marshall Tests

Bitumen Content (% by total weight)	Corrected Stability	Flow	ρA	*VA*	VMA	VFB
4.0%	1923.65	2.50	2312.56	7.12%	16.10%	53.24
4.5%	1941.88	2.77	2324.76	5.62%	15.77%	59.03
5.0%	1975.01	3.09	2339.76	4.27%	15.62%	67.30
5.5%	1960.36	3.41	2329.02	2.76%	15.19%	83.96
6.0%	1938.16	3.47	2312.95	1.70%	15.17%	87.42

4.4.2 Marshall Stability Index

The stability is considered to be the maximum load subjected to the specimen at failure under constant loading of a rate equal to 50 mm/min (Jendia, 2000). From the results of the Marshall tests and as shown in Figure (4.6), the maximum stability is achieved at 1967 kg with equivalent bitumen content of 5.15%.

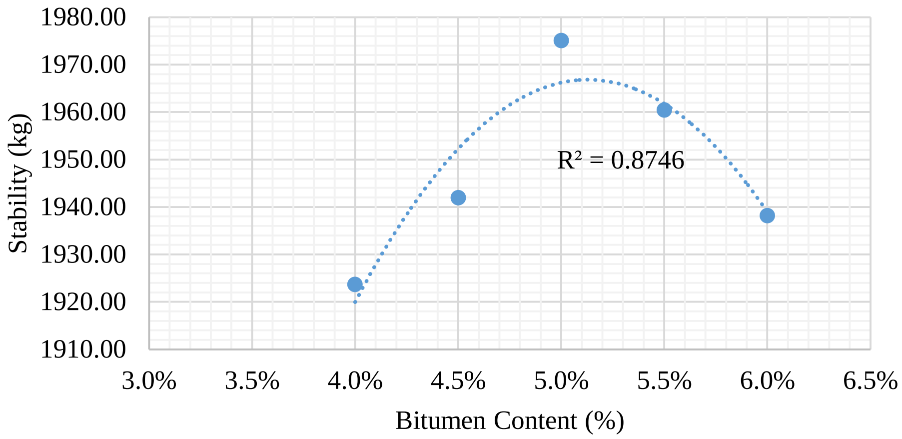

Figure (4.6): Stability VS. Bitumen Content

4.4.3 Flow

Flow is the total amount of deformation which occurs at maximum load (Jendia, 2000). From the results of the Marshall tests and as shown in Figure (4.7) it is noticed that the maximum flow of asphalt mix is at 6.00% bitumen content.

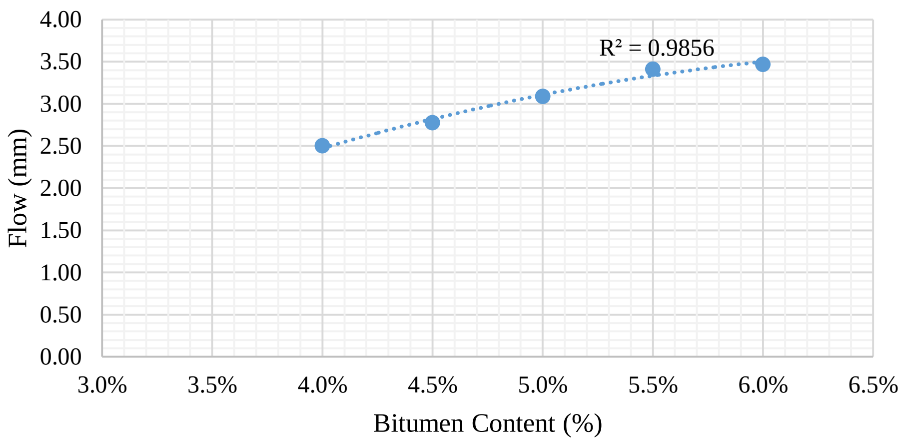

Figure (4.7): Flow VS. Bitumen Content

4.4.4 Bulk Density

Based on the Marshall tests results and as shown in Figure (4.8), the maximum bulk density equals 2336 kg/m3 and is equivalent to a bitumen content of 5.00%.

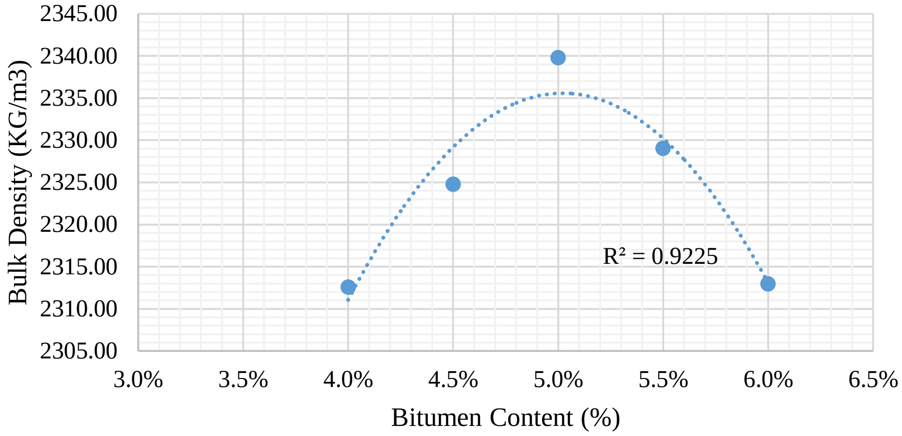

Figure (4.8): Bulk Density VS. Bitumen Content

4.4.5 Air Void Content (Va)

The air voids, Va, is the total volume of the small pockets of air between the coated aggregate particles throughout a compacted paving mixture, expressed as a percent of the bulk volume of the compacted paving mixture (Pratico & Moro, 2012). Results of Marshall Tests indicated that the air voids content decrease in a constant rate as the bitumen content increases. It also revealed that the equivalent air voids for bitumen content of 5% is 4% which is the median value for air voids.

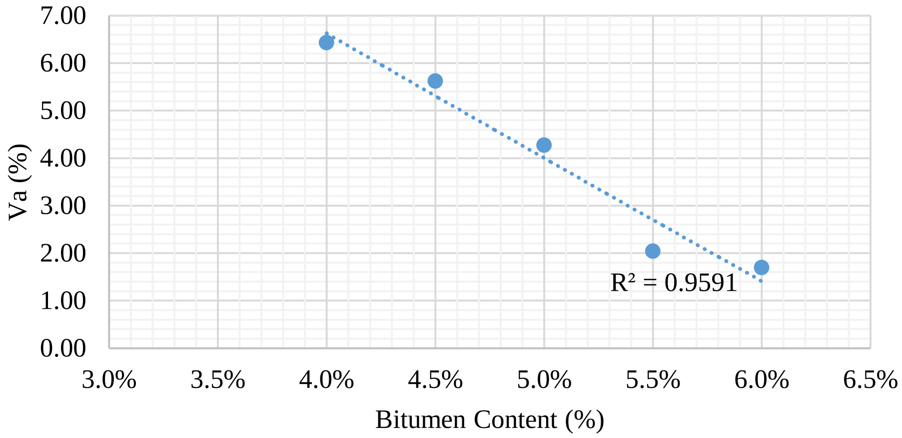

Figure (4.9): Air Void Content (VA-%) VS. Bitumen Content

4.4.6 Voids in Mineral Aggregates (VMA)

The voids in the mineral aggregate, VMA, are defined as the intergranular void space between the aggregate particles in a compacted paving mixture that includes the air voids and the effective bitumen content, expressed as a percent of the total volume (Pratico & Moro, 2012). As shown in Figure (4.10), the percentage of voids in mineral aggregate gradually decrease with the increase of the bitumen content.

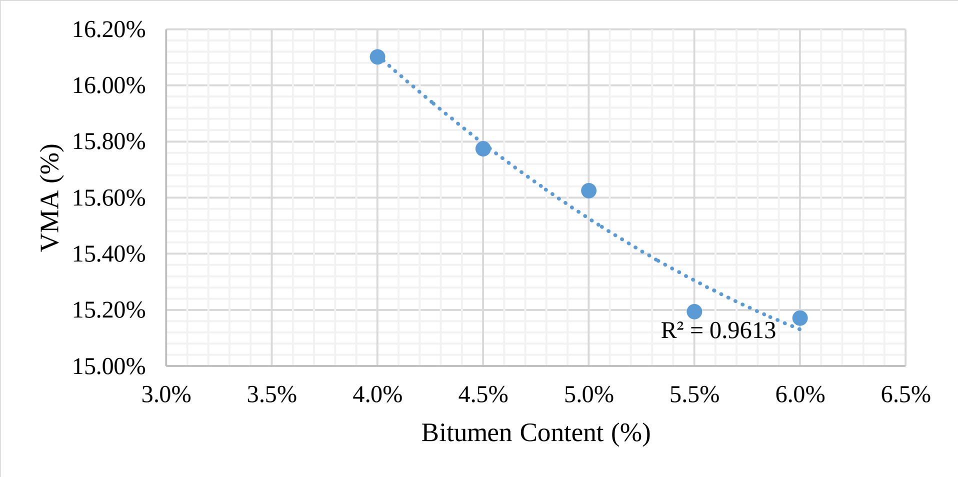

Figure (4.10): Voids in Mineral Aggregates (VMA-%) VS. Bitumen Content

4.4.7 Voids Filled with Bitumen (VFB)

The voids filled with bitumen, VFB, is the percentage of the intergranular void space between the aggregate particles (VMA) that are filled with bitumen (Pratico & Moro, 2012). The experimental results show that the voids filled with bitumen would increase gradually with the bitumen content.

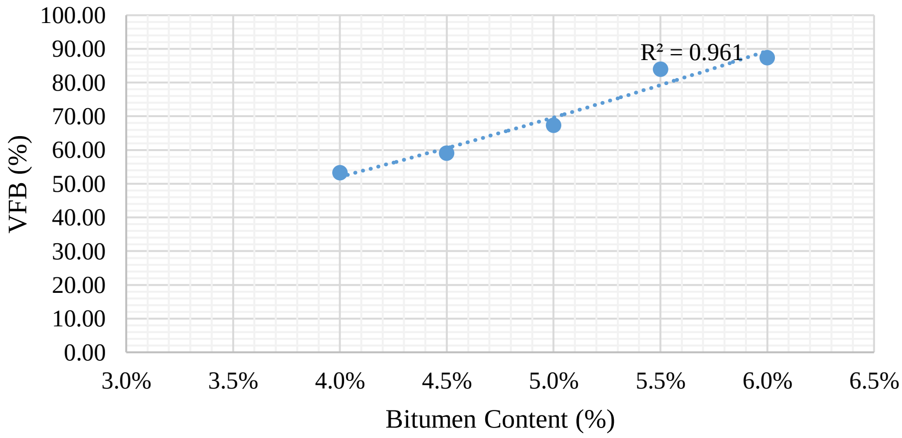

Figure (4.11): Voids Filled with Bitumen (VFB) VS. Bitumen Content

4.4.8 Optimum Bitumen Content (OBC)

Optimum bitumen content is the bitumen content equivalent to the maximum stability, maximum bulk density and median of the air voids, where, those values were founded to be 5.15%, 5% and 4.85%, respectively. Based on the literature review (Jendia, 2000), the OBC is the average values of the aforementioned, which is **5.00% bitumen content**.

