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Reuse of Reclaimed Asphalt Pavement in Asphalt Mixtures of a Binder Course in Palestine

استخدام الرصفة الاسفلتية المدورة في الخليط الاسفلتي كطبقة رابطة في فلسطين

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إقـــــرار

أنا الموقع أدناه مقدم الرسالة التي تحمل العنوان:

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نتيجة الحكم على أطروحة ماجستير

بناءً على موافقة شئون البحث العلمي والدراسات العليا بالجامعة الإسلامية بغزة على تشكيل لجنة الحكم على أطروحة الباحث/ **ثائر منصور عبدالله عابد** لنيل درجة الماجستير في **كلية *الهندسة*** قسم الهندسة المدنية- البنى التحتية وموضوعها:

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وبعد المناقشة التي تمت اليوم الأربعاء 28 ربيع الأول 1435هـ، الموافق 2014/01/29م الساعة العاشرة صباحاً، اجتمعت لجنة الحكم على الأطروحة والمكونة من:

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وبعد المداولة أوصت اللجنة بمنح الباحث درجة الماجستير في **كلية *الهندسة*/** قسم الهندسة المدنية- البنى التحتية.

واللجنة إذ تمنحه هذه الدرجة فإنها توصيه بتقوى الله ولزوم طاعته وأن يسخر علمه في خدمة دينه ووطنه.

والله ولي التوفيق،،،

مساعد نائب الرئيس للبحث العلمي وللدراسات العليا

أ.د. فؤاد علي العاجز

بسم الله الرحمن الرحيم

﴿ يَرْفَعِ اللَّهُ الَّذِينَ آمَنُوا مِنْكُمْ وَالَّذِينَ أُوتُوا الْعِلْمَ دَرَجَاتٍ وَاللَّهُ بِمَا تَعْمَلُونَ خَبِيرٌ ﴾

المجادلة الآية 11

صدق الله العظيم

Dedication

I would like to dedicate this work to my family specially

my father who loved and raised me,

my mother which I hope that she is alive now to complete my happiness,

my brothers and

my loving caring wife,

for their sacrifice and endless support.

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for his valuable advice, continuous encouragement, professional support and guidance. Hoping my thesis to get the satisfaction of Allah and you as well.

Abstract

The application of using reclaimed asphalt pavement (RAP) is an important issue in every country especially those which own less natural resources such as Gaza Strip. The undertaken research work includes the development of a proposal for Reusing RAP as an asphalt binder course in road pavements. The study aims at investigating the possibility to reuse RAP as a binder course in the asphalt pavement and to decide the percent of RAP in the mix. The proposed study has been developed using RAP and mixing it with different percents of virgin aggregate as 0%, 30%, 70%, and 100% so as to know the maximum percent of RAP to be added and its best bitumen content by .testing 60 samples

In this research, number of tests on bitumen is implemented such as softening, penetration, and ductility tests; aggregate tests such as: sieve analysis, specific gravity, absorption, unit weight, moisture content, los Angeles are conducted; Marshal samples are prepared using both different mixes of RAP and virgin aggregate to investigate the properties of the asphalt mix; flow, stability and comparing the results with the .specifications in this research the bitumen in the RAP

Its noticed that the bitumen content increases by increasing the RAP percent. Study recommends that RAP is to be used in asphalt binder with a maximum percent of 50% - a bitumen content is 5.55% and it is preferable to use a percent ofrap of 30%with bitumen content of 5.43%. It is also recommended that more tests on different percents and different sample ages are to be conducted.

ملخص البحث

يعتبر تطبيق استخدام الركام الإسفلتي من الأمور الهامة في كل بلد خصوصا في تلك البلدان التي لا تمتلك الكثير من المصادر الطبيعية لمكونات الخليط الإسفلتي مثل قطاع غزة. ويقدم هذا البحث دراسة حول إعادة استخدام الركام الإسفلتي في الطبقة الرابطة الاسفلتية لرصفات الطرق .

الهدف الرئيسي من هذه الدراسة دراسة إمكانية استخدام هذا الركام كمادة في الخلطة الاسفلتية في الطبقة الربطة وكذلك تحديد نسبة الركام الإسفلتي المعاد استخدامه في الخليط الحصوي, حيث تم عمل عدة عينات مارشال تحتوي على نسب مختلفة من الركام الإسفلتي مع نسب من الحصويات الجديدة , تمثلت هذه النسب في (0%, 30% , 50%, 70%, 100%) وذلك لمعرفة أقصى نسبة ركام اسفلتي يمكن إضافتها مع أفضل نسبة بيتومين وذلك من خلال فحص 60 عينة.

وقد تم إجراء العديد من الفحوصات الخاصة بالبتومين مثل فحص الغرز وفحص الممطولية والتميع وكذلك إجراء فحوصات الحصويات مثل فحص التدرج الحصوي والكثافة النوعية والامتصاص والوزن النوعي والمحتوى المائي وفحص لوس انجلوس, وكذلك فقد تم تجهيز عينات مارشال بنسب مختلفة من الركام مع نسب من الحصويات الجديدة لتحديد خواص الخليط الإسفلتي من خلال الخصائص أهمها الثبات والانسياب والكثافة الظاهرية ونسب فراغات الهواء في الخلط الإسفلتي.

وقد أظهرت النتائج انه عند زيادة الركام الإسفلتي سوف تزيد الحاجة إلى نسبة بيتومين أعلى , وتوصي الدراسة بان يكون أقصى نسبة استخدام للركام هي 50 % مع إضافة 5.55% كنسبة بيتومين , ولكن يفضل استخدام نسبة 30% بنسبة بيتومين 5.43% ,وكذلك توصي الدراسة بان يتم عمل المزيد من الفحوصات على نسب بيتومين أخرى كذلك على عينات مختلفة في العمر الإنشائي.

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List of Abbreviations

AASHTO	American Association State Highway and Transportation Official
ASTM	American Society for Testing and Materials
BS	British Standards
CBR	California Bearing Ratio
IUG	Islamic University - Gaza
RCA	Recycled Concrete Aggregate
RA	Recycled Aggregate
RAP	Reclaimed Asphalt Pavement
RMA	Recycled Masonry Aggregate.
RHMA	Recycled Hydraulic Mixed Aggregate.
RSA	Recycled Sand Aggregate.
SSD	Saturated Surface Dry condition
UNDP	United Nations Development Program
VFB	Voids Filled Bitumen
VMA	Voids Mineral Aggregates
MOHU	Ministry of Housing and Utilities

List of Symbols

d_{25}	Density of bitumen at 25 C.
ρ_{bit}	Theoretical maximum density of asphalt mix
ρ_A	Density of asphalt mix
$\rho_{\min}$	Density of aggregate in the blend
Vb	Bitumen volume
Va	Air voids

Chapter 1
Introduction

1.1. Background

Reclaimed Asphalt Pavement (RAP) is the waste materials that produced in the process of construction, renovation, or demolition of asphalt pavement . the Asphalt pavement are commonly removed due to continuous process of resurfacing, reconstruction and rehabilitation, the accumulated material that produced during those process become RAP which contain many valuable reusable material such as asphalt binder, bitumen and aggregate.

RAP can be used as granular base or sub base material in virtually all pavement types, including paved and unpaved roadways, parking areas, bicycle paths, gravel road rehabilitation, shoulders, residential driveways, trench backfill, engineered fill, pipe bedding, and culvert backfill (Schroeder, 1994).

Although the use of RAP in granular base applications does not recover the asphalt cement potential in the old pavement, it does provide an alternate application where no other markets (asphalt paving) are available or where unsuitable material (such as soil or mud) may have been combined with the RAP so that it cannot be used as part of a recycled pavement (Hanks, 2003).

RAP rates between 10 and 30% are commonly used in hot recycled bituminous mixes.

According to several studies, with these rates bituminous mixtures perform similarly to conventional mixtures (Kandhal et al., 1995). However, environmental restrictions are causing an increase in RAP content added to recycled mixtures used in bituminous pavement construction and rehabilitation. This has a beneficial effect from the economic point of view and makes pavement construction sustainable over time due to lower energy and natural resource consumption (Maupin Jr. et al., 2009).

Laboratory and experimental field studies on mixtures containing large amounts of RAP show the feasibility of this technique (Kim et al., 2009). However, as its use in road construction and rehabilitation projects becomes more widespread, further research is necessary due to the damaging effect of traffic and climatic conditions on mixtures.

1.2. Statement problem

In Gaza Strip a lot of quantities of Reclaimed Asphalt Pavement (RAP) is found due to the destructions of roads and infrastructures by Israeli bulldozers and air force since the last several years, destruction of Gaza airport, and the demolition waste resulted from the destruction of old roads, which contains several valuable natural resources such as bitumen and aggregate which are very lake in Gaza due to the siege and the lake of natural resources, the cost of recycling RAP for road construction is less than the cost of doing it with virgin materials, so it is important to recycle RAP and have a full benefit of it instead of dumping it in the landfills which causes an environmental and health problems, knowing that the area of Gaza Strip is limited.

Gaza Strip is suffering from lake of construction material like aggregate and bitumen due to the siege on Gaza, and the lake of source material like rocks and mountains to be as a source of aggregate, furthermore, it is difficult to find landfill in the small area of Gaza to dump the huge quantity of waste into it, therefore, it is important to reclaim it.

1.3. Aims

The main aim of this research is to investigate the possibility to reuse RAP as a binder course in the asphalt pavement and to determine the percent of RAP in the mix design and its best bitumen content.

1.4. Objectives

In order to achieve the aim of this research the following main adjectives should be assessed:

- Studying the properties of RAP in the Gaza Strip.
- Investigating the feasibility of using the RAP as asphalt binder course.
- Finding the optimum percent of RAP added to the virgin aggregate which can be used in binder course.
- Presenting an appropriate mix design for RAP with virgin one to apply it in practical field

1.5. Research importance

The following points show the importance of the research:

- Reusing of the RAP aggregate in producing the asphalt mixtures.
- Providing temporary alternative for the virgin material when it is absent due to the siege on Gaza Strip.
- Maintain the environment by using RAP and reducing the fill areas.
- The economic feasibility in mean of the cost of the pre-used material.

1.6. Research limitation

The results of this research depended on the limitation and criteria that was taken into account during the experiments, the limitation is that The samples were collected from one place of Salah El Deen Street, because selecting sample from more than one place leads to huge number of samples, which consume huge time resources and efforts.

1.7. Research Methodology

In order to achieve the research objectives, the following methodology has been followed:

A. **Literature review**

Extensive survey is performed about all available topics related to RAP in order to improve a background about using RAP in binder mix. Literature review concentrates on the following points:

- Historical uses and application RAP in producing binder pavement and properties of the produced binder mix.
- Experimental tests were conducted on RAP to check the ability of using RAP in binder pavement.
- Recommendation that must be considered in using RAP in binder pavement.
- Advantages and disadvantages of using RAP in binder pavement.

B. Sample collection

Filed exploration was performed in order to collect representative sample of available RAP in the Gaza Strip. Suitable representative sample was brought from Salah El Deen street.

C. Aggregate tests

Experimental tests were performed on the collected RAP sample to find its mechanical and physical properties and compare it with international standard requirements.

D. Preparing the binder samples

Binder pavement samples were prepared using different percentage of aggregate and different bitumen ratios, Standard tests were performed to find the mechanical and physical properties of produced binder pavement samples. Comparisons between binder mix samples produced by RAP and natural aggregate were performed to check the effect of using RAP on binder properties.

F. Evaluation and recommendation

Evaluation and recommendation were done after performing tests and analysis results.