Once the optimum bitumen content (OBC) were determined, a verification test was conducted to insure consistent results. The results of the verification tests were as following:

Table (4.7): Verification of Results, 5.00% Bitumen Content

	Sample NO.	Corrected Stability	Flow	ρ_A	V_A	V_b	VMA	VFB
5% - VERIFICATION	1	1974.60	3.32	2342.19	4.29%	11.37%	15.66%	67.32
	2	1977.12	3.30	2341.29	4.24%	11.37%	15.61%	67.13
	3	1978.75	3.27	2342.82	4.30%	11.37%	15.67%	67.46
	Average	1976.82	3.30	2342.10	4.28%	11.37%	15.65%	67.30
Municipality of Gaza Regulations	MAX	900	2	2300.00	3		13	60
	MIN	-	4	-	7		-	75

4.5 Results of Asphalt Mixtures with Natural Sand

Per the methodology presented in chapter three, and to investigate the effect of adding natural sand to the asphalt mixture, a replacement of Trabia by natural sand will be implemented in the following order: 2.5%, 5%, 7.5%, 10%, 15% and 38% by weight, where, 38% replacement ratio means the replacement of all Trabia with Natural Sand.

Marshall test will be used to conduct the samples containing various sand contents at a bitumen content of 5.00% in terms of stability, flow, bulk density, air voids contents, voids in mineral aggregates and voids filled with bitumen.

For each of the natural sand by Trabia replacement ratio, three samples will be tested. The results of each replacement ratio as well as the average results of the entire experimental program (18 samples) are shown in the following subsections.

4.5.1 2.5% Replacement Ratio

First Trabia by Sand replacement ratio was 2.5%. This ratio was chosen to investigate the effect of introducing natural sand at low quantities. The verification results from the experimental program without natural sand we be considered as a control data, as shown in Table (4.7).

Table (4.8): Results for Asphalt Mixture with 2.5% Replacement Ratio

TEST DESCRIPTION	**2.50% - SAND REPLACEMENT**			
	SAMPLE NO			AVERAGE
	1	2	3	
CORRECTED STABILITY [kg]	1798	1711	1620	1709.7
PLASTIC FLOW [mm]	2.31	2.48	3.41	2.7
BULK DRY SPECIFIC GRAVITY [kg/m^3]	2346	2346	2345	2345.8
AIR VOIDS OF TOTAL MIX [V.T.M] %	3.1	3.1	3.1	3.06
PERCENT BITUMEN VOLUME V_B %	11.4	11.4	11.4	11.4
VOIDS OF MINERAL AGG. [V.M.A] %	14.4	14.5	14.5	14.5
VOIDS FILL WITH BITUMEN [V.F.B] %	78.87	78.81	78.71	78.80

As shown in Table (4.8), adding 2.5% natural sand to the mixture did not affect the bulk density, however, a noticeable decrease in the stability value was recorded as well as the flow value and air voids percentage. No significant difference was observed regarding the percent of bitumen volume (V_b), with a slight difference for the values of voids of mineral aggregates (VMA) and voids filled with bitumen (VFB).

4.5.2 5.0% Replacement Ratio

5.0% replacement ratio was considered for the second patch. An equivalent reduction in Trabia percent was considered. The results are as following in table (4.9):

Table (4.9): Results for Asphalt Mixture with 5.0% Replacement Ratio

TEST DESCRIPTION	**5.00% - SAND REPLACEMENT**			
	SAMPLE NO			AVERAGE
	1	2	3	
CORRECTED STABILITY [kg]	1968	2042	2003	2004.5
PLASTIC FLOW [mm]	2.28	2.51	2.33	2.4
BULK DRY SPECIFIC GRAVITY [kg/m^3]	2366	2355	2371	2364.4
AIR VOIDS OF TOTAL MIX [V.T.M] %	3.2	3.7	3.0	3.23
PERCENT BITUMEN VOLUME V_B %	11.5	11.4	11.5	11.5
VOIDS OF MINERAL AGG. [V.M.A] %	14.7	15.1	14.5	14.8
VOIDS FILL WITH BITUMEN [V.F.B] %	78.06	75.62	79.21	77.63

By comparing the aforementioned results to the control data, no noticeable differences were recorded in terms of bulk density and stability values. Yet, the flow value was lower than the value from the control data. The same thing goes for the air voids. No significant difference was recorded regarding the percentage of the bitumen volume (V_b), voids of mineral aggregates (VMA) and voids filled with bitumen (VFB).

4.5.3 7.50% Replacement Ratio

A 7.5% replacement ratio was considered for the third patch; the results are as following in table (4.10):

Table (4.10): Results for Asphalt Mixture with 7.50% Replacement Ratio

TEST DESCRIPTION	**7.50% - SAND REPLACEMENT**			
	SAMPLE NO			AVERAGE
	1	2	3	
CORRECTED STABILITY [kg]	1872	1846	2305	2007.6
PLASTIC FLOW [mm]	2.68	2.70	2.67	2.7
BULK DRY SPECIFIC GRAVITY [kg/m^3]	2382	2381	2383	2381.7
AIR VOIDS OF TOTAL MIX [V.T.M] %	4.0	4.0	3.9	3.97
PERCENT BITUMEN VOLUME V_B %	11.6	11.6	11.6	11.6
VOIDS OF MINERAL AGG. [V.M.A] %	15.5	15.6	15.5	15.5
VOIDS FILL WITH BITUMEN [V.F.B] %	74.46	74.24	74.70	74.46

An increase in both the bulk density and stability values were recorded. The flow value was lower than the value for the control data, however, within limits. Slight differences were recorded in terms of air voids percentage (V_a), bitumen volume percentage (V_b), void of mineral aggregates (VMA) and voids filled with bitumen (VFB).

4.5.4 10% Replacement Ratio

A 10.00% replacement ratio was considered for the fourth patch; the results are as shown in Table (4.11). In terms of bulk density, the mixture with 10% replacement ratio recorded higher value. In terms of stability, the control value recoded a higher value, indicating a negative effect for considering a replacement ratio of 10%. The flow value is lower than the value of the control specimen, however remain nominal. Slight differences were recorded in terms of air voids percentage (V_a), bitumen volume percentage (V_b), void of mineral aggregates (*VMA*) and voids filled with bitumen (*VFB*).

Table (4.11): Results for Asphalt Mixture with 10.00% Replacement Ratio

TEST DESCRIPTION	**10.00% - SAND REPLACEMENT**			
	SAMPLE NO			AVERAGE
	1	2	3	
CORRECTED STABILITY [kg]	1839	1685	2005	1843.2
PLASTIC FLOW [mm]	2.35	2.05	2.44	2.3
BULK DRY SPECIFIC GRAVITY [kg/m^3]	2367	2366	2385	2373.1
AIR VOIDS OF TOTAL MIX [V.T.M] %	3.3	3.4	2.6	3.33
PERCENT BITUMEN VOLUME V_B %	11.5	11.5	11.6	11.5
VOIDS OF MINERAL AGG. [V.M.A] %	14.8	14.9	14.2	14.6
VOIDS FILL WITH BITUMEN [V.F.B] %	77.53	77.32	81.70	78.85

4.5.5 15.00% Replacement Ratio

A 15.00% replacement ratio was considered for the fifth patch; the results are as shown in Table (4.12). In terms of bulk density, the mixture with 15% replacement ratio recorded a slightly higher value. In terms of stability, the control value recoded a higher value, indicating a negative effect for considering a replacement ratio of 15%. The flow value is lower than the value of the control specimen, however remain nominal. Slight differences were recorded in terms of air voids percentage (V_a), bitumen volume percentage (V_b), void of mineral aggregates (*VMA*) and voids filled with bitumen (*VFB*).

4.5.6 38.00% Replacement Ratio

A final patch with 38% replacement ratio was considered. This patch did not contain any Trabia, hence, the ability to investigate the effect of adding natural sand with absence of Trabia. Results as shown in Table (4.13). Results indicated a lower stability value, with almost identical bulk density value. The remaining values are within the limits and close to the control data values.

Table (4.12): Results for Asphalt Mixture with 15.00% Replacement Ratio

TEST DESCRIPTION	15.00% - SAND REPLACEMENT			
	SAMPLE NO			AVERAGE
	1	2	3	
CORRECTED STABILITY [kg]	1798	1711	1620	1843.2
PLASTIC FLOW [mm]	2.21	2.12	2.23	2.3
BULK DRY SPECIFIC GRAVITY [kg/m^3]	2346	2352	2376	2373.1
AIR VOIDS OF TOTAL MIX [V.T.M] %	4.3	4.0	3.0	3.33
PERCENT BITUMEN VOLUME V_B %	11.4	11.4	11.5	11.5
VOIDS OF MINERAL AGG. [V.M.A] %	15.6	15.4	14.6	14.6
VOIDS FILL WITH BITUMEN [V.F.B] %	72.76	74.03	79.22	78.85

Table (4.13): Results for Asphalt Mixture with 38.00% Replacement Ratio

TEST DESCRIPTION	38.00% - SAND REPLACEMENT			
	SAMPLE NO			AVERAGE
	1	2	3	
CORRECTED STABILITY [kg]	1009	978	954	980.0
PLASTIC FLOW [mm]	1.83	1.79	1.75	1.8
BULK DRY SPECIFIC GRAVITY [kg/m^3]	2290	2284	2292	2288.5
AIR VOIDS OF TOTAL MIX [V.T.M] %	6.6	6.8	6.5	6.59
PERCENT BITUMEN VOLUME V_B %	11.1	11.1	11.1	11.1
VOIDS OF MINERAL AGG. [V.M.A] %	17.7	17.9	17.6	17.7
VOIDS FILL WITH BITUMEN [V.F.B] %	62.78	62.00	63.11	62.63

Following is a summarization for the aforementioned results. Appendix "D" contains the extended data of the tests.

Table (4.14): Results for Asphalt Mixture with Various Sand Contents at 5.00% Bitumen Content

TEST DESCRIPTION	Results						LIMITS (Asphalt Institute, 1997)	
	Average Values							
	2.50%	5.00%	7.50%	10.00%	15.00%	38.00%	LOWER	UPPER
CORRECTED STABILITY [kg]	1709.75	2004.50	2007.57	1843.16	1709.75	980.02	900	-
PLASTIC FLOW [mm]	2.73	2.38	2.68	2.28	2.19	1.79	2	4
BULK DRY SPECIFIC GRAVITY [kg/m^3]	2345.84	2364.38	2381.66	2373.13	2357.78	2288.51	2300	
STIFFNESS [kg/mm]	647.83	844.94	748.47	808.80	782.41	547.45	450	
AIR VOIDS OF TOTAL MIX [V.T.M] %	3.06	3.23	3.97	3.33	4.00	6.59	3	7
PERCENT BITUMEN VOLUME V_B %	11.39	11.48	11.56	11.52	11.45	11.11		
VOIDS OF MINERAL AGG. [V.M.A] %	14.45	14.79	15.53	14.62	15.21	17.74	13	-
VOIDS FILL WITH BITUMEN [V.F.B] %	78.80	77.63	74.46	78.85	75.34	62.63	60	75

As shown in Table (4.14), and based on the experimental program results, asphalt mixture with 7.50% natural sand will achieve the maximum stability values of 2007.57 KG in compare to other sand contents. It is clear from the results that all samples managed to exceed the lower limits of the stability value as required per local regulations, which is 900 KG. regarding the flow results, the maximum flow value recorded was 2.73 mm for a sand content of 2.50%.

However, at sand content of 7.50%, the flow value recorded was 2.68 mm. Such values remain within the limits of local regulations.

In terms of air voids (V_a), the median value kept increasing as the natural sand content increases until 7.50%, at which, an air void value of 3.97% was obtained. This value is the closest to the median value of 5.00%. For Voids of Mineral Aggregates (*VMA%*), the minimum value scored was around 2.50% of natural sand content while the maximum value was at 38.00% natural sand content. At a sand content of 7.50%, the value of VMA was nominal and equal to 15.53%, which is above the minimum limitation. Regarding the Voids Filled with Bitumen (*VFB%*), a diverge and unclear pattern was obtained, however, for a sand content of 7.50%, the value of VFB was 74.76%, which is within the acceptable limits. In terms of bulk density, which is a vital assessment criterion for determining the optimum sand content, the maximum value obtain, e.g., 2381.66 kg/m^3, was equivalent to a sand content of 7.50%.It looks 5-8% sand content might give higher stability than control value.

The results of the aforementioned experimental works are described in the Figures (4.12-17).