1.8. Thesis organization

Thesis is divided into six chapters; each chapter covers a certain area as follows :

Chapter One introduces the reader to the ground feature of the subject, and presents the objective and importance of this research. Chapter Two presents literature review that covers the previous international and local efforts supported in this filed. Chapter Three presents the material used and experimental program, Chapter four focus on the sampling and testing procedure that will be conducted, Chapter five presents the test results on binder pavement which produced using different percentage of RAP. Chapter six is the conclusions and recommendations.

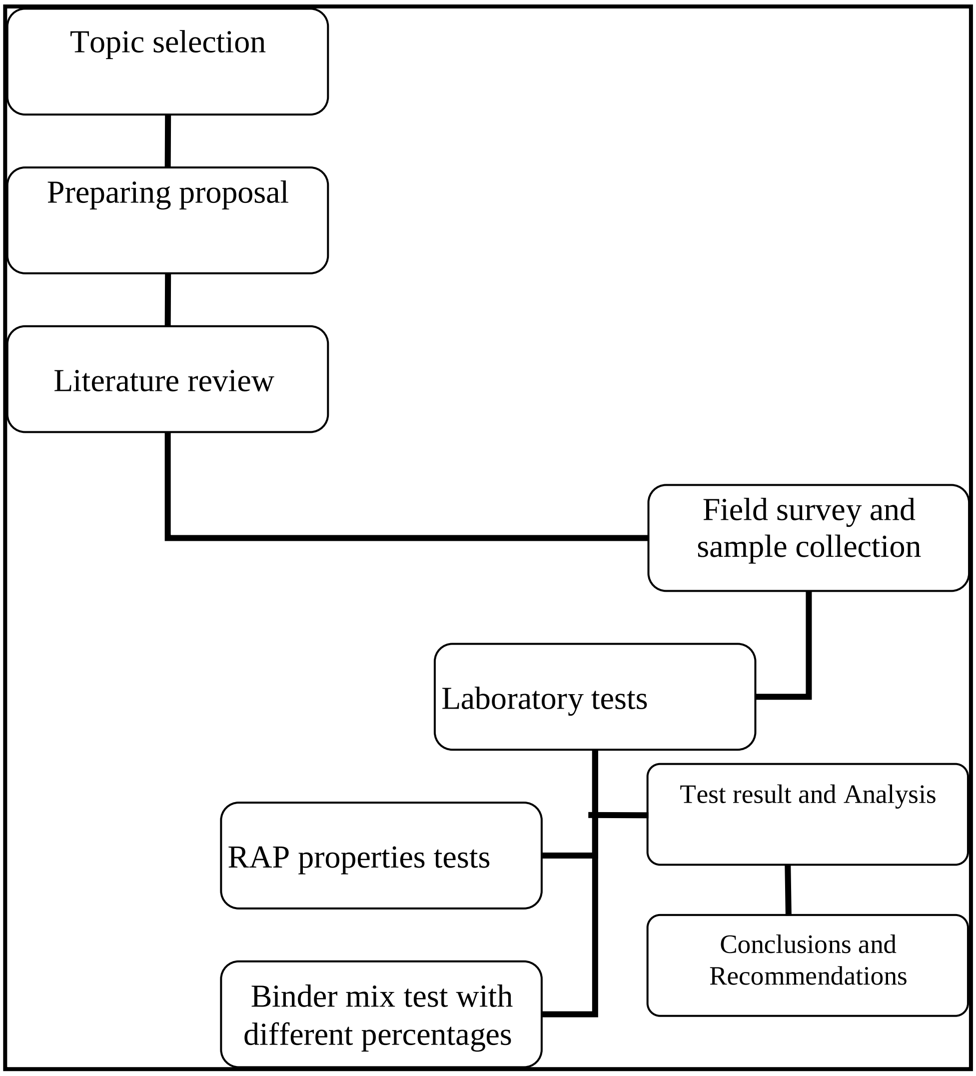

Figure 1.1: Summary of methodology flow chart

Chapter 2
Literature Review

2.1. Historical background

The history of using recycling asphalt pavement back to 1915, but it wasn't become commonly used until the Arab oil embargo in 1970s when the asphalt binder price skyrocket (Randy et al., 2010).

There was estimation conducted by Federal Highway Administration's (FHWA) and the U.S. Environmental Protection Agency for reclaimed asphalt pavement which indicate that there are more than 90million tons of asphalt pavement were converted into material suited for use every year and 80 percent of RAP was recycled to be used as asphalt pavement (Turner-Fairbank Highway Research Center, 2011).

Figure 2.1: Site process of reusing binder course (Randy, 2010)

There was high improvement in asphalt technology as a result of developing the recycling approaches due to high dement of asphalt binder, which leads to reduce the cost of asphalt binder costs. The approaches for pavement construction and rehabilitation which were used during 1970s period are still in use till today.

For more than 20 years the process of using RAP are properly developed, as there are many research conducted for enhancing the properties of asphalt pavement which produced using PAP, as in many cases it was blended with conventional aggregates, and nowadays its considered standard practice in many areas "At least 13 state agencies (Arizona, Illinois, Louisiana, Maine, Nebraska, New Hampshire, North Dakota, Oregon, Rhode Island, South Dakota, Texas, Virginia, and Wisconsin) have used RAP as aggregate in base course. At least four state agencies (Alaska, New York, Ohio, and Utah) have used RAP as unbound aggregate in subbase, and at least two states (California and Vermont) have experience with RAP use in stabilized base course". (Collins and ciesielski, 1994).

In addition to the states listed above, it has also been reported that:

"RAP has been used as a base course additive in Idaho and New Mexico, and as a subbase additive in at least 10 other states, including Connecticut, Georgia, Iowa, Kansas, Massachusetts, Minnesota, Montana, klahoma, Tennessee, and Wyoming. It has further been reported that Kentucky has had some limited experience with the use of RAP in roadbase, although no information is available concerning its performance" (Saeed et al., 1995, Report No. 1348-1).

Although the high improvement of RAP recycling technology, this is not yet popular in Gaza strip. However it's found popular other countries with huge amount.

"Aggregate and bitumen is the most recyclable materials. In the USA 80% of the total amount of RAP is reused with about 33 million tons, . In the year 1995, 20 million tons of recycled hot mix was produced in Japan, which constituted 30% of the total hot mix production, about 7.3 million tons in Germany, 0.84 million tons in Sweden, 0.53 million tons in Denmark and around 0.12 million tons in Netherlands" (Ikeda and Kimura, 1997, pp. 99-106).

2.2. Crushing and grading

It can be observed that RAP aggregate gradation is finer than the limit that recommended by international codes such as ASHTO Specifications. This is mainly due to rushing of aggregate during milling process, in addition to aggregate wear that occurs during mixing, compaction and traffic serving of the asphalt concrete mix (Al-Rousan et al., 2008).

The collected RAP form site has to be processed to appropriate required aggregate gradation using the common used equipment consisting of a primary crusher, screening units, secondary crusher, conveyors, and a stacker. To avoid agglomeration of crushed RAP it should be mixed with conventional aggregate in order to make the mix homogeneous. The blended material that is stockpiled for a considerable period of time may harden and needs recrashing, rescreening before it can be incorporated into granular base applications. So the blended RAP aggregate should not let in place for a lot of time, because the stockpiled material is likely to become overly wet, and needs to be reprocessed before using (User Guidelines for Waste and Byproduct Materials in Pavement Construction, 2012)

2.3. Process of recycling RAP

The process of forming RAP is begin by cold milling, heating/softening and removal existing aged asphalt or plant waste hot-mix asphalt (HMA) materials. Recycling (HMA) material produced by a reusable mixture of aggregate and asphalt binder which in my reference called reclaimed asphalt pavement (RAP). There are a lot of reason behind recycling of asphalt pavements such as technical, economical, and environmental (Kennedy et al., 1998).

2.4. RAP mix and percentage

Based on experience that gained during RAP development process, most states of USA have established limits for the the maximum percentage of RAP that can be used, ranging typically between 10 to 50%. However, high percentages of RAP are not commonly used in practice (Al-Qadi et al, 2007).

Based on material and cost consideration, it was concluded that the using reclaimed HMA pavement provides a saving ranging from 14 to 34% for a RAP content varying between 20 to 50% (Kandhal and Mallick 1997).

There was standard applied for several stats in USA which specify that a minimum percentage of virgin binder content e.g., 70 percent of the binder content must be virgin binder (Turner-Fairbank Highway Research Center, 2011).

After selecting a specific RAP material for use in HMA, high stiffness binder effect on HMA has to be taken into consideration. And the amount of RAP materials that will be used in the HMA, has to be firstly detriment by the designer. It was observed that the low percentage of RAP in the mix (up to 20% by mix total weight) had little to no effect on the blend of virgin and RAP binder (Kennedy et al., 1998).

“However, when an intermediate or high amount of RAP is used, the effect of the RAP binder on the mix properties becomes significant and ultimately may even require changing the grade of the binder added to the mix” (Al-Qadi et al., 2009).

There are many factors that effect on the properties of RAP such as aggregate type, quality and size, extracted binder properties, etc. The RAP composition is affected by the previous maintenance and preservation activities that were applied to the existing pavement (airfield asphalt pavement technology program, 2008).

“This procedure is crucial to reduce bias due to unforeseen factors that would affect measurements. In order to estimate the amount of asphalt in the RAP material, extraction test (ASTM D2172-95) was performed followed by sieve analysis of the clean aggregate. The asphalt content of RAP was found to be 5.9%” (Al-Rousan et al., 2008).

Practically, it was concluded that 50% is the maximum amount of RAP that can be used for recycling drum mix, however 50% is practical limit. Extremely high gas temperature is required for 50 % of RAP percentage, and in that case a relatively smaller amount of virgin aggregates would be available to protect the RAP from the flame. Most drum mix plants recycle 30 to 50 percent of RAP (Mokwa, 2005).

“The popular maximum percentage is 50%, but this percent is not the best percentage, Now that more states are converging on 50% as a maximum, more tests, ranging from 0 to 50% RAP, need to be conducted, The majority of the studies conducted tests on blends of 25%, 50% and 100% RAP. Changing small percent of RAP will have little effect on field blend due to the imprecise nature of construction, a 10 to 15% change could result in a large effect” (Eeic, 2007).

The maximum RAP that allowed by most of agencies range form 10-25% in surface mixes and a higher percentage of RAP in base mixes, However, its restricted in some agencies to use of RAP in the surface course for pavements with high applied number of equivalent single axle load (ESAL) (airfield asphalt pavement technology program, 2008).

2.5. Advantage of recycling

There are many advantages behind using RAP in new HMA such as reduce production cost and conserves diminishing resources of aggregates and petroleum products. and also RAP is less construction cost, less disposal materials, Conservation of energy, Reduced transportation cost, conservation of aggregates and binders, Preservation of environment (reduction in toxic and greenhouse gas emissions), and Reduction in road wears due to less transport of materials (airfield asphalt pavement technology program, 2008).

Also there are many researches that emphasis on the advantages of using RAP in new asphalt mixtures environmental benefits which include; reduction of the carbon footprint of the product and any of its end uses, conservation of landfill space, making asphalt paving an excellent sustainability practice. Also economic concerns such as;

reduces the cost of the mix. In addition, the reuse of materials provides an opportunity to stabilize construction prices, which may fluctuate as the economy and demand for raw materials change. Both the environmental and the economic benefits of recycling have been enhanced by new methods that allow using increased amounts of RAP in asphalt mixtures.

2.6. Durability of binder pavement using RAP

"The durability of the recycled mixtures was also evaluated by a number of researchers. In their study, the recycled mixtures had better resistance to the action of water than the virgin mixtures" (Kiggundu and Newman, 1989). Another study showed that the durability of recycled asphalt concrete mixtures was better than that of the conventional mixtures (Dunning and Mendenhall, 1978).

The RAP is a deteriorated bituminous mix that contains aged bitumen and aggregates. Hence, its performance is poorer when compared to the fresh mix. The purpose of the bituminous recycling is to regain the properties of the RAP, such that it tends to perform as good as fresh mix. Thus, the process of bituminous recycling involves mixing of the RAP, fresh bitumen, rejuvenators and new aggregates in suitable proportions. Rejuvenators are low viscosity oily substance, which helps to bring down the high viscosity of aged bitumen (Aravind K., Animesh Das, 2007).

Cost savings increase as higher RAP percentages are being used. However, physical changes due to the addition of high RAP percentages can pose a challenging mix design problem and significantly affect the HMA performance. One potential physical change between a virgin HMA pavement and a HMA pavement containing RAP materials is the modulus increase of the latter. The increased modulus is mainly due to the effect of the RAP's binder. The increased dynamic modulus may be affected by the increased amount of RAP material passing the #200 sieve. The binder in RAP materials is significantly stiffer than the binder in virgin HMA (Kemp and Predoehl, 1981).

2.7. Engineering properties

Some of the engineering properties of RAP that are of particular interest when RAP is used in granular base applications include gradation, bearing strength, compacted density, moisture content, permeability, and durability.

Gradation: The gradation for milled RAP is governed by the spacing of the teeth and speed of the pulverizing unit. Wider tooth spacing and higher speed result in larger particle sizes and coarser gradation. RAP can be readily processed to satisfy graduation requirements for granular base and subbase specifications, such as (AASHTO M147,1993). Gradation is perhaps the most important property of an aggregate. It affects almost all the important properties of a HMA, including stiffness, stability, durability, permeability, workability, fatigue resistance , frictional resistance, and resistance to moisture damage (Michael et al., 2002).

Bearing Strength: The bearing capacity of blended RAP is strongly dependent on the proportion of RAP to conventional aggregate. The bearing capacity decreases with increasing RAP content. The California Bearing Ratio (CBR) is reduced below that expected for conventional granular base when the amount of RAP exceeds 20 to 25 percent CBR values have been shown to decrease almost directly with increasing RAP contents (Senior et al., 1994).

Compacted Density: Due to the coating of asphalt cement on RAP aggregate, which inhibits compaction, the compacted density of blended granular material tends to decrease with increasing RAP content.(Senior et al., 1994).

Moisture Content: The optimum moisture content for RAP blended aggregates is reported to be higher than for conventional granular material, particularly for RAP from pulverizing operations, due to higher fines content and the absorptive capacity of these fines (Hanks, A. J. and E. R. Magni, 1989).

Permeability: The permeability of blended granular material containing RAP is similar to conventional granular base course material (Hanks, A. J. and E. R. Magni, 1989).

One major factor that is still unclear is the level of interaction between aged and virgin asphalt binders. If RAP acts like a black rock, the aged and virgin binders will not interact. Hence, it would be assumed that RAP does not significantly change the virgin binder properties. In that case, the use of blending charts may be invalid. However, it is usually assumed that RAP does not act as a black rock and that the aged asphalt blends with the virgin binder during mixing. In fact, many design procedures including the design method assumes that all the aged binder is fully available in the mixture and would effectively contribute to the blend. This means that the amount of virgin asphalt binder can be reduced by the full amount of asphalt binder in the RAP for the percentage specified (Imad L. Al-Qadi, 2007).

There is no different in strength at low temperature when using between 15% & 25% RAP, and there is some differences in strength when suing more than 40% RAP mix at higher test temperature, and when adding small amount of RAP this may not change mix properties a lot (McDaniel et al., 2000).

By experiment its shown that Marshall Mix Design method can be used to design 15 and 30% RAP mixes, the RAP mixes is better or equivalent thermal cracking resistance to that of no RAP mix (Hajj et al., 2007).

It is founded that pavements containing 20-50% RAP performed as the same as the conventional pavements for a period of 6 to 9 years after construction .And there are no big differences in the recovered asphalt binder properties from pavements containing RAP and pavements with 0% RAP (Paul, 1996).

"No difference found between virgin & recycled surface after 1.5 to 2.25 years of service. Both virgin and recycled sections performed well with no significant rutting, raveling & weathering, & fatigue cracking .

-Recovered binder tests from the projects showed good resistance to fatigue and rutting

-Results from additional projects: No difference found between extracted binder properties of recycled & virgin pavements. Recycled pavements are performing as well as virgin pavements (Kandhal, 1995).

%18RAP mix performed well for moisture resistance in the lab and field (Pelland, 2003).

2.8. Performance of RAP asphalt mixture

In the 1990, two reports were published evaluating the field performance of recycled asphalt pavements with varying percentages of RAP. After 1–2.5 years of service, there were no signs of rutting, raveling, or fatigue cracking in any of the study sections. This indicated that the virgin and RAP sections performed equally well (Kandhal et al., 1995).

later this study were expanded to more pavement sections including virgin and recycled asphalt pavements with 10–40 percent RAP, Based on visual observations, there was no significant difference in the performance of the virgin and recycled pavement sections. It should be noted, however, that 1–3 years is not sufficient to evaluate the long-term service performance of the pavement sections (Al-Qadi, 2007) .

In Louisiana, the field performance of conventional and recycled asphalt pavements that were 6–9 years old were evaluated and analyzed the pavements for condition, serviceability, and structural analysis. The RAP sections contained 20–50 percent RAP. It was found that no significant difference in terms of the pavement conditions and serviceability ratings (Paul, 1996) .

It found that negligible effect of RAP at low RAP content, but at intermediate RAP content, effect of RAP compensated by using virgin binder 1 grade softer on both high

& low temperature grades, at high RAP content: use blending chart, the properties of low RAP content mix similar to that of no RAP mix.

- High RAP content stiffens the mix at high, intermediate, and low temperature.
- Higher RAP content exhibits more rutting resistance and lower beam fatigue life when no change made in virgin binder grade. (Airfield asphalt pavement technology program, 2008).

2.9. Mix design consideration

RAP material generally contains relatively high percentages of material passing the #200 (0.0029-inch (0.075-mm)) sieves as a result of the milling and/or crushing operations. This can limit the amount of RAP that can be used in a mix design and meet the dust to asphalt ratio, airvoids, and VMA. The gradation of the virgin aggregate must compensate for this. Using more of the coarse portion of fractionated RAP may help, as would washing the aggregate or removing dust at the plant during production (Turner-Fairbank Highway Research Center, 2011).

The percentage of asphalt binder in RAP should also be considered when determining the trial asphalt binder content. The asphalt binder content of the total mixture for mix batching includes virgin and reclaimed asphalt binder. The mixture trial AC is calculated or estimated by experience during the trial blend analysis. Thus, the amount of binder in RAP is considered when determining how much virgin asphalt binder is required. It may be necessary to adjust the virgin asphalt binder grade when RAP is used in the mix to achieve the appropriate grade (Turner-Fairbank Highway Research Center, 2011)

2.10. High RAP Mix Design

For asphalt mixtures containing high RAP, a method is needed to select the appropriate grade for the virgin binder. A softer virgin binder may be required to balance the stiffer-aged RAP binder.

Reusing RAP materials is allowed by the UK Specification for Highway Works the production of asphaltic wearing course, binder course and road base with the maximum amount of 10% in wearing course and 50% in all other layers; additional performance requirements are required when the recycled content exceeds 25% by mass (Scott Wilson, 2008).

Hot mix recycling has certain advantages amongst various pavement recycling methods, such as, comparable performance to that of conventional mixes and better quality control. This is because constituents are mixed under controlled conditions and it is possible to monitor mixing process continuously. The advantages of this process, is less workspace required for laying the recycled mix. this is suitable for the roads where the right-of-way is restricted (Betenson, 1995).

The properties of the mix is affect by the amount of RAP used in the recycled mix, other study indicates that mix property is not significantly affected by the quantity of RAP used. Stiffness modulus of recycled mix has found to be better than virgin mix, whereas other researchers have found similar or lower stiffness. Similarly, the indirect tensile strength of recycled mix is found to be satisfactory or better, or even poorer than its corresponding virgin mix. Its found that the recycled mix has a greater resistance to rutting than virgin mix and from field studies, rutting performance of recycled mix has been found better than virgin mix (Aravind, 2006).

2.11. Composition of asphalt mixes

Asphalt mixes are composite materials that consist of asphalt binder mixed with filler/fines (together with asphalt called the mastic) and aggregates **(**Koneru et al., 2008**).**

The mixes of asphalt pavements consist of asphalt binder that connect between the filler together and the aggregates.

The major properties to be incorporated in asphalt paving mixtures are stability, durability, flexibility and skid resistance (in the case of wearing surface). Traditional mix design methods are established to determine the optimum asphalt content that would perform satisfactorily, particularly with respect to stability and durability **(**Asi, 2007).

Asphalt Mix design is the selection of the components to achieve a desirable balance in these properties for the specific pavement application. Selection of the components and their relative proportions is also influenced by the pavement section in which the mix will be incorporated. Design of asphalt-aggregate mix consists of the following steps **:(** Waynelee et al., 2002**).**

- Select the type and gradation of the mineral aggregates.
- Select the type and grade of asphalt binder.

- Select the amount of asphalt binder to satisfy the project –specific requirements for mix properties.

2.12. Methods of mix design and Marshal Mix Design

Regarding the mix design methods, there are many methods that used overall the world such as Marshall mix design method, Hubbard-field mix design method, Hveem mix design method, Asphalt Institute Tri- axial method of mix design, etc, but the two most widely accepted methods are Marshall Mix design method and Hveem mix design method**(**Asi, 2007**)**.

In Marshal Method, The basic concepts were formulated by Bruce Marshall of the Mississippi State Highway Department. Just prior to World War II, the U.S. Army Corps of Engineers improved and added certain features to his test procedure. These efforts resulted in the mix design criteria that were adopted by the American Society for Testing Materials in use today. The Marshall Method is applicable only to hot-mix asphalt paving mixtures using penetration grades of asphalt and containing dense or fine-graded aggregates with a maximum size of 25 mm (1-inch) or less. The Method is intended for the laboratory design of hot-mix asphalt paving mixtures. The Marshall Method of mix design consists of the following steps: (Kett,1998).

1. Preparation of test specimens.
2. Bulk specific gravity determination.
3. Stability and flow test.
4. Density and voids.

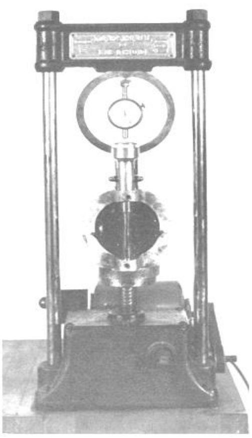

Figure 2.2: Marshall Stability and Flow Test Apparatus (ASTM D1559- 89).

2.13. The Mechanical Properties Asphalt Binder Course

Table (2.1) shows the mechanical properties for asphalt binder based Municipality of Gaza and Asphalt institute code. Those specifications were applied in this thesis.

Table 2.1: The Mechanical Properties of the Asphalt Binder Course from Municipality of Gaza , and Asphalt institute.

Properties	MOG Spc, 1998 (Local)		Asphalt institute 1998 (International)	
	Min.	Max.	Min.	Max.
Stability (kg)	900	-	817	-
Flow (mm)	2	4	2	3.5
Air void Va (%)	3	7	3	5
VMA (%)	13.5	-	13	-
Bulk density (Pa)	2.3	-	2.3	-

2.14. Specifications of aggregate

2.14.1. standard specifications for aggregate gradation

There are many standard specifications for applied internationally for aggregate gradation, such as International Specification (ASTM D3515- D-4), and Egyptian standard.