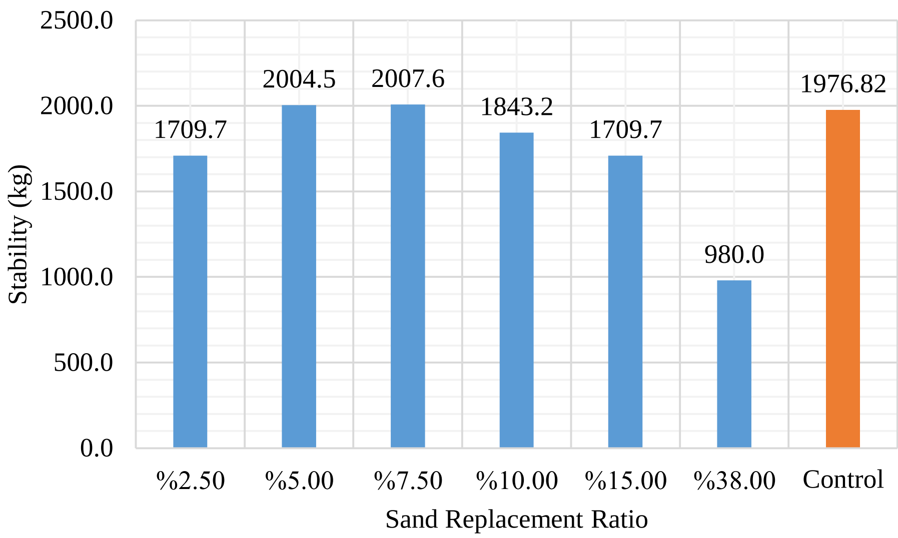

Figure (4.12): Stability Vs. Natural Sand Content

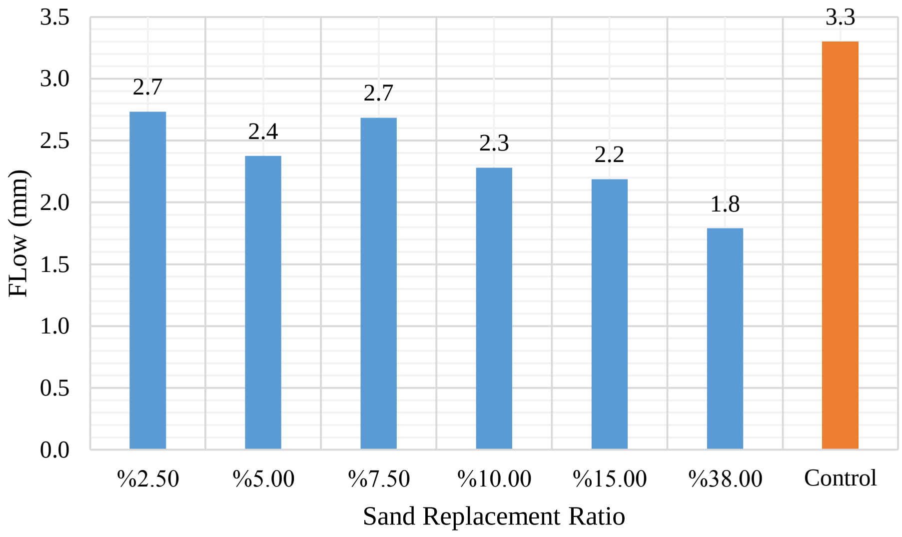

Figure (4.13): Flow Vs. Natural Sand Content

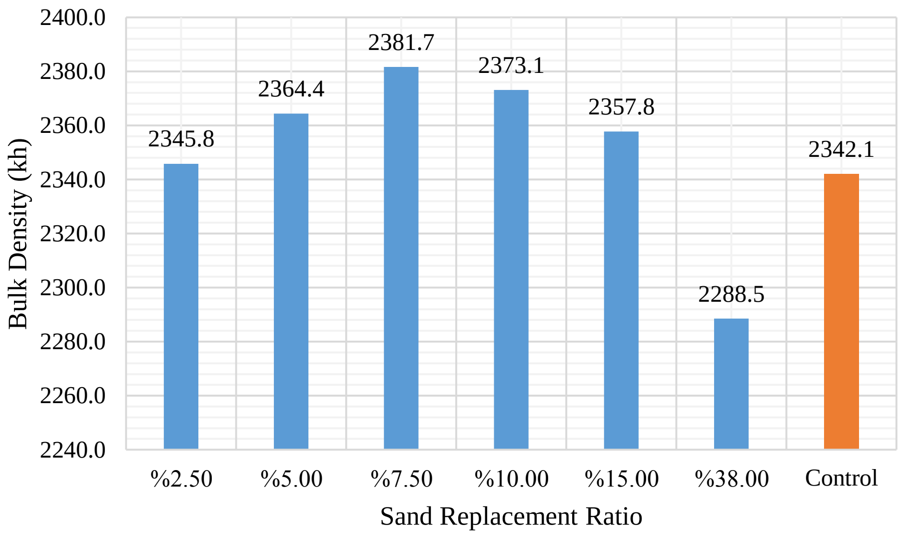

Figure (4.14): Bulk Density Vs. Natural Sand Content

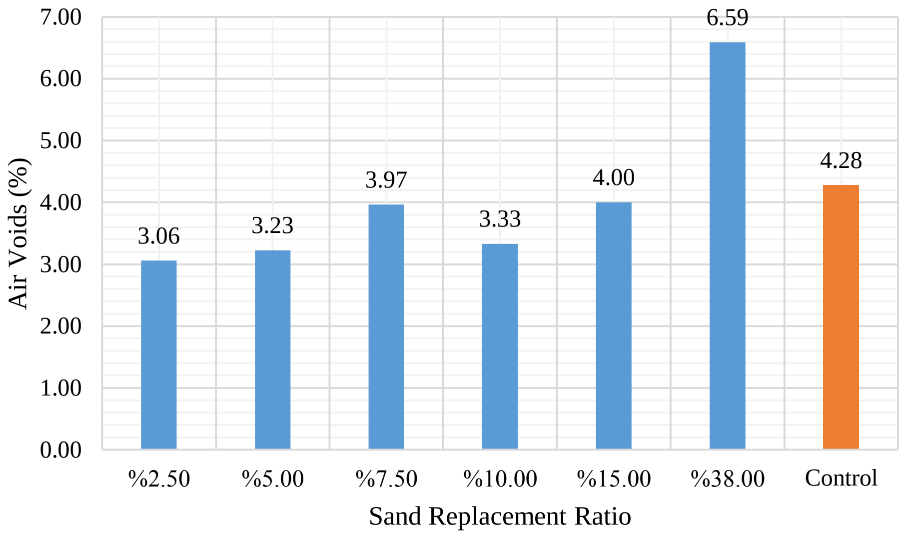

Figure (4.15): Air Voids Vs. Natural Sand Content

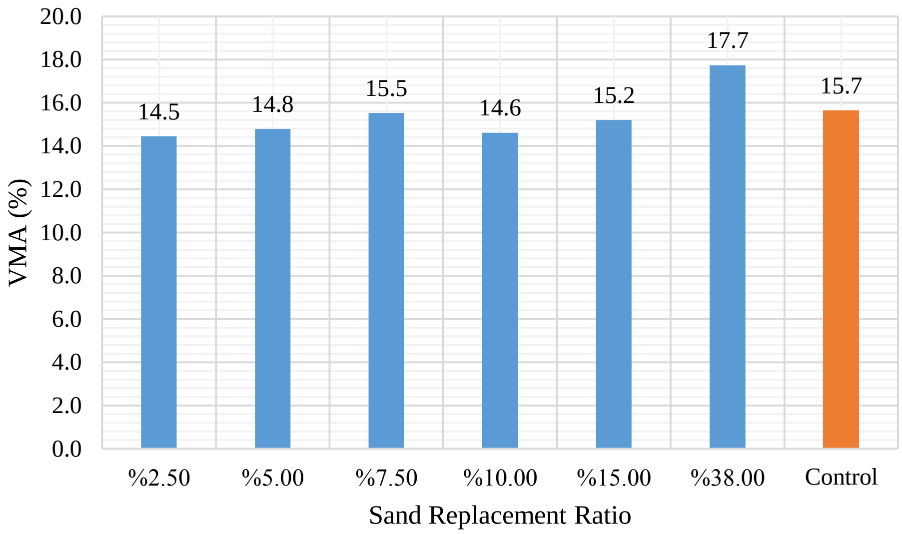

Figure (4.16): Voids of Mineral Aggregates (VMA%) Vs. Natural Sand Content

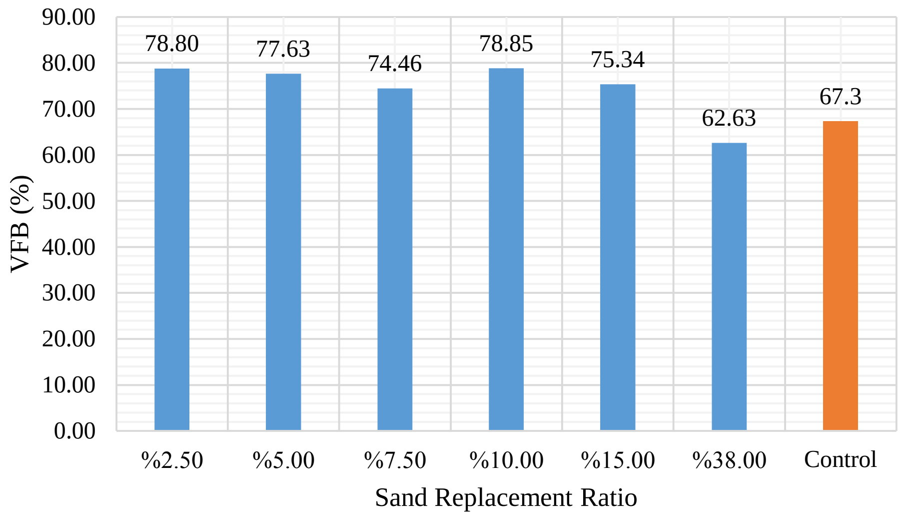

Figure (4.17): Voids Filled with Bitumen (VFB%) Vs. Natural Sand Content

4.5.7 Determining the Optimum Sand Content

Based on the experimental findings, and as shown in Table (4.13) and Figure (4.12), it's clear that all samples exceeded the lower limit of stability value with various level. The maximum value recorded for the stability was at 7.50% natural sand content. Figure (4.15) shows the impact of increasing natural sand content of the percentage of the air voids. With the median value being 5.00%, the closest is at a natural sand content equal to 7.50%. similarly, and as shown in Figure (4.14), the maximum bulk density was 2381.66 kg/m3 and was obtained at natural sand content equal to 7.50%. Based on the aforementioned results, and in terms of stability, air voids percentage and bulk density, a natural sand content of 7.50% yielded the optimum results. Table (4.15) Shows the results of an asphalt mix with a sand replacement ratio equal to 7.50%.

Table (4.15): Optimum Natural Sand Content at 7.50% in comparison to Local Regulations

Property	**7.50% Natural Sand**	**0.00% Natural Sand**	**Municipality of Gaza Specifications**		**International Spec. (Asphalt Institute, 1997)**	
			Min	**Max**	**Min**	**Max**
STABILITY [kg]	2007.6	1975.01	900	-	817	-
PLASTIC FLOW [mm]	2.7	3.09	2	4	2	3.5
BULK DENSITY (kg\m^3)	2381.7	2339.76	2300	-	2300	-
AIR VOIDS OF TOTAL MIX [V.T.M] %	4.0	4.27	3	7	3	5
VOIDS OF MINERAL AGG. [V.M.A] %	15.5	15.62	13.5	-	13	-
VOIDS FILL WITH BITUMEN [V.F.B] %	74.46	67.30	60	75	65	78

4.6 Re-Determine Optimum Bitumen Content

Introducing the natural sand to the asphalt mixture seems to affect the majority of its mechanical properties. And since the main aim of introducing natural sand is to investigate its effect on the mechanical properties, and determine whether it can enhance certain factors or not while maintaining the same cost or lower, it is, then, reasonable to reinvestigate the effect of introducing natural sand, i.e., the optimum content, on the bitumen content, since it is the highest costly ingredient in the asphalt mixture.

Based on the experimental program, a natural sand content of 7.50% would yield the most optimum properties in terms of stability, air voids and bulk density, indicating a suitable replacement ratio of Trabia by natural sand.

To study the effect of adding natural sand on the bitumen content, a follow-up experimental program was carried out on 3 groups of samples with each group consisting of three samples. Each group contains natural sand content of 7.5%, with different bitumen content, i.e., 4%, 4.5% and 5%. The aim of this follow-up experiments is to determine if introducing natural sand content will affect the optimum bitumen content in terms maximum stability, maximum bulk density and median air voids.

An asphalt mixture with 5.00% bitumen content and 7.50% natural sand content is already investigated in the previous experimental work and considered as a control mixture for the reinvestigation process. For this mixture, the average stability value for the three samples was 2007.6 kg, while the average bulk density was 2381.7 kg/m^3, and the average air voids was 4.0%.

Table (4.16) contains the experimental results for the remaining two groups. Results indicated that for a bitumen content with 4.50% and natural sand with 7.50%, the stability value was 1997.1 kg, a lower value compared to the control mixture. The same thing goes for the bulk density with a value of 2364.4 kg/m3 and the air voids content with a value of 3.7%.

For an asphalt mixture with bitumen content of 4.50% and a natural sand content of 7.50%, where was a noticeable drop in the stability value, i.e. 1684.7 kg compared to 2007.6 kg for the control mixture. Moreover, for this bitumen content, a more decreasing rate in the bulk density was noticed with a value of 2336.8 kg/m^3.

Table (4.16): Experimental Results for 4.0% and 4.50% Bitumen Content and 7.50% Natural Sand

TEST DESCRIPTION	4.50% Bitumen Content				4.00% Bitumen Content			
	SAMPLE NO			AVRG	SAMPLE NO			AVRG
	1	2	3		1	2	3	
BULK DRY SPECIFIC GRAVITY [kg/m3]	2517	2449	2451	2472.5	2274	2336	2340	2316.6
CORRECTED STABILITY [kg]	2106	2040	1845	1997.1	1698	1751	1605	1684.7
PLASTIC FLOW [mm]	2.35	2.43	2.10	2.3	2.31	2.44	2.32	2.4
STIFFNESS [kg/mm]	896	840	879	871.5	735	718	692	714.8
AIR VOIDS OF TOTAL MIX [V.T.M] %	4.3	5.7	5.6	5.2	7.8	5.2	5.1	6.0
PERCENT BITUMEN VOLUME VB %	11.0	10.7	10.7	10.8	8.8	9.1	9.1	9.0
VOIDS OF MINERAL AGG. [V.M.A] %	15.3	16.4	16.3	16.0	16.6	14.3	14.2	15.0
VOIDS FILL WITH BITUMEN [V.F.B] %	71.94	65.25	65.60	67.6	53.22	63.51	64.16	60.3

The optimum content is based on bitumen content corresponding to three criteria, 1. The maximum stability value, 2. The maximum bulk density value and 3. The median value for the air voids (Jendia, 2000).

Based on the results and using MS-EXCEL regression tools and as shown in the figures below, the following results were obtained:

1. The maximum stability value is 2007.6 kg, corresponding to 5.00% bitumen content,
2. The maximum bulk density value is 2474 kg/m^3, corresponding to 4.55% bitumen content,
3. The median air voids value is 5.60%, corresponding to 4.25% bitumen content.

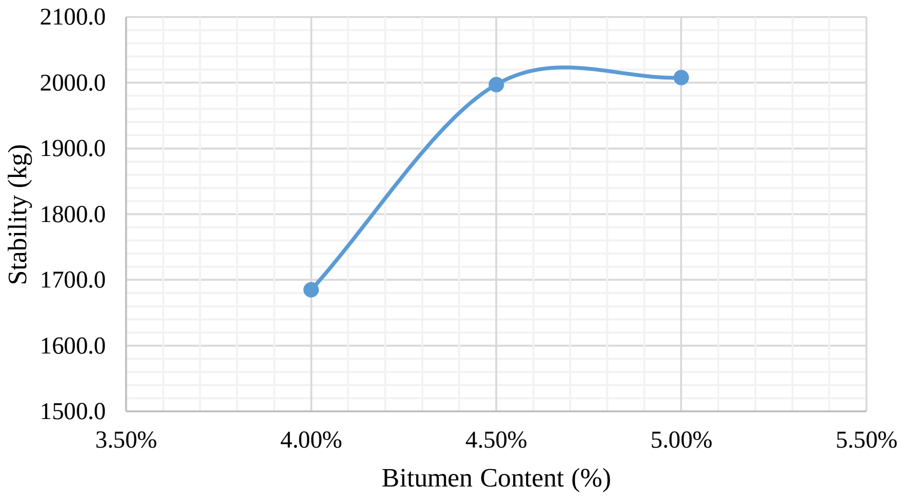

Figure (4.18): Stability VS. Bitumen Content at 7.50% Natural Sand

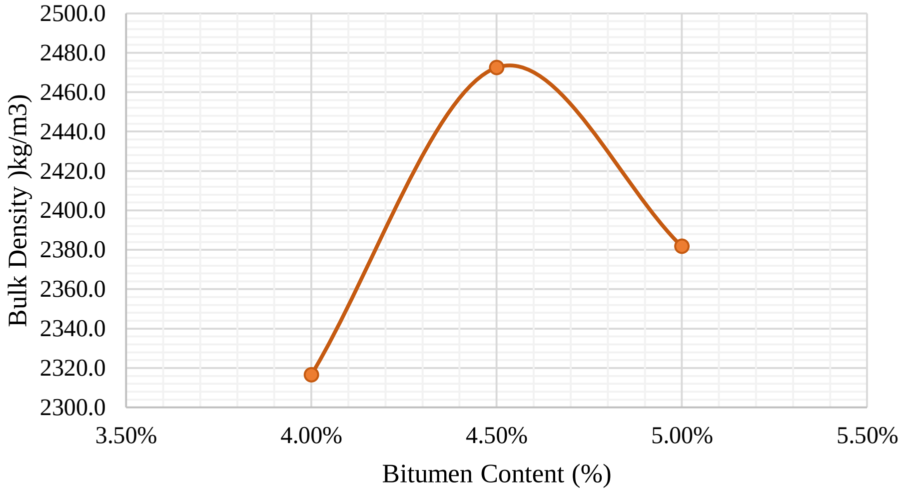

Figure (4.19): Bulk Density VS. Bitumen Content at 7.50% Natural Sand

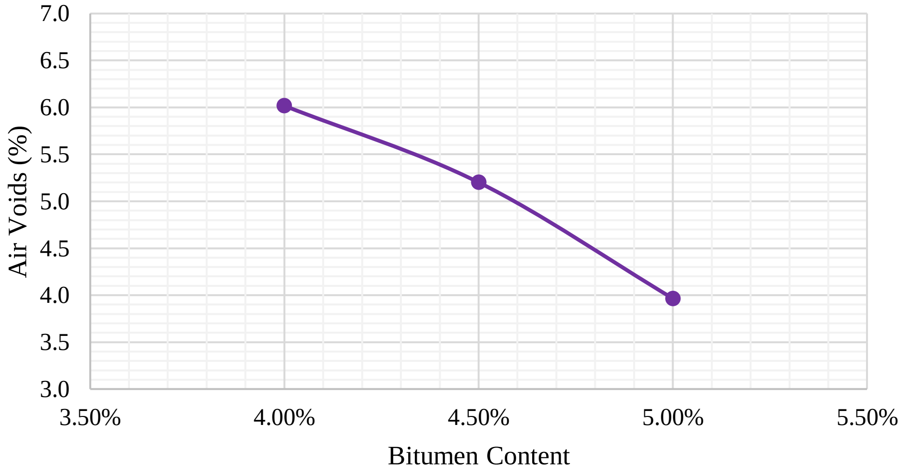

Figure (4.20): Air Voids VS. Bitumen Content at 7.50% Natural Sand

Using the following equation to determine the OBC for an asphalt mixture with 7.5% natural sand content:

$$(OBC)\% = \frac{Bitumen_{Max-Stability} + Bitumen_{Max-Density} + Bitumen_{MED-VA}}{3}$$

$$= \frac{5.00 + 4.55 + 4.25}{3} = 4.60\%$$

Therefore, adding the optimum natural sand content, i.e., 7.5%, to the asphalt mixture led to a decrease in the optimum bitumen content from 5.00% to 4.60% while a noticeable improvement was recorded for certain mechanical properties like the bulk density, and to a certain level, the stability value.

Chapter 5

Conclusion and Recommendations

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The main goal of this study is to investigate the effect of replacing Trabia by natural sand on the mechanical properties of the asphalt mixture. With the results obtained from the experimental works, the following conclusions can be drawn:

1. From the environmental prospective, adding natural sand to the asphalt mixture would not produce a hazardous material, since the sand is an ecofriendly fine aggregate,
2. Natural sand can be used to replace Trabia as a fine aggregate and yield enhanced mechanical properties,
3. When compared to the control specimen, i.e., no natural sand content, the asphalt mixture with Trabia by natural sand replacement yielded more desirable results in terms of stability,
4. A slight increase in the bulk density took place by introducing the natural sand as a replacement for the Trabia fine aggregate,
5. In terms of Voids Filled with Bitumen and Voids of Mineral Aggregates, a significant increase was recorded by introducing the natural sand as a replacement for the Trabia fine aggregate,
6. Natural sand replacement ratio of 7.50% yield the optimum mechanical properties in terms of stability, bulk density, median aid voids, voids of mineral aggregates and voids filled with bitumen,
7. A modified optimum bitumen content of 4.6% were obtained for asphalt mixtures with 7.50% natural sand replacement ratio,
8. All the mechanical properties of the asphalt mixture with natural sand replacement ratio of 7.50% lays with the local regulation limitations,
9. Replacement ratio of 5-8% natural sand would still yield satisfactory results,
10. The results of this study are only applicable to the same gradation of the aggregates.

5.2 Recommendations

1. More researches are needed to study the effect of natural sand in base course and wearing course layers of asphalt pavement,
2. More researches are needed to study the effect of various natural sand types,
3. Based on the findings of this research, we strongly recommend using asphalt mixture with embedded natural sand content in real-life application to assess its long term behavior.
4. It is recommended to examine the asphalt mixture with 38% natural sand content in paved agricultural roads, and assess its long term behavior. 38.0% replacement ratio would not yield the optimum mechanical properties for the asphalt mixture, but it's feasible from an economical point of view. In addition, agricultural roads are not subjected in general to high traffic loads.

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Appendices

Appendix "A"

Aggregates Physical Properties

Specific Gravity (ASTM C127) and absorption (ASTM C128)

Consider the following:
A = Weight of oven-dry sample in air (grams)
B = Weight of saturated - surface -dry sample in air (grams)
C = Weight of saturated sample in water (grams)

- *Bulk Dry (S.G.) =* ***A/(B-C)***
- *Saturated Surface Dry (SSD) S.G. =* ***B/(B-C)***
- *Apparent S.G. =* ***A/(A-C)***
- *Effective S.G. =* ***[Bulk$_{(dry)}$ + Apparent]/2***
- *Absorption =* ***[(B-A)/A] *100***

1.1 Coarse aggregate (Folia 0/19)

A: 1546.8 grams
B: 1580.59 grams
C: 969.18 grams

- *Bulk Dry (S.G.): 2.53*
- *(SSD) S.G: 2.59*
- *Apparent S.G.: 2.68*
- *Effective S.G.: 2.60*
- *Absorption: 2.18%*

1.2 Coarse aggregate (Adasia 0/12.5)

A: 1190.4 grams
B: 1208.92 grams
C: 751.1 grams

- *Bulk Dry (S.G.): 2.60*
- *(SSD) S.G: 2.64*
- *Apparent S.G.: 2.71*
- *Effective S.G.: 2.65*
- *Absorption: 1.56%*

1.3 Coarse Aggregate (Simsimia 0/9.5)

A: 1188.2 grams
B: 1214.21 grams
C: 743.1 grams

- *Bulk Dry (S.G.): 2.52*
- *(SSD) S.G: 2.58*
- *Apparent S.G.: 2.67*
- *Effective S.G.: 2.60*
- *Absorption: 2.19%*

1.4 Fine Coarse (Trabia 0/4.75)

A: 488.9 grams
B: 500 grams
C: 313.9 grams

- *Bulk Dry (S.G.): 2.63*
- *(SSD) S.G: 2.69*

- *Apparent S.G.:* *2.79*
- *Effective S.G.: 2.71*
- *Absorption:* *2.27%*

1.5 Fine Coarse (Sand 0/0.6)

A: 496.5 grams
B: 500.2 grams
C: 307.8 grams

- *Bulk Dry (S.G.):* *2.58*
- *(SSD) S.G:* *2.60*
- *Apparent S.G.:* *2.63*
- *Effective S.G.: 2.61*
- *Absorption:* *0.75%*

the following table summarizes the physical properties of the aggregates.

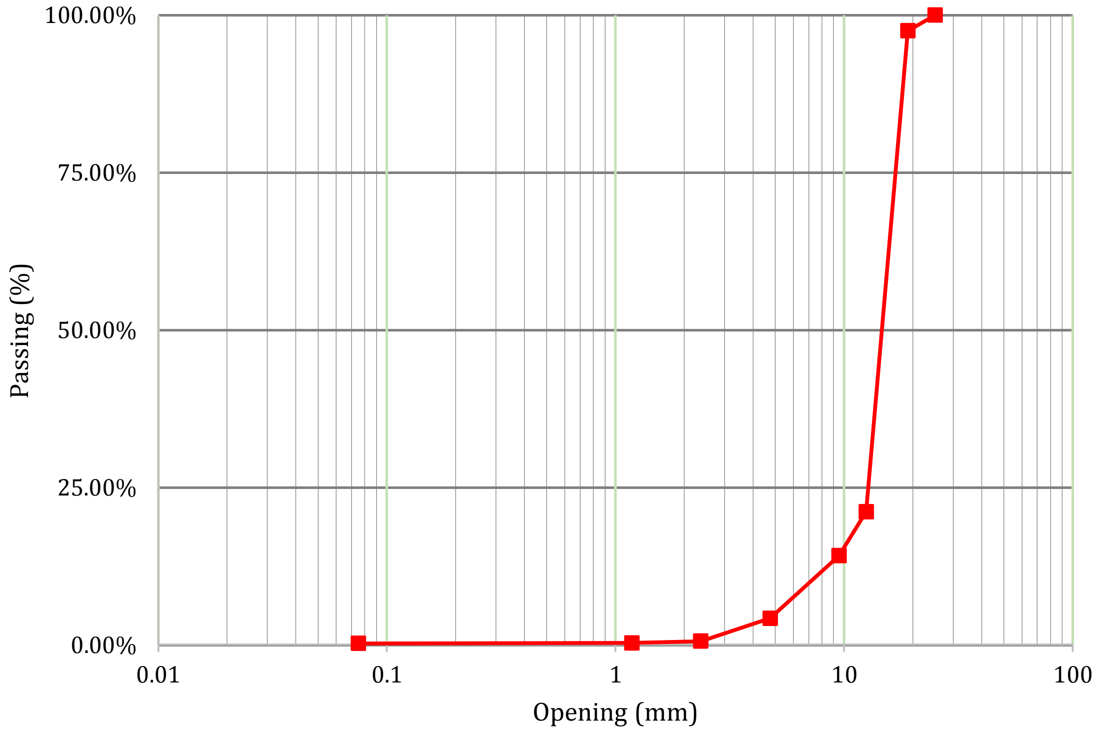
Physical Properties	Folia (0/19.0)	Adasia (0/12.5)	Simsimia (0/9.5)	Trabia (0/4.75)	Sand (0/0.6)
Bulk Dry (S.G.)	2.53	2.60	2.52	2.63	2.58
(SSD) S. G	2.59	2.64	2.58	2.69	2.60
Apparent S.G.	2.68	2.71	2.67	2.79	2.63
Effective S.G.	2.60	2.65	2.60	2.71	2.61
Absorption:	2.18%	1.56%	2.19%	2.27%	0.75%

Appendix "B"