A. International Specification (ASTM D3515- D-4)

Typical grading limits for the aggregate used in American binder courses are shown in Table 2.1 and Figure 2.1

Table 2.2: Gradation of Asphalt Binder Course (ASTM D5315 – D-4)

Sieve size (mm)	Percentage by Weight Passing	
	Min	Max
25.00	100	100
19.00	90	100
12.50	--	--
9.50	56	80
4.75	35	65
2.36	23	49
0.30	5	19
0.15	--	--
0.075	2	8

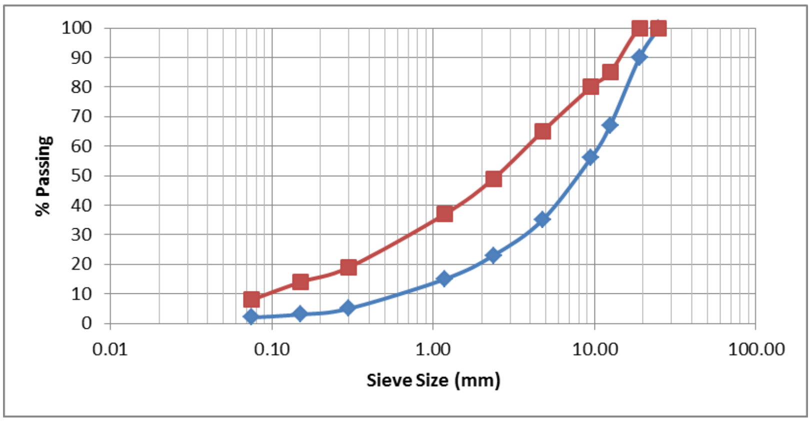

Figure 2.3: Gradation of Asphalt Binder Course (ASTM D3515)

B. Egyptian Specifications

Egyptian Code for development of the urban and rural roads

Table 2.2 and Figure 2.2 show the Egyptian specification gradation for the asphalt binder course. the gradation of the Egyptian specification. Table 2.4 illustrates the mechanical properties.

Table 2.3: Gradation of Egyptian Asphalt Binder Course (MOHW, 1998)

Sieve size (mm)	Percentage by Weight Passing	
	Min	Max
19.00	100	100
12.50	75	100
9.50	60	85
4.75	35	55
2.36	20	35
0.30	6	16
0.15	4	12
0.075	2	8

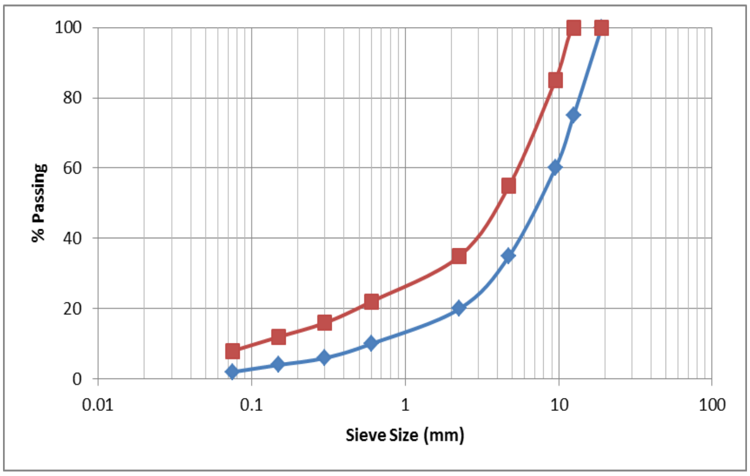

Figure 2.4: Gradation of Egyptian Asphalt Binder Course

2.15. Summary of literature review

Table 2.4Summary of literature review

#	Researcher or reference	Note
1	Al-Qadi et. al, 2007	maximum percentage of RAP between 10 to 50% high percentages of RAP are not commonly used in most states of USA.
2	Turner-Fairbank Highway Research Center, 2011	70 percent of the binder content must be virgin binder applied for several stats in USA.
3	Kennedy et al. 1998	low percentage of RAP in the mix (up to 20% by mix total eight) had little to no effect on the blend of virgin and RAP binder.
4	Al-Rousan T. et al, 2008	The asphalt content of RAP was 5.9%
5	Mokwa, 2005	maximum percentage of RAP between 30 to 50%.
6	Eric J. McGarrah, 2007	The popular maximum percentage is 50%, this percent is not the best percentage. a 10 to 15% change could result in a large effect
7	airfield asphalt pavement technology program, 2008	The maximum RAP that allowed by most of high ways agencies range form 10-25% in surface mixes and a higher percentage of RAP in base mixes.
8	airfield asphalt pavement technology program, 2008	its restricted in some agencies to use of RAP in the surface course for pavements with high applied number of equivalent single axle load (ESAL)

Chapter 3
Specification & Materials

3.1. Introduction

In this chapter it will define the specification to be used and comparison of the it with each gradation of the five trials, the rest of the chapter define the specifications and comparison between the virgin aggregate and aggregate from RAP.

3.2. The specification used in this research

The Egyptian specifications seem to be similar to ASTM Specifications particularly in the gradation; In this research Egyptian specifications is used, as it is regional and neighbor to Gaza Strip (i.e. Gradation and mechanical properties).

3.3. Gradation of virgin aggregates (0 % RAP) comparing with the Egyptian specifications

3.3.1. Gradation of virgin aggregate (0 % RAP) comparing with the Egyptian specifications.

Table (3.1) represents the percent of passing according to the Egyptian Specifications

Table 3.1: Gradation virgin aggregate comparing with the Egyptian specifications

Sieve size (mm)	Percentage by Weight Passing Egyptian Specifications		%passing
	Lower Level	Upper Level	
19	100	100	100
12.5	75	100	83
9.5	60	85	66
4.75	35	55	49
2.36	20	35	32
0.3	6	16	13
0.15	4	12	7
0.075	2	8	0

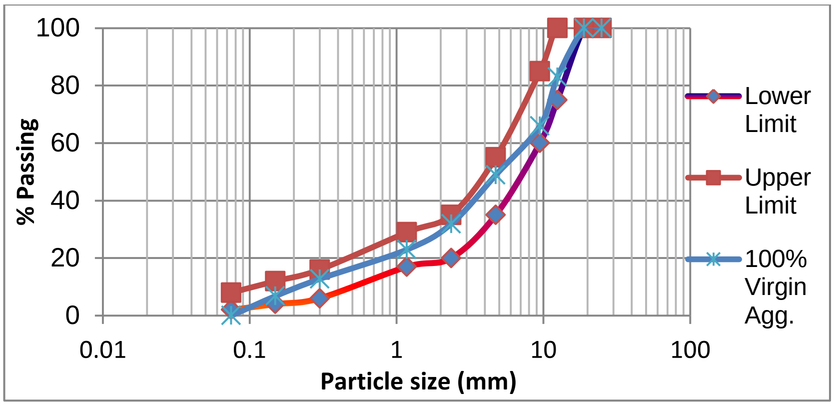

Figure 3.1: Gradation of Virgin aggregate comparing with the Egyptian specifications

Table (3.1) and figure (3.1) show the used virgin aggregate, this aggregate was collected form aggregate that available in Gaza local market. table 3.1 shows that the used virgin aggregate are located within the Egyptian specifications.

3.3.2. Gradation of the aggregate which extracted from 100% RAP comparing with the Egyptian specifications.

In order to investigate the physical properties of RAP, sieve analysis was conducted for aggregate that collected from RAP from Gaza after extraction. Table (3.2) and Figure (3.2) show that the gradation is finer than that required according to Egyptian specification

Table 3.2: Gradation of the aggregate RAP after extraction comparing with Egyptian specifications

Sieve size (mm)	Percentage by Weight Passing Egyptian Specifications		%passing of RAP
	Lower Level	Upper Level	
25	85	100	100
19	69	91	95
12.5	55	79	85
9.5	50	70	75
4.75	35	55	60
2.36	28	49	46
0.3	5	20	11
0.15	4	15	5
0.075	2	8	1

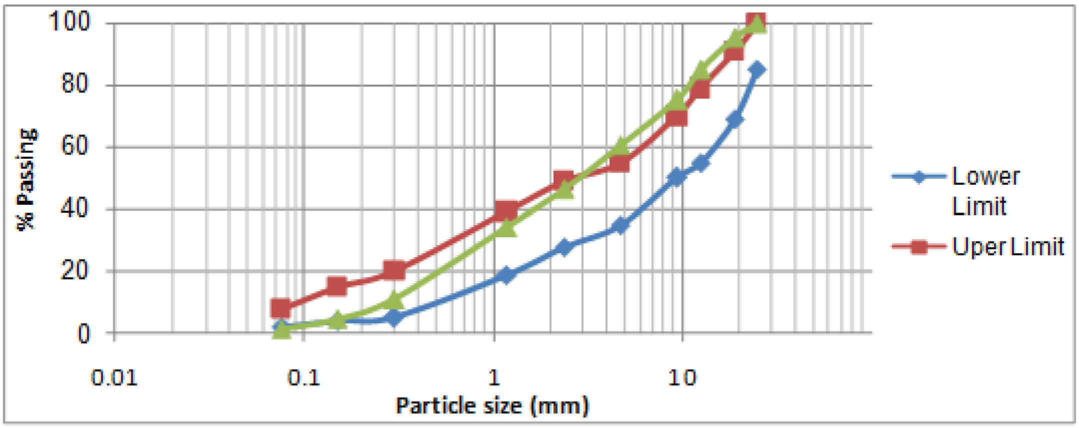

Figure 3.2: Sieve analysis of the RAP after extraction according to Egyptian specification

Table (3.2) and figure (3.2) show that the gradation is finer than that required according to Egyptian specification, so this gradation is not accepted based on specification respective. So in order to modify the physical specification of aggregate that produced form RAP, different percentage of virgin aggregate is added to the RAP aggregate.

3.3.3. Gradation of the aggregate which is mixed of extracted 30% RAP and 70% virgin aggregate comparing with the Egyptian specifications.

Table 3.3: Gradation of mix of 30% RAP aggregate and 70% virgin aggregate

Sieve size (mm)	Percentage by Weight Passing. Egyptian Specifications		%passing of Mix
	Lower Level	Upper Level	
19	100	100	99
12.5	75	100	92
9.5	60	85	67
4.75	35	55	44
2.36	20	35	31
0.3	6	16	13
0.15	4	12	8
0.075	2	8	4

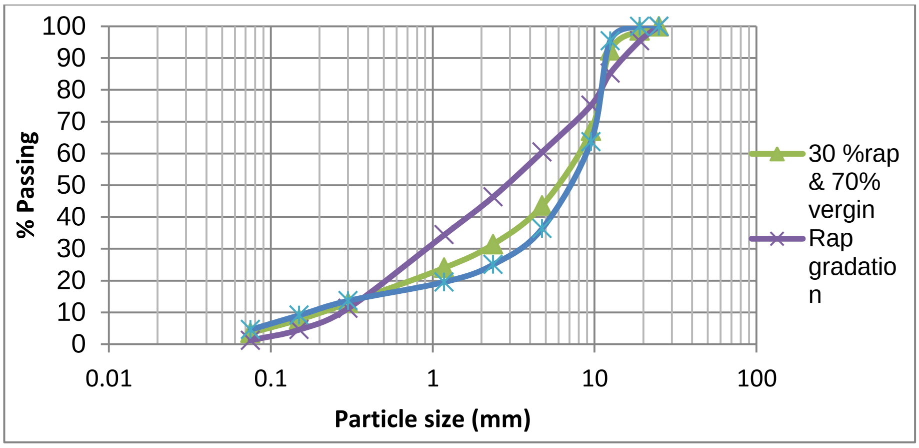

Figure 3.3: Gradation of 30% RAP and 70% virgin aggregate

By adding 30% aggregate from RAP and 70% of virgin aggregate, the gradation of new aggregate mix was modified and matches the required specification as illustrated in the table (3.3) and figure (3.3).

3.3.4. Gradation of the aggregate which is mixed of extracted 50% RAP and 50% virgin aggregate comparing with the Egyptian specifications.

Table 3.4: Gradation of mix of 50% RAP aggregate and 50% virgin aggregate

Sieve size (mm)	Percentage by Weight Passing. Egyptian Specifications		%passing of Mix
	Lower Level	Upper Level	
25	100	100	100
19	100	100	98
12.5	75	100	93
9.5	60	85	64
4.75	35	55	49
2.36	20	35	32
0.3	6	16	12
0.15	4	12	4
0.075	2	8	2

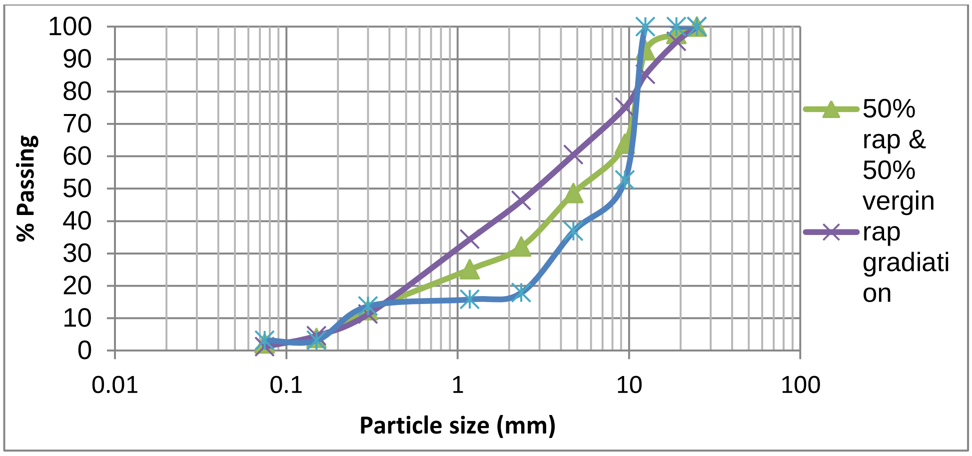

Figure 3.4: Gradation of mix of 50% RAP aggregate and 50% virgin aggregate

The percentage of RAP and virgin was changed to be 50% aggregate from RAP and 50% of virgin aggregate, the gradation of new aggregate mix was also slightly matches the required specification as illustrated in the table (3.4) and figure (3.4)

3.3.5. Gradation of the aggregate which is mixed of extracted 70% RAP and 30% virgin aggregate comparing with the Egyptian specifications.

Table 3.5: Gradation of 70% RAP aggregate and 30% virgin aggregate

Sieve size (mm)	Percentage by Weight Passing. Egyptian Specifications		%passing of Mix
	Lower Level	Upper Level	
25	100	100	100
19	100	100	97
12.5	75	100	91
9.5	60	85	81
4.75	35	55	62
2.36	20	35	37
0.3	6	16	11
0.15	4	12	5
0.075	2	8	2

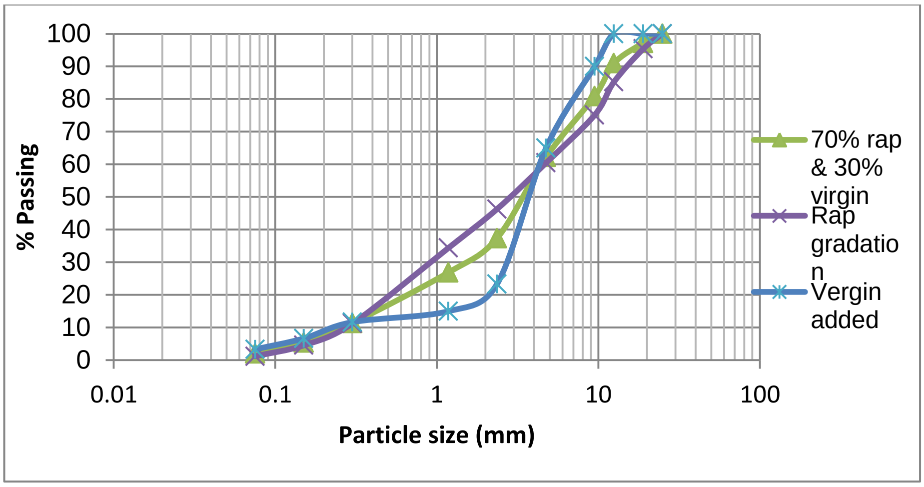

Figure 3.5: : Gradation of 70% RAP aggregate and 30% virgin aggregate

By changing the percentage of RAP and virgin to be 70% aggregate from the RAP and 30% of virgin aggregate, the gradation of new aggregate mix was hardly matches the required specification, this new percentage match the specification only after adding virgin aggregate with good grade that fill the RAP aggregate gradation. As shown in the table (3.5) and figure (3.5).

3.4. Specifications and comparison between the virgin aggregate and aggregate from RAP

Below the tests:

3.4.1. Unit weight

Unit weight is one of the most important factors required to determine the properties of aggregate. Its importance becomes obvious when calculating the mix design of asphalt pavement for aggregate. The practical density of aggregate is generally affected by the amount of moisture present, and the geological properties of aggregate. The density of aggregate has an important effect on the unit mass of asphalt pavement and the quality of aggregate needed for asphalt pavement. The determination of practical unit weight was carried according to ASTM C29

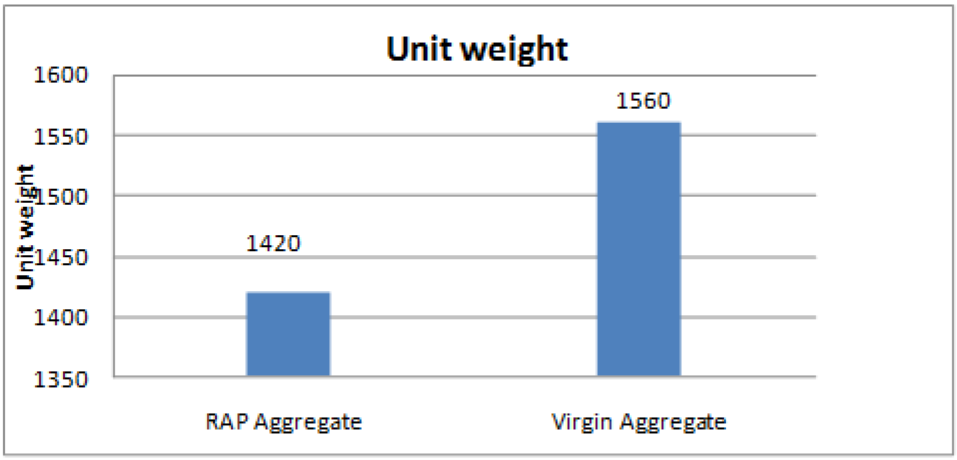

Figure 3.6: Unit weight for RAP aggregate and virgin

The Unit weight of the compacted aggregate extracted from the RAP and natural course aggregates used was. For natural aggregates only the unit weight after they were dried in an oven was measured, but RAP aggregates due to its high water absorption. The air-dried and water saturated densities were also of interest as expected. The unit weight of the RAP aggregates dried in an oven (1420 kg/m3) was smaller than the corresponding value for the virgin aggregates (1560 kg/m3).

3.4.2. Moisture Content

The amount of water content in the material, and the water content depends mainly in the amount of water which exist in course and fine aggregate.

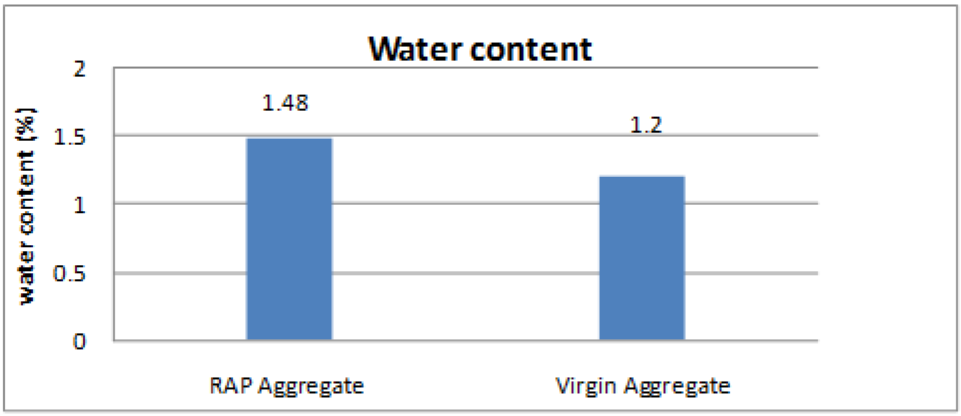

Figure 3.7: Water content for RAP aggregate and virgin

In figure (3.7) it was found that the water content of the RAP aggregate is in the normal range. However, this value would change, based on the weather conditions and season. The water content of pure RAP aggregate was 1.48% and for virgin aggregate was 1.2 %.

3.4.3. Specific Gravity

Specific gravity is defined as the weight of unit volume of aggregate to the weight of equal volume of water. Specific gravity expresses the density of the solid fraction of the aggregate, and it is used to determine the volume of aggregate in concrete as well as to determine the volume of pores.

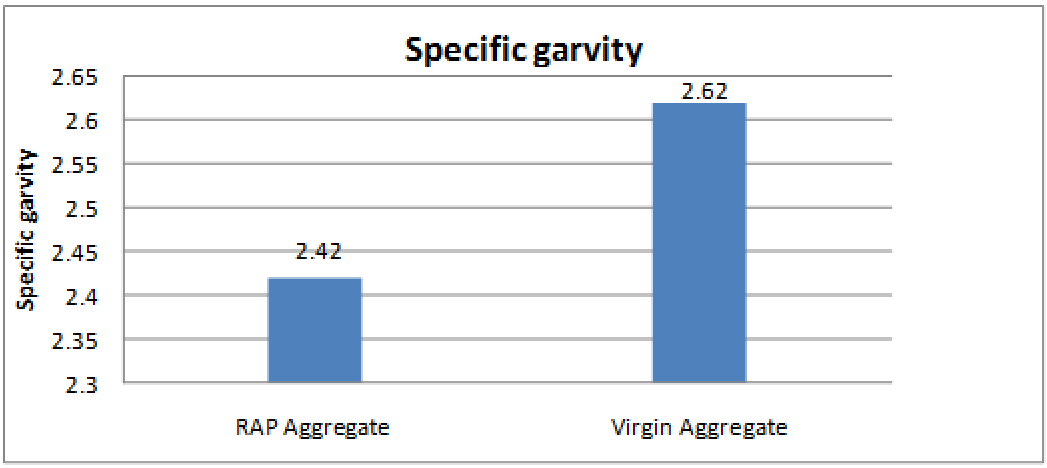

Figure 3.8: Specific gravity tests for RAP aggregate and virgin

3.4.4. Resistance to degradation (Los Angeles test)

The Los Angeles test is a measure of degradation of mineral aggregates of standard grading resulting from a combination of actions including abrasion or attrition, impact, and grinding in a rotating steel drum containing a specified number of steel spheres. The L.A. Abrasion test is widely used as an indicator of the relative quality or competence of mineral aggregates.