Aggregates Sieve Analysis

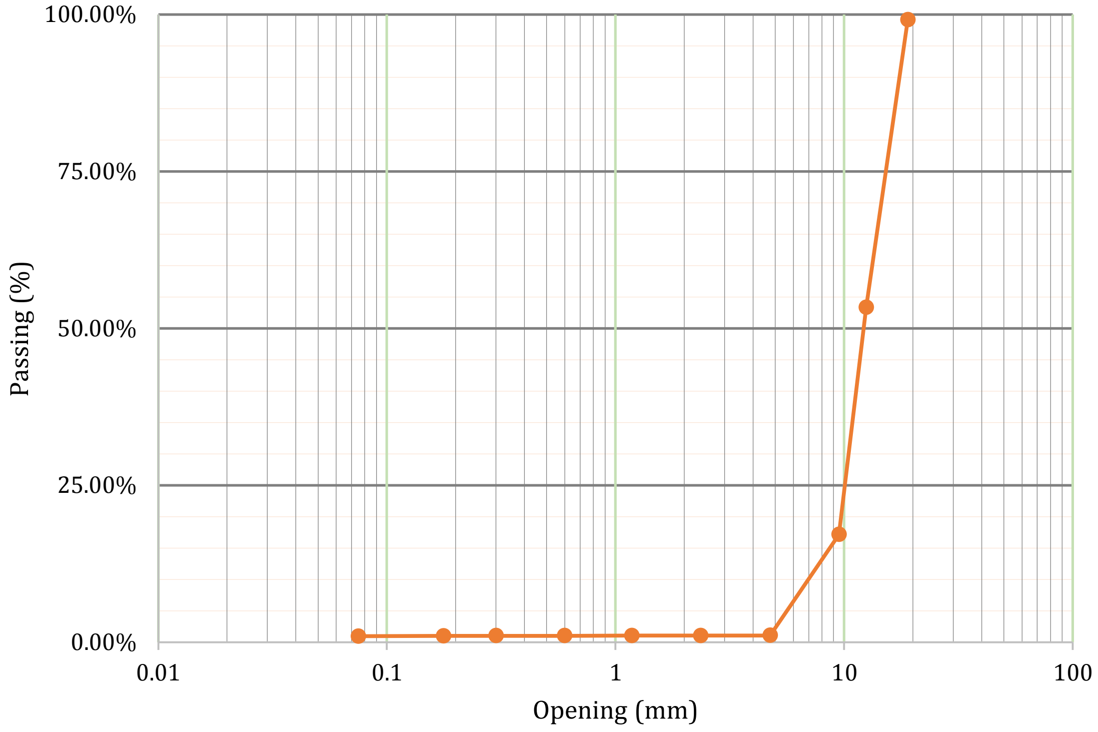
B.1 Coarse aggregate (Folia 0/19)

FOLIYA (0/19.0)				
SIEVE NO	OPENING (mm)	Cumulative Retained (Grams)	Cumulative Retained (%)	Passing (%)
1''	25	0	0.00%	100.00%
3/4''	19	63.2	2.50%	97.50%
1/2''	12.5	1993.8	78.84%	21.16%
3/8''	9.5	2170.9	85.84%	14.16%
#4	4.75	2422.1	95.77%	4.23%
# 10	2.36	2514.1	99.41%	0.59%
# 16	1.18	2521	99.68%	0.32%
# 200	0.075	2522.8	99.75%	0.25%
PAN		2529	100.00%	0.00%



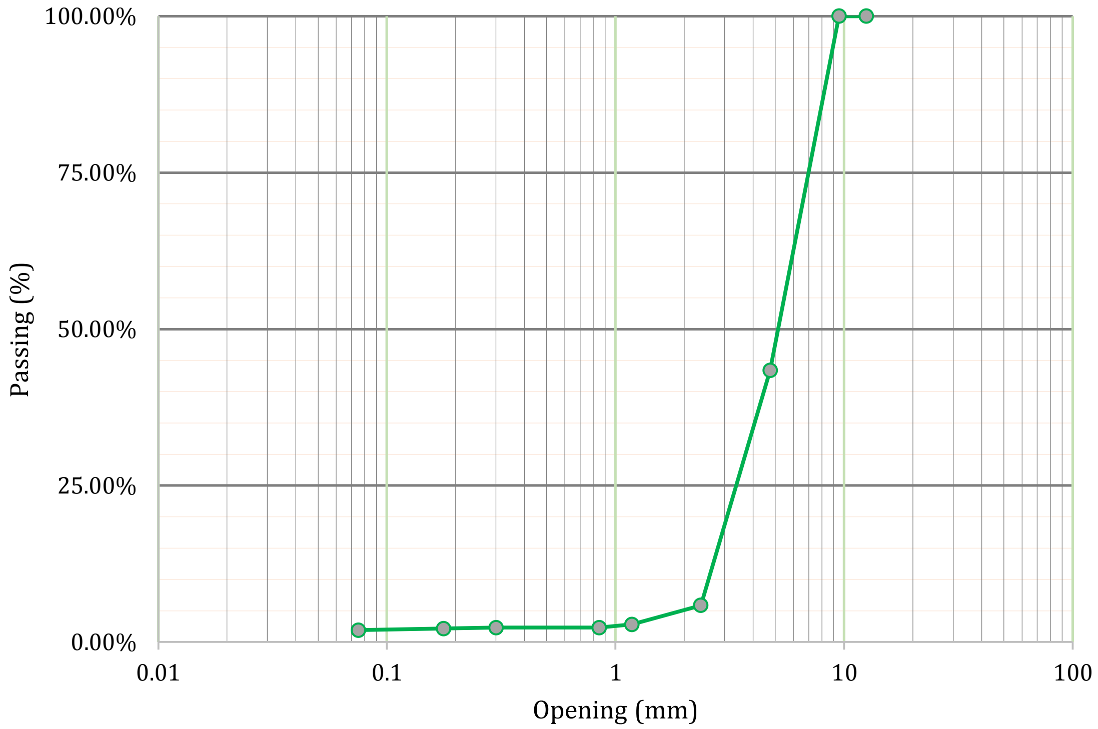
B.2 Coarse aggregate (Adasia 0/12.5)

ADASIA (0/12.5)				
SIEVE NO	OPENING (mm)	Cumulative Retained (Grams)	Cumulative Retained (%)	Passing (%)
1''	25	0	0.00%	100.00%
3/4''	19	12.6	0.84%	99.16%
1/2''	12.5	699.9	46.66%	53.34%
3/8''	9.5	1242.3	82.82%	17.18%
#4	4.75	1483.3	98.89%	1.11%
# 8	2.36	1483.7	98.91%	1.09%
# 16	1.18	1483.8	98.92%	1.08%
#30	0.6	1484.1	98.94%	1.06%
#50	0.3	1484.1	98.94%	1.06%
#80	0.177	1484.6	98.97%	1.03%
#200	0.075	1485.3	99.02%	0.98%
PAN		1500	100.00%	0.00%



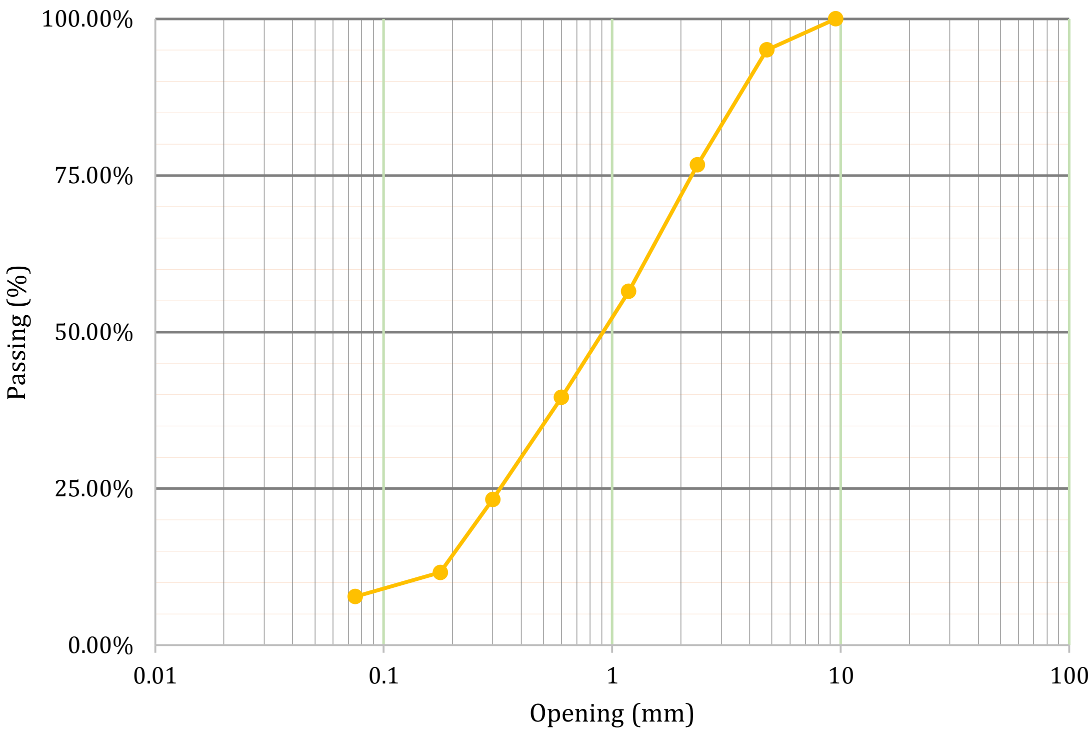
B.3 Coarse Aggregate (Simsimia 0/9.5)

Simsimia (0/9.5)				
SIEVE NO	OPENING (mm)	Cumulative Retained (Grams)	Cumulative Retained (%)	Passing (%)
1/2"	12.5	0	0.00%	100.00%
3/8''	9.5	0	0.00%	100.00%
#4	4.75	566.2	56.62%	43.38%
# 8	2.36	941.4	94.14%	5.86%
#16	1.18	971.8	97.18%	2.82%
#20	0.85	976.9	97.69%	2.31%
#50	0.3	977	97.70%	2.30%
#80	0.177	978.4	97.84%	2.16%
#200	0.075	981	98.10%	1.90%
PAN		1000	100.00%	0.00%



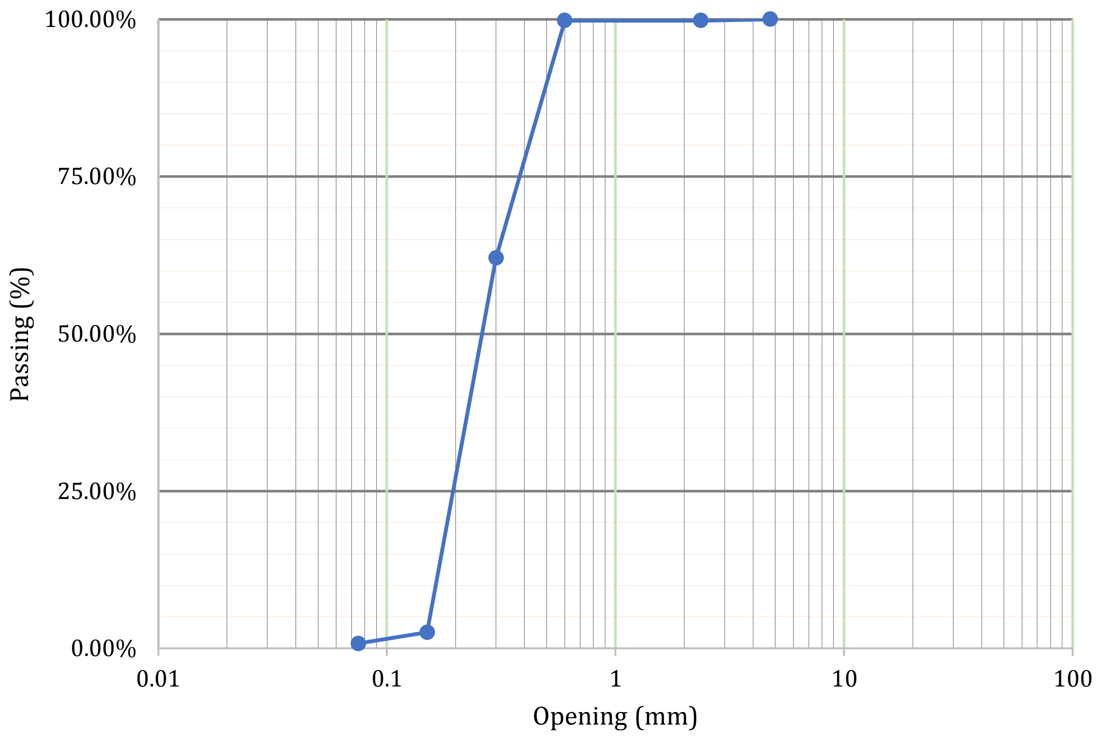
B.4 Fine Coarse (Trabia 0/4.75)