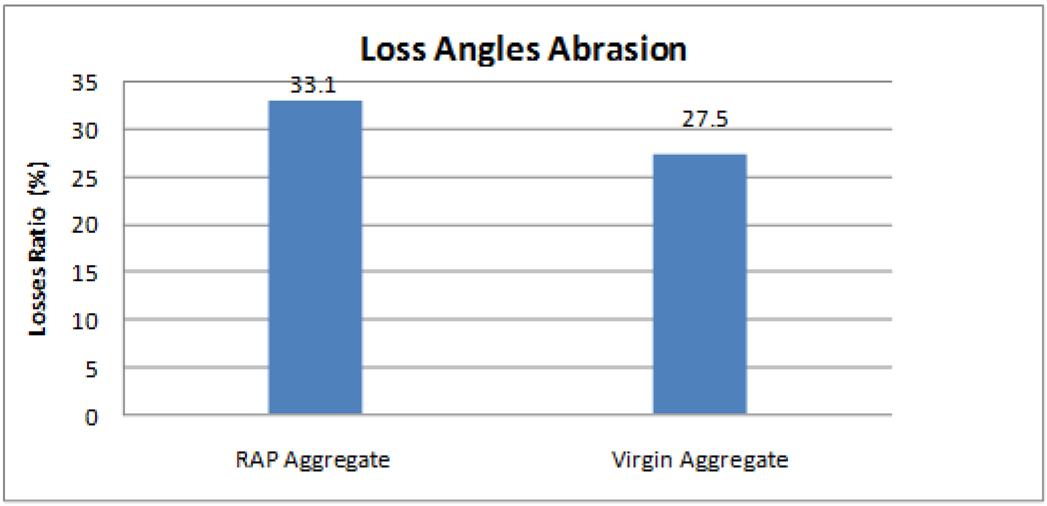

Figure 3.9: Los Angles Test for RAP aggregate and virgin

As shown in figure (3.9) the value of Loss Angles Abrasion of recycled aggregate test doesn't show a relatively high value, the average Los angles value for RAP sample at 500 revelations was 33.1. This indicates that RAP aggregate is adequate for Asphalt application.

3.5. Tests of bitumen

In this stage the experimental program, the following properties of bitumen will be measured

- Penetration test.
- Ductility test.
- Specific gravity test.
- Softening point test.

3.5.1. Bitumen penetration test

Test specification: ASTM D5-06, and the Container dimension: 75mm x75mm, then The test result is as listed in table (3.6)

Table 3.6: Bitumen penetration test

Results	Sample 1 (container dimension 75mmX 55mm)			Sample 2 (container dimension 75mmX 55mm)		
Trial	**1**	**2**	**3**	**4**	**5**	**6**
Final	73	70	69	71	74	69
Initial	0	0	0	0	0	0
Penetration Value	73	70	69	71	74	69
Average for each test	70.66			71.33		

Penetration value for material = (70.66+71.33)/2 = 70.99, The average penetration value was found 70.99 so according to the pacifications the bitumen will be in the 70/80 grade and this grade is adequate in Gaza strip.

3.5.2. *Ductility test (ASTM D113-86)*

Test specification: ASTM 113-86

The test result is as listed in table (3.9)

Table 3.7: Bitumen Ductility test results

Specimen	Ductility, cm
A	132
B	122
C	112
Sum	366
Average	122

According to the test of three samples and the average ductility is 122 c, this value fit the specification which requires to be more than 100 cm.

3.5.3. *Specific gravity test (ASTM D70)*

Test specification: ASTM D70

The test result is as listed in table (3.8)

Table 3.8: Bitumen specific gravity test results

Weight of sample (gm)	28
Weight of pycnometer + water at25ºC (gm)	1783.72
Weight of pycnometer + water at25ºC (gm) + Sample	1783.939

$$Density = \frac{28}{(1783.72 + 28) - 1783.939} = 1.007\, g/cm^3$$

Specific gravity= 1.007

3.5.4. *Softening point of bitumen (ASTMD36, 2002)*

Thermometer reading = 47.4^{o} C.

Table 3.9: Softening Point of Bitumen

Sample	Softening point (^{o}C)
A	47.5
B	47.3
Average	47.4

3.5.5. *Flash and fire point tests (ASTM D92-90)*

Test specification: ASTM D92-90

The test result is as listed in table (3.10)

Flash point: the lowest temperature at which the application of test flame causes the vapors from the bitumen to momentarily cash fire in the form of the flash

Fire point: the lowest temperature at which the application of test flame causes the the bitumen to fire and burn at least for 5 seconds.

Table 3.10: flash and fire point tests

Flash point (°C)	273
Fire point (°C)	284

3.5.6. *Summary of bitumen tests results*

Table 3.11: Summary of bitumen tests results

Test	Results	specification
Penetration (0.01 mm)	70.99	70- 80 (70/80 binder grade)
Ductility (cm)	122cm	Min 100
Softening point (°C)	47.4°C	(45 – 52)°C
Density (g/cm^3)	1.007	0.97-1.06
Flash point (°C)	273	Min 230 °C
Fire point (°C)	284	

3.5.7. *Comments on the previous results*

Penetration test: The average penetration value was found 70.99 so according to the pacifications the bitumen will be in the 70/80 grade and this grade is adequate in Gaza strip.

Ductility test : According to the test of three samples and the average ductility is 122 c, this value fit the specification which requires to be more than 100 cm.

Softening point test : this test is important so as the bitumen don't change from solid state to liquid state the result of the test is 47.4C which is within the range of the specifications.

Density and Flash point tests: the results of these test are within the specifications

Chapter 4

Sample Preparation and Testing results

4.1. Sample preparation and mix

Trial mixes were prepared as follows:

Trail A: Using 100% RAP without any virgin material taking into consideration the bitumen in the RAP

Trail B: Using 70% RAP and 30% virgin aggregate taking into consideration the bitumen in the RAP

Trail C: Using 50% RAP and 50 % virgin aggregate taking into consideration the bitumen in the RAP

Trail D: Using 30% RAP and 70% virgin aggregate taking into consideration the bitumen in the RAP

Trail F: Using 0% RAP and 100% virgin aggregate

In order to find the best mechanical properties and the optimum bitumen content for the asphalt binder course, the following procedure was applied:

Trail mixes for the gradation were carried out in the laboratory with using several percentages of bitumen (4.5%, 5%, 5.5% and 6%) for each gradation. Marshall method was adopted taking into account the percent of the bitumen in binder not to work with the Rap as black rock.

The samples were tested and their mechanical properties were determined. The results of the mechanical properties were compared with the international specifications.

Propose the gradation or the range which achieve the best mechanical properties with least bitumen content.

There are two types of aggregate; each gradation has four different percentages of bitumen (from 4.5% to 6% at 0.5% incremental). three Marshall specimens are needed for each mix, three are essential and the fourth mix is used to find the theoretical density of the bitumen. The total number of specimens was 60 Marshall Specimens as illustrated in Table (4.1).

Table 4.1: Number of Marshal Specimens

Gradation \ Bit. Ratio		4.5%	5.0%	5.5%	6.0%
0% Rap	Marshal	3	3	3	3
30% Rap	Marshal	3	3	3	3
50% Rap	Marshal	3	3	3	3
70% Rap	Marshal	3	3	3	3
100% Rap	Marshal	3	3	3	3
Total No. of samples		60			

4.2. Samples preparing

Mix design procedure was used for preparing the samples as listed below;

1. Run extraction test on the RAP samples to determine :

a- RAP aggregate gradation .

b. RAP asphalt content which was found 5.8%.

2. Prepare separated grads of virgin aggregate

3. Blend RAP and virgin aggregate to obtain a gradation which meets specifications.

4. Approximate the asphalt demand of the combined aggregates.

5. Estimate the percent of new asphalt in the mix. This is estimated with a formula in the manual.

6. Perform trial mix design using the Marshall method.

7. Draw the six chart to get the flow and stability

8. From the chart get the optimum bitumen content

4.3. Testing Program

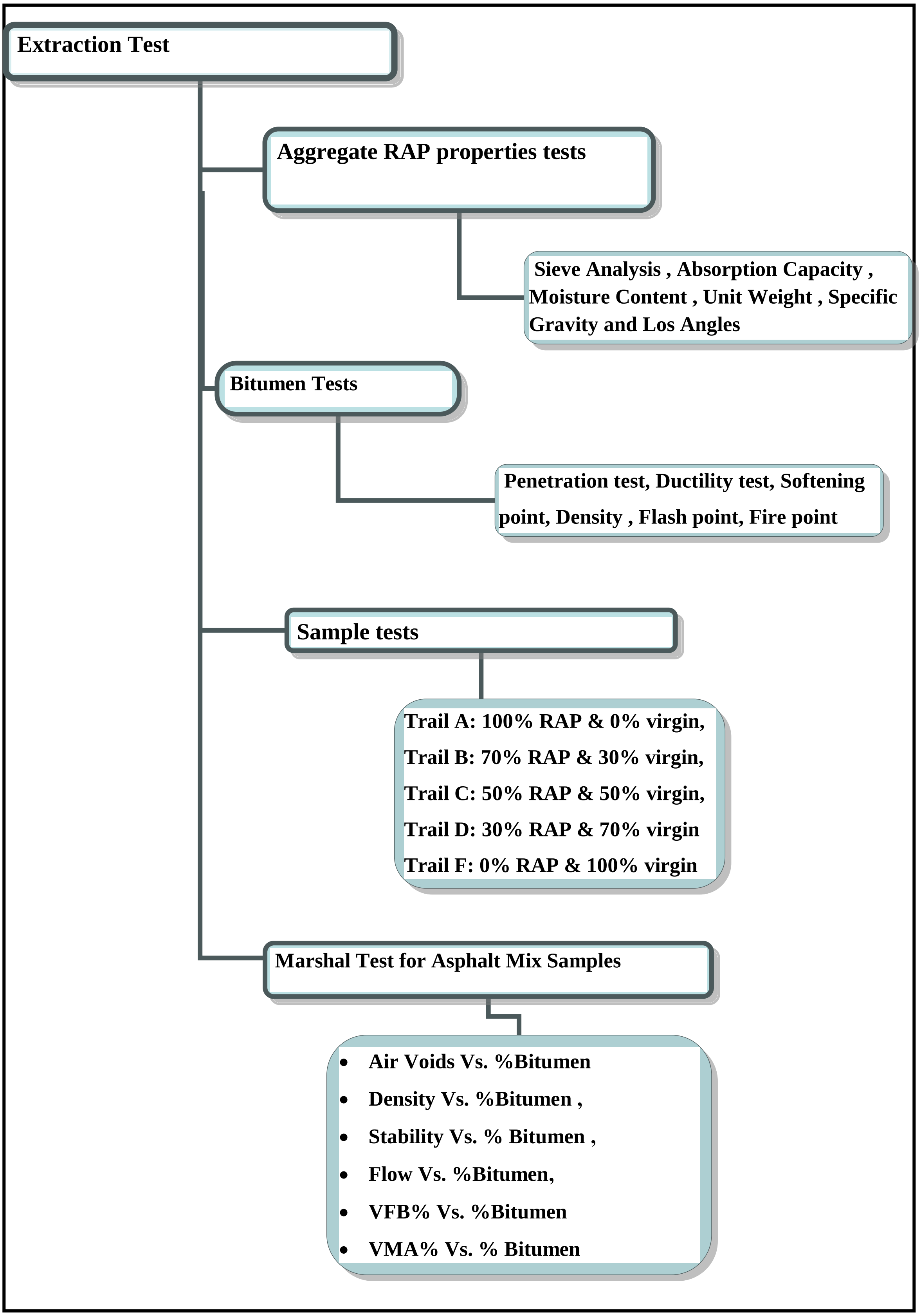

Figure 4.1: Testing program

4.4. Analysis and test results

The optimum bitumen content (OBC) for proposed mix is the average of three values of the bitumen content,

$$\text{Optimum}\,\%m_b = \frac{(\%m_b)_{Va} + (\%m_b)_{Stabilty} + (\%m_b)_{\rho a}}{3} \,(Jendia, 2000)$$

Equation 4.1 include:

a- Bitumen content at highest stability $(\%m_b)_{Stabilty}$

b- Bitumen content at highest value of bulk density $(\%m_b)_{\rho a}$

c- Bitumen content at the median of allowed percentage of air voids $(\%m_b)_{Va}$

Marshal graphs are utilized to obtained these three values

Table (4.2) show the properties of the asphalt mix using the optimum bitumen content with both recycled and conventional aggregate.

4.5. Trial A: mix of 0% RAP and 100% Virgin aggregate

Table (4.2) shows when added 100 % virgin aggregate to asphalt mix the curve will be within the Egyptian specification for the coarse aggregate in Asphalt binder course. Figures (4.1) to (4.6) presents the mechanical properties of asphalt mix with different bitumen contents.

Table 4.2: mechanical properties of asphalt mix with different bitumen content for mix of 0% RAP and 100% virgin

Bitumen Content 4.5 %										
Sample#	**Volume(cm3)**	**Corr. stability(Kg)**	**Flow (mm)**	**Stiffness (kg/mm)**	**ρ_A (g/cm3)**	**ρ_{bit} (g/cm3)**	**V_a %**	**V_b %**	**VMA %**	**VFB %**
1	496.40	1107.00	2.80	395.36	2.28	2.44	6.65	10.10	16.76	60.28
2	494.00	1078.00	2.90	371.72	2.28	2.44	6.78	10.09	17.87	56.45
3	497.90	1045.00	3.25	321.54	2.30	2.44	5.87	10.19	17.05	59.73
Average	**496.10**	**1076.67**	**2.98**	**362.87**	**2.29**	**2.44**	**6.43**	**10.12**	**17.23**	**58.82**
Bitumen Content 5 %										
Sample#	**Volume(cm3)**	**Corr. stability(Kg)**	**Flow (mm)**	**Stiffness (kg/mm)**	**ρ_A (g/cm3)**	**ρ_{bit} (g/cm3)**	**V_a %**	**V_b %**	**VMA %**	**VFB %**
1	512.00	1416.73	3.60	393.54	2.30	2.45	5.74	11.34	17.08	66.40
2	519.80	1387.48	3.40	408.08	2.31	2.45	5.46	11.38	16.84	67.56
3	517.50	1426.31	3.60	396.20	2.30	2.45	6.03	11.31	17.34	65.22
Average	**516.43**	**1410.17**	**3.53**	**399.27**	**2.30**	**2.45**	**5.74**	**11.34**	**17.08**	**66.40**

Bitumen Content 5.5 %										
Sample#	**Volume(cm3)**	**Corr. stability(Kg)**	**Flow (mm)**	**Stiffness (kg/mm)**	**ρ_A (g/cm3)**	**ρ_{bit} (g/cm3)**	**V_a %**	**V_b %**	**VMA %**	**VFB %**
1	507.85	1507.00	3.70	407.30	2.31	2.44	5.05	12.53	14.78	84.78
2	511.60	1578.00	3.80	415.26	2.30	2.44	5.50	12.47	17.97	69.39
3	509.64	1568.00	3.78	414.81	2.33	2.44	4.42	12.61	17.03	74.06
Average	**509.70**	**1551.00**	**3.76**	**412.46**	**2.32**	**2.44**	**4.99**	**12.54**	**16.60**	**76.08**

Bitumen Content 6%										
Sample#	**Volume(cm3)**	**Corr. stability(Kg)**	**Flow (mm)**	**Stiffness (kg/mm)**	**ρ_A (g/cm3)**	**ρ_{bit} (g/cm3)**	**V_a %**	**V_b %**	**VMA %**	**VFB %**
1	511.90	1555.05	4.20	370.25	2.30	2.44	3.85	13.37	17.22	77.64
2	523.24	1486.60	4.10	362.59	2.29	2.44	4.00	13.34	17.34	76.93
3	504.90	1385.17	3.90	355.17	2.29	2.44	3.50	13.37	16.87	65.20
Average	**513.35**	**1475.61**	**4.07**	**362.67**	**2.29**	**2.44**	**3.78**	**13.36**	**17.14**	**73.26**

Figures (4.2) to (4.7) show the mechanical properties of asphalt 0% RAP and 100% virgin

Air Voids Vs. Bitumen %

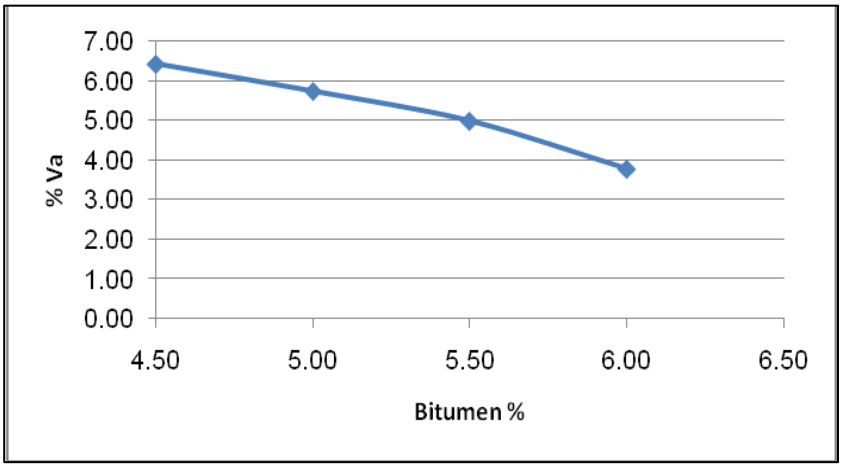

Figure 4.2: Air Voids Vs. % Bitumen for 0% RAP and 100% virgin

Density Vs. % Bitumen

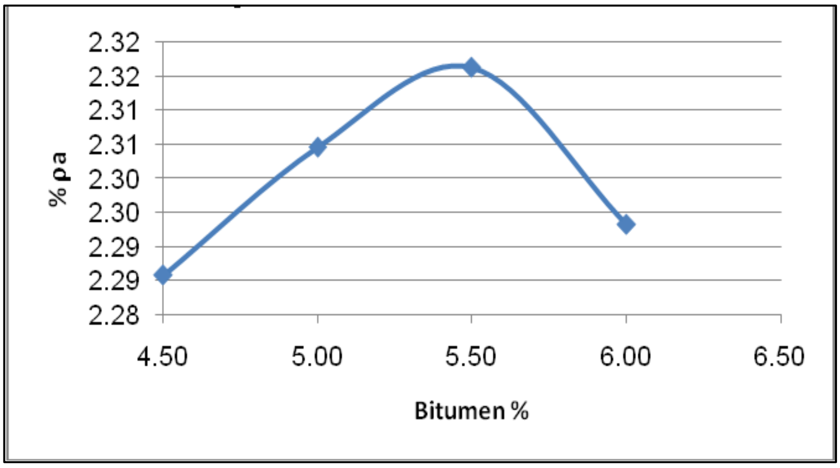

Figure 4.3: Density Vs. % Bitumen for 0% RAP and 100% virgin

Stability Vs. % Bitumen

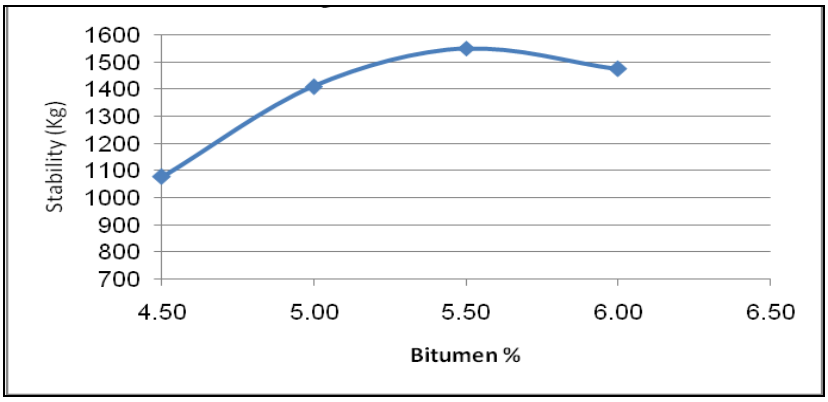

Figure 4.4: Stability Vs. %Bitumen for 0% RAP and 100% virgin

Flow Vs. Bitumen %

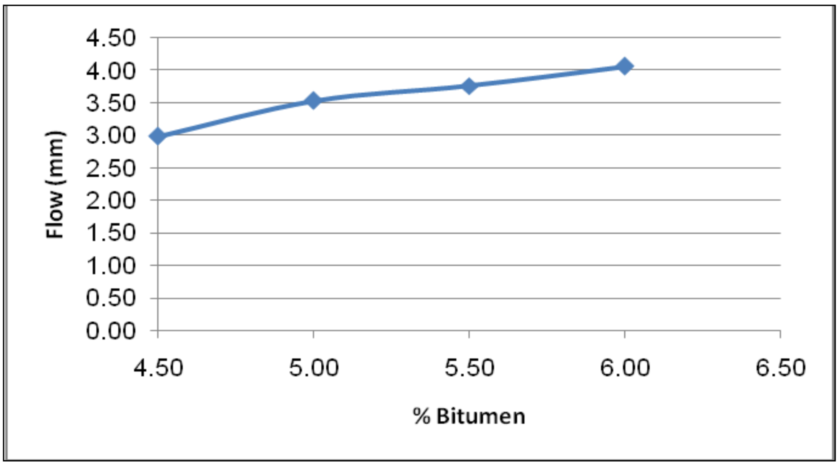

Figure 4.5: Stability Vs. %Bitumen for 0% RAP and 100% virgin

VFB% Vs. Bitumen %

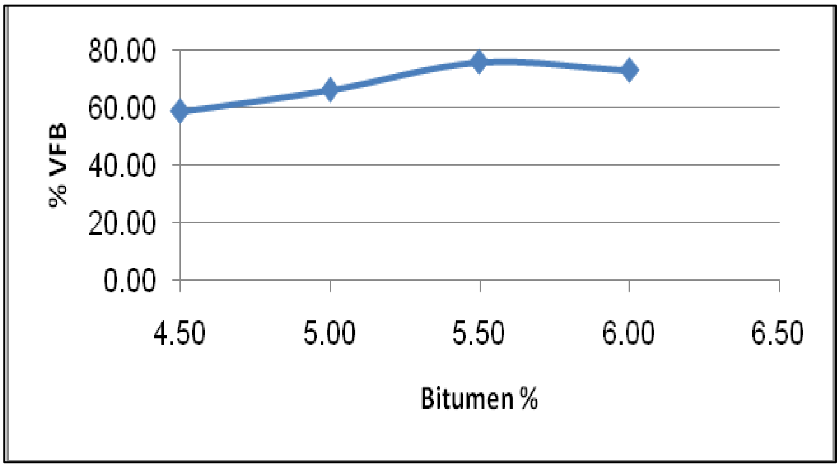

Figure 4.6: VFB% Vs. %Bitumen for 0% RAP and 100% virgin

VMA% Vs. Bitumen %

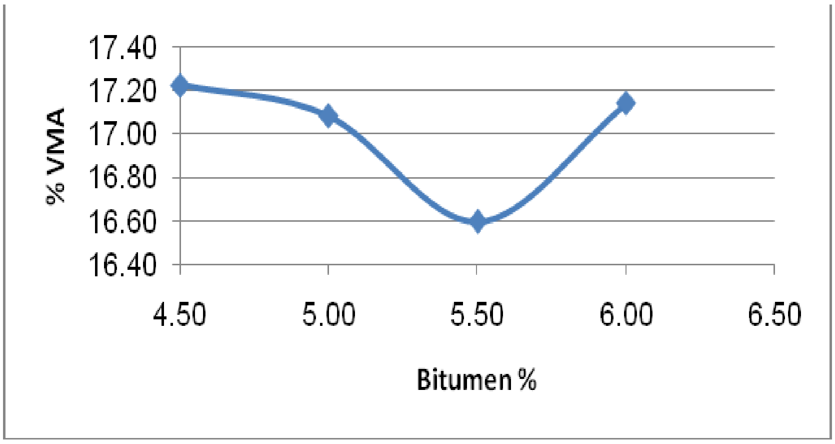

Figure 4.7: VMA% Vs. %Bitumen for 0% RAP and 100% virgin

Calculation of the optimum bitumen percentage

$$\text{Optimum}\,\%m_b = \frac{(\%m_b)_{Va} + (\%m_b)_{Stabilty} + (\%m_b)_{\rho a}}{3}$$