TRABIA (0/4.75)				
SIEVE NO	OPENING (mm)	Cumulative Retained (Grams)	Cumulative Retained (%)	Passing (%)
3/8''	9.5	0	0.00%	100.00%
#4	4.75	39.7	4.96%	95.04%
# 8	2.36	186.6	23.30%	76.70%
#16	1.18	348.5	43.51%	56.49%
#20	0.6	484.1	60.44%	39.56%
#50	0.3	614.6	76.73%	23.27%
#80	0.177	707.9	88.38%	11.62%
#200	0.075	738.8	92.23%	7.77%
PAN		801	100.00%	0.00%



B.5 Fine Coarse (Sand 0/0.6)

SAND (0/0.6)				
SIEVE NO	OPENING (mm)	Cumulative Retained (Grams)	Cumulative Retained (%)	Passing (%)
#4	4.75	0	0.00%	100.00%
# 10	2.36	1.1	0.22%	99.78%
#25	0.6	1.1	0.22%	99.78%
#40	0.3	190.1	37.96%	62.04%
#100	0.15	488	97.44%	2.56%
#200	0.075	497	99.24%	0.76%
PAN		500.8	100.00%	0.00%



Appendix "C"

Aggregate Blending

Aggregate Type	#	Grain Size [mm]													Proposed Percentage
		0.075	0.075/0.15	0.15/0.3	0.3/0.425	0.425/0.6	0.6/1.18	1.18/2.36	2.36/4.75	4.75/9.5	9.5/12.5	12.5/19	19/25	Sum	
Filler	1	76.55	12.45	9.25	1.35	0	0.4	0	0	0	0	0	0	0.4	3.14%
	2	2.40	0.39	0.29	0.04	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00		
Trabia	3	7.77	3.86	11.65	0.00	16.29	16.93	20.21	18.34	4.96	0.00	0.00	0.00	100	39.79%
	4	3.09	1.53	4.63	0.00	6.48	6.74	8.04	7.30	1.97	0.00	0.00	0.00		
Natural Sand	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00%
	6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
Simimia	7	1.9	0.26	0.14	0	0	0.51	3.04	37.52	56.62	0	0	0	99.99	15.71%
	8	0.30	0.04	0.02	0.00	0.00	0.08	0.48	5.89	8.90	0.00	0.00	0.00		
Adasia	9	0.98	0.05	0.03	0	0	0.02	0.01	0.03	16.07	36.16	45.82	0.84	100.00	25.65%
	10	0.25	0.01	0.01	0.00	0.00	0.01	0.00	0.01	4.12	9.28	11.75	0.22		
Folia	11	0.25	0	0	0	0	0.07	0.27	3.64	9.93	7.00	76.34	2.50	100.00	15.71%
	12	0.04	0.00	0.00	0.00	0.00	0.01	0.04	0.57	1.56	1.10	11.99	0.39		
Summation		6.08	1.98	4.96	0.04	6.48	6.84	8.56	13.77	16.55	10.38	23.75	0.61	100.0	
Passing (%)		6.1	8.1	13.0	13.1	19.5	26.4	35.0	48.7	65.3	75.6	99.4	100.0		
Sieve Size (mm)		0.075	0.15	0.3	0.425	0.6	1.18	2.36	4.75	9.5	12.5	19	25		
Minimum (%)		2	3	5	6	8	15	23	35	56	67	90	100	ASTM Specifications D3515-01	
Maximum (%)		8	14	19	22	26	37	49	65	80	85	100	100		
Check (Within Limits)		TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE		

Appendix "D"

Asphalt Mix Test Results

- Natural Sand content = 2.5% (By weight of total aggregates)
- No. of blows on each side: 75 blow
- 3/4" binder course mix
- Bitumen = 5.0 % (By total weight)
- Mixing temperature: 150 ºC

TEST DESCRIPTION	**2.50% - SAND REPLACEMENT**			
	SAMPLE NO			AVERAGE
	1	2	3	
WEIGHT OF SAMPLE IN AIR [gm]	1199.4	1205.3	1206.8	1203.8
WEIGHT OF SAMPLE SSD [gm]	1201.1	1207.4	1209.4	1206.0
WEIGHT OF SAMPLE IN WATER [gm]	689.9	693.6	694.9	692.8
SAMPLE VOLUME [cm^3]	511.2	513.8	514.5	513.2
BULK DRY SPECIFIC GRAVITY [kg/m^3]	2346	2346	2345	2345.8
% BITUMEN CONTENT OF TOTAL MIX %	5.00	5.00	5.00	5.0
BITUMEN DENSITY AT 25 °C [g/cm^3]	1.03	1.03	1.03	1.0
MAX SPECIFIC GRAVITY [kg/m^3]	2420	2420	2420	2420.0
MARSHALL STABILITY READING [DIV]	1322.2	1258	1191	1257.2
STABILITY CORRECTION FACTOR	1.0	1.0	1.0	1.0
CORRECTED STABILITY [kg]	1798	1711	1620	1709.7
PLASTIC FLOW [mm]	2.31	2.48	3.41	2.7
STIFFNESS [kg/mm]	778	690	475	647.8
AIR VOIDS OF TOTAL MIX [V.T.M] %	3.1	3.1	3.1	3.06
PERCENT BITUMEN VOLUME V_B %	11.4	11.4	11.4	11.4
VOIDS OF MINERAL AGG. [V.M.A] %	14.4	14.5	14.5	14.5
VOIDS FILL WITH BITUMEN [V.F.B] %	78.87	78.81	78.71	78.80

- Natural Sand content = 5.00 % (By weight of total aggregates)
- No. of blows on each side: 75 blow
- 3/4" binder course mix
- Bitumen = 5.0 % (By total weight)
- Mixing temperature: 150 ºC

TEST DESCRIPTION	**5.00% - SAND REPLACEMENT**			
	SAMPLE NO			AVERAGE
	1	2	3	
WEIGHT OF SAMPLE IN AIR [gm]	1205.2	1196.0	1203.5	1201.6
WEIGHT OF SAMPLE SSD [gm]	1206.3	1198.1	1205.3	1203.2
WEIGHT OF SAMPLE IN WATER [gm]	697.0	690.3	697.8	695.0
SAMPLE VOLUME [cm^3]	509.3	507.8	507.5	508.2
BULK DRY SPECIFIC GRAVITY [kg/m^3]	2366	2355	2371	2364.4
% BITUMEN CONTENT OF TOTAL MIX %	5.00	5.00	5.00	5.0
BITUMEN DENSITY AT 25 °C [g/cm^3]	1.03	1.03	1.03	1.0
MAX SPECIFIC GRAVITY [kg/m^3]	2445	2445	2445	2445.4
MARSHALL STABILITY READING [DIV]	1447.3	1502	1472.6	1473.9
STABILITY CORRECTION FACTOR	1.0	1.0	1.0	1.0
CORRECTED STABILITY [kg]	1968	2042	2003	2004.5
PLASTIC FLOW [mm]	2.28	2.51	2.33	2.4
STIFFNESS [kg/mm]	863	813	858	844.9
AIR VOIDS OF TOTAL MIX [V.T.M] %	3.2	3.7	3.0	3.23
PERCENT BITUMEN VOLUME V_B %	11.5	11.4	11.5	11.5
VOIDS OF MINERAL AGG. [V.M.A] %	14.7	15.1	14.5	14.8
VOIDS FILL WITH BITUMEN [V.F.B] %	78.06	75.62	79.21	77.63

- Natural Sand content = 7.5 % (By weight of total aggregates)
- No. of blows on each side: 75 blow
- 3/4" binder course mix
- Bitumen = 5.0 % (By total weight)
- Mixing temperature: 150 ºC

TEST DESCRIPTION	**7.50% - SAND REPLACEMENT**			
	SAMPLE NO			AVERAGE
	1	2	3	
WEIGHT OF SAMPLE IN AIR [gm]	1203.8	1213.8	1216.2	1211.3
WEIGHT OF SAMPLE SSD [gm]	1199.5	1210.5	1211.4	1207.1
WEIGHT OF SAMPLE IN WATER [gm]	694.0	700.6	701.0	698.5
SAMPLE VOLUME [cm^3]	505.5	509.9	510.4	508.6
BULK DRY SPECIFIC GRAVITY [kg/m^3]	2382	2381	2383	2381.7
% BITUMEN CONTENT OF TOTAL MIX %	5.00	5.00	5.00	5.0
BITUMEN DENSITY AT 25 °C [g/cm^3]	1.03	1.03	1.03	1.0
MAX SPECIFIC GRAVITY [kg/m^3]	2480	2480	2480	2480.0
MARSHALL STABILITY READING [DIV]	1376.37	1357	1694.76	1476.2
STABILITY CORRECTION FACTOR	1.0	1.0	1.0	1.0
CORRECTED STABILITY [kg]	1872	1846	2305	2007.6
PLASTIC FLOW [mm]	2.68	2.70	2.67	2.7
STIFFNESS [kg/mm]	698	684	863	748.5
AIR VOIDS OF TOTAL MIX [V.T.M] %	4.0	4.0	3.9	3.97
PERCENT BITUMEN VOLUME V_B %	11.6	11.6	11.6	11.6
VOIDS OF MINERAL AGG. [V.M.A] %	15.5	15.6	15.5	15.5
VOIDS FILL WITH BITUMEN [V.F.B] %	74.46	74.24	74.70	74.46

- Natural Sand content = 10.0 % (By weight of total aggregates)
- No. of blows on each side: 75 blow
- 3/4" binder course mix
- Bitumen = 5.0 % (By total weight)
- Mixing temperature: 150 ºC

TEST DESCRIPTION	**10.00% - SAND REPLACEMENT**			
	SAMPLE NO			AVERAGE
	1	2	3	
WEIGHT OF SAMPLE IN AIR [gm]	1205.7	1203.7	1207.6	1205.7
WEIGHT OF SAMPLE SSD [gm]	1206.4	1204.7	1208.9	1206.7
WEIGHT OF SAMPLE IN WATER [gm]	697.1	696.0	702.7	698.6
SAMPLE VOLUME [cm^3]	509.3	508.7	506.2	508.0
BULK DRY SPECIFIC GRAVITY [kg/m^3]	2367	2366	2385	2373.1
% BITUMEN CONTENT OF TOTAL MIX %	5.00	5.00	5.00	5.0
BITUMEN DENSITY AT 25 °C [g/cm^3]	1.03	1.03	1.03	1.0
MAX SPECIFIC GRAVITY [kg/m^3]	2449	2449	2449	2449.0
MARSHALL STABILITY READING [DIV]	1352.5	1239	1474.6	1355.3
STABILITY CORRECTION FACTOR	1.0	1.0	1.0	1.0
CORRECTED STABILITY [kg]	1839	1685	2005	1843.2
PLASTIC FLOW [mm]	2.35	2.05	2.44	2.3
STIFFNESS [kg/mm]	783	822	822	808.8
AIR VOIDS OF TOTAL MIX [V.T.M] %	3.3	3.4	2.6	3.33
PERCENT BITUMEN VOLUME V_B %	11.5	11.5	11.6	11.5
VOIDS OF MINERAL AGG. [V.M.A] %	14.8	14.9	14.2	14.6
VOIDS FILL WITH BITUMEN [V.F.B] %	77.53	77.32	81.70	78.85

- Natural Sand content = 15.0 % (By weight of total aggregates)
- No. of blows on each side: 75 blow
- 3/4" binder course mix
- Bitumen = 5.0 % (By total weight)
- Mixing temperature: 150 ºC

TEST DESCRIPTION	**15.00% - SAND REPLACEMENT**			
	SAMPLE NO			AVERAGE
	1	2	3	
WEIGHT OF SAMPLE IN AIR [gm]	1210.5	1209.6	1180.2	1205.7
WEIGHT OF SAMPLE SSD [gm]	1212.4	1210.7	1181.2	1206.7
WEIGHT OF SAMPLE IN WATER [gm]	696.3	696.4	684.5	698.6
SAMPLE VOLUME [cm^3]	516.1	514.3	496.7	508.0
BULK DRY SPECIFIC GRAVITY [kg/m^3]	2346	2352	2376	2373.1
% BITUMEN CONTENT OF TOTAL MIX %	5.00	5.00	5.00	5.0
BITUMEN DENSITY AT 25 °C [g/cm^3]	1.03	1.03	1.03	1.0
MAX SPECIFIC GRAVITY [kg/m^3]	2450	2450	2450	2449.0
MARSHALL STABILITY READING [DIV]	1322.2	1258	1191	1355.3
STABILITY CORRECTION FACTOR	1.0	1.0	1.0	1.0
CORRECTED STABILITY [kg]	1798	1711	1620	1843.2
PLASTIC FLOW [mm]	2.21	2.12	2.23	2.3
STIFFNESS [kg/mm]	814	807	726	808.8
AIR VOIDS OF TOTAL MIX [V.T.M] %	4.3	4.0	3.0	3.33
PERCENT BITUMEN VOLUME V_B %	11.4	11.4	11.5	11.5
VOIDS OF MINERAL AGG. [V.M.A] %	15.6	15.4	14.6	14.6
VOIDS FILL WITH BITUMEN [V.F.B] %	72.76	74.03	79.22	78.85

- Natural Sand content = 38.0 % (By weight of total aggregates)
- No. of blows on each side: 75 blow
- 3/4" binder course mix
- Bitumen = 5.0 % (By total weight)
- Mixing temperature: 150 ºC

TEST DESCRIPTION	**38.00% - SAND REPLACEMENT**			
	SAMPLE NO			AVERAGE
	1	2	3	
WEIGHT OF SAMPLE IN AIR [gm]	1189.2	1205.5	1195.8	1196.8
WEIGHT OF SAMPLE SSD [gm]	1189.9	1206.0	1196.4	1197.5
WEIGHT OF SAMPLE IN WATER [gm]	670.6	678.3	674.6	674.5
SAMPLE VOLUME [cm^3]	519.4	527.7	521.8	523.0
BULK DRY SPECIFIC GRAVITY [kg/m^3]	2290	2284	2292	2288.5
% BITUMEN CONTENT OF TOTAL MIX %	5.00	5.00	5.00	5.0
BITUMEN DENSITY AT 25 °C [g/cm^3]	1.03	1.03	1.03	1.0
MAX SPECIFIC GRAVITY [kg/m^3]	2451	2451	2451	2451.0
MARSHALL STABILITY READING [DIV]	741.7	719	701.3	720.6
STABILITY CORRECTION FACTOR	1.0	1.0	1.0	1.0
CORRECTED STABILITY [kg]	1009	978	954	980.0
PLASTIC FLOW [mm]	1.83	1.79	1.75	1.8
STIFFNESS [kg/mm]	551	546	545	547.4
AIR VOIDS OF TOTAL MIX [V.T.M] %	6.6	6.8	6.5	6.59
PERCENT BITUMEN VOLUME V_B %	11.1	11.1	11.1	11.1
VOIDS OF MINERAL AGG. [V.M.A] %	17.7	17.9	17.6	17.7
VOIDS FILL WITH BITUMEN [V.F.B] %	62.78	62.00	63.11	62.63

Appendix "E"

Asphalt Mix Results – Re-determining OBC, 7.50% Natural Sand

- Natural Sand content = 7.50 % (By weight of total aggregates)
- No. of blows on each side: 75 blow
- 3/4" binder course mix
- Bitumen = 4.5 % (By total weight)
- Mixing temperature: 150 ºC

TEST DESCRIPTION	4.50% Bitumen Content			
	SAMPLE NO			Average
	1	2	3	
WEIGHT OF SAMPLE IN AIR [gm]	1200.5	1214.7	1207.0	
WEIGHT OF SAMPLE SSD [gm]	1201.9	1217.2	1210.0	
WEIGHT OF SAMPLE IN WATER [gm]	725.0	721.2	717.6	
SAMPLE VOLUME [cm3]	476.9	496.0	492.4	
BULK DRY SPECIFIC GRAVITY [kg/m3]	2517	2449	2451	2472.5
% BITUMEN CONTENT OF TOTAL MIX %	4.50	4.50	4.50	
BITUMEN DENSITY AT 25 °C [g/cm3]	1.03	1.03	1.03	
MAX SPECIFIC GRAVITY [kg/m3]	2630	2597	2597	2608.0
MARSHALL STABILITY READING [DIV]	1549	1500	1357	
STABILITY CORRECTION FACTOR	1.0	1.0	1.0	
CORRECTED STABILITY [kg]	2106	2040	1845	1997.1
PLASTIC FLOW [mm]	2.35	2.43	2.10	2.3
STIFFNESS [kg/mm]	896	840	879	871.5
AIR VOIDS OF TOTAL MIX [V.T.M] %	4.3	5.7	5.6	5.2
PERCENT BITUMEN VOLUME VB %	11.0	10.7	10.7	10.8
VOIDS OF MINERAL AGG. [V.M.A] %	15.3	16.4	16.3	16.0
VOIDS FILL WITH BITUMEN [V.F.B] %	71.94	65.25	65.60	67.6

- Natural Sand content = 7.50 % (By weight of total aggregates)
- No. of blows on each side: 75 blow
- 3/4" binder course mix
- Bitumen = 4.0 % (By total weight)
- Mixing temperature: 150 ºC

TEST DESCRIPTION	**4.00% Bitumen Content**			
	SAMPLE NO			Average
	1	2	3	
WEIGHT OF SAMPLE IN AIR [gm]	1190.8	1215.9	1209.2	
WEIGHT OF SAMPLE SSD [gm]	1193.8	1218.8	1211.6	
WEIGHT OF SAMPLE IN WATER [gm]	670.0	698.4	694.8	
SAMPLE VOLUME [cm3]	523.8	520.4	516.8	
BULK DRY SPECIFIC GRAVITY [kg/m3]	2274	2336	2340	2316.6
% BITUMEN CONTENT OF TOTAL MIX %	4.00	4.00	4.00	
BITUMEN DENSITY AT 25 °C [g/cm3]	1.03	1.03	1.03	
MAX SPECIFIC GRAVITY [kg/m3]	2465	2465	2465	2464.9
MARSHALL STABILITY READING [DIV]	1549	1500	1357	
STABILITY CORRECTION FACTOR	1.0	1.0	1.0	
CORRECTED STABILITY [kg]	1698	1751	1605	1684.7
PLASTIC FLOW [mm]	2.31	2.44	2.32	2.4
STIFFNESS [kg/mm]	735	718	692	714.8
AIR VOIDS OF TOTAL MIX [V.T.M] %	7.8	5.2	5.1	6.0
PERCENT BITUMEN VOLUME VB %	8.8	9.1	9.1	9.0
VOIDS OF MINERAL AGG. [V.M.A] %	16.6	14.3	14.2	15.0
VOIDS FILL WITH BITUMEN [V.F.B] %	53.22	63.51	64.16	60.3

Appendix "F"

Photos

Flash Point Test

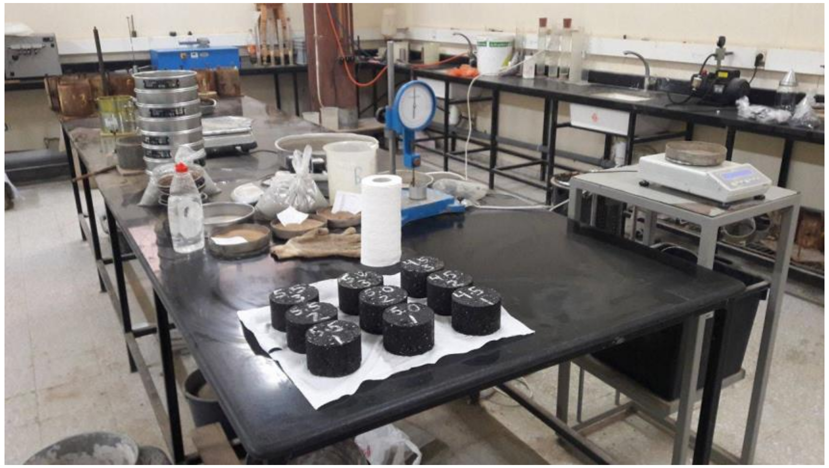
Specific Gravity Test for Bitumen

Sieve Analysis

Samples Compaction

Unit Weight Test


Specific Gravity Test for Natural Sand


Samples Preparation


Los Angeles Abrasion Test