$$\text{Mb\%} = \frac{5.5 + 5.5 + 5.4}{3} = 5.47\%$$

Table 4.3: Calculation of the optimum bitumen percentage 0% RAP and 100% virgin

Properties	value	MOG Spc, 1998 (Local)	
		Min.	Max.
Stability (kg)	1550	900	-
Flow (mm)	3.7	2	4
Air void Va (%)	5.0	3	7
VMA (%)	16.6	13.5	-
Bulk density (Pa)	2.32	2.3	-

From the results from table (4.3), it is noted that when it is used 100% virgin aggregate it is found that the stability will be acceptable, and also the flow will be within the rang with the a specific aggregate gradation the bitumen content will be 5.47%

4.6. Trial B: mix of 30% Rap and 70% Virgin aggregate

In this section, the curve, the outputs of job mix with different bitumen contents, The table 4.4 shows when added 30 % RAP aggregate to asphalt mix the curve it will be within the range of Egyptian specification for the coarse aggregate in Asphalt binder course. Figures (4.8) to (4.13) presents the mechanical properties of asphalt mix with different bitumen contents.

Table 4.4: Mechanical properties of asphalt mix with different bitumen content between for mix of 30% RAP and 70% virgin

Bitumen Content 4.5 %										
Sample#	**Volume(cm3)**	**Corr. stability(Kg)**	**Flow (mm)**	**Stiffness (kg/mm)**	**ρ_A (g/cm3)**	**ρ_{bit} (g/cm3)**	**V_a %**	**V_b %**	**VMA %**	**VFB %**
1	509.70	1281.00	2.30	556.96	2.27	2.44	6.66	10.07	17.50	57.53
2	507.80	1271.15	2.50	508.46	2.29	2.44	6.00	10.14	16.14	62.82
3	501.00	1361.07	2.70	504.10	2.29	2.44	5.93	10.15	16.08	63.11
Average	**506.17**	**1304.41**	**2.50**	**523.17**	**2.28**	**2.44**	**6.20**	**10.12**	**16.57**	**61.15**
Bitumen Content 5 %										
Sample#	**Volume(cm3)**	**Corr. stability(Kg)**	**Flow (mm)**	**Stiffness (kg/mm)**	**ρ_A (g/cm3)**	**ρ_{bit} (g/cm3)**	**V_a %**	**V_b %**	**VMA %**	**VFB %**
1	499.90	1393.80	2.90	480.62	2.32	2.45	4.60	11.43	16.03	71.30
2	522.33	1383.20	3.05	453.51	2.31	2.45	5.55	11.37	16.91	67.21
3	528.35	1475.80	3.10	476.06	2.28	2.45	6.83	11.21	18.04	62.13
Average	**516.86**	**1417.60**	**3.02**	**470.06**	**2.30**	**2.45**	**5.66**	**11.34**	**16.99**	**66.88**

Bitumen Content 5.5 %										
Sample#	**Volume(cm3)**	**Corr. stability(Kg)**	**Flow (mm)**	**Stiffness (kg/mm)**	**ρA (g/cm3)**	**ρbit (g/cm3)**	**V_a %**	**V_b %**	**VMA %**	**VFB %**
1	512.93	1462.50	3.00	487.50	2.32	2.44	5.17	12.54	17.71	70.80
2	509.68	1460.22	3.15	463.56	2.32	2.44	5.20	12.55	17.75	70.70
3	502.27	1369.88	2.95	464.36	2.32	2.44	4.83	12.58	17.41	72.28
Average	**508.29**	**1430.87**	**3.03**	**471.81**	**2.32**	**2.44**	**5.07**	**12.55**	**17.62**	**71.26**
Bitumen Content 6%										
Sample#	**Volume(cm3)**	**Corr. stability(Kg)**	**Flow (mm)**	**Stiffness (kg/mm)**	**ρA (g/cm3)**	**ρbit (g/cm3)**	**V_a %**	**V_b %**	**VMA %**	**VFB %**
1	527.55	1247.00	4.00	311.75	2.28	2.44	4.52	13.27	18.79	77.00
2	523.70	1190.55	4.20	283.46	2.29	2.44	3.95	13.33	18.28	72.92
3	524.15	1108.05	3.90	284.11	2.29	2.44	3.78	13.36	18.14	73.66
Average	**525.13**	**1181.86**	**4.03**	**293.11**	**2.29**	**2.44**	**4.08**	**13.32**	**18.40**	**74.53**

Figures (4.8) to (4.13) show mechanical properties of asphalt 30% RAP and 70% virgin

Air Voids Vs.
% Bitumen

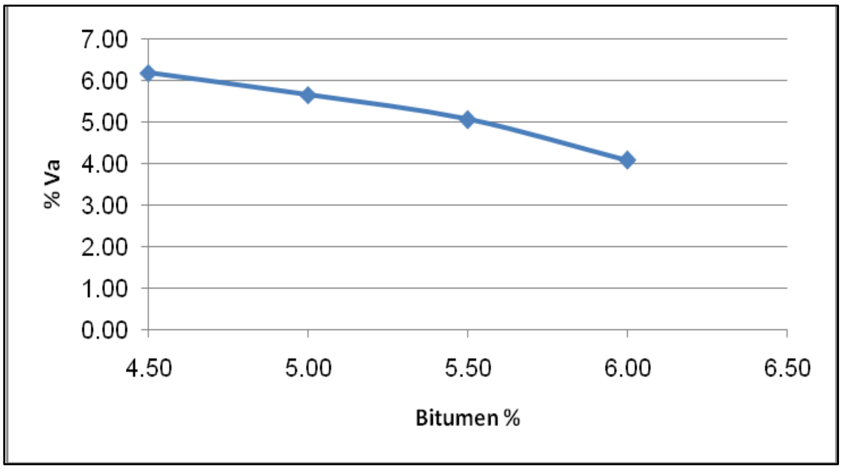

Figure 4.8: Air Voids Vs. % Bitumen for 30% RAP and 70% virgin

Density Vs.
% Bitumen

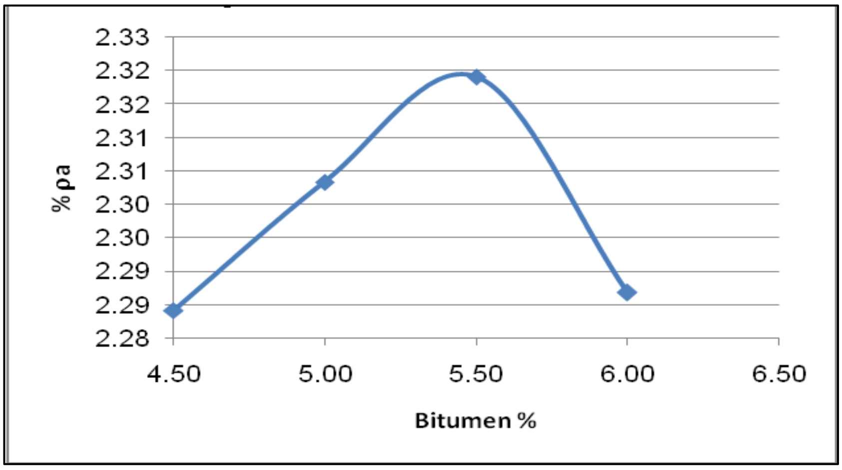

Figure 4.9: Density Vs. % Bitumen for 30% RAP and 70% virgin

Stability Vs.
% Bitumen

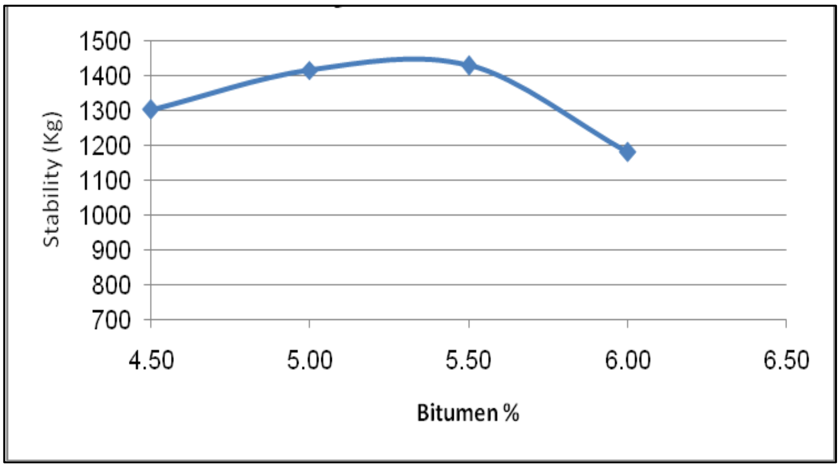

Figure 4.10: Stability Vs. %Bitumen for 30% RAP and 70% virgin

Flow Vs. Bitumen %

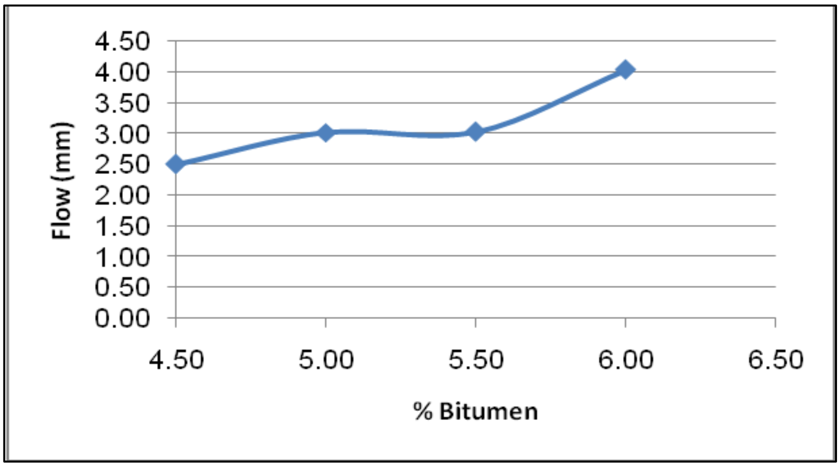

Figure 4.11: Stability Vs. %Bitumen for 30% RAP and 70% virgin

VFB% Vs. Bitumen %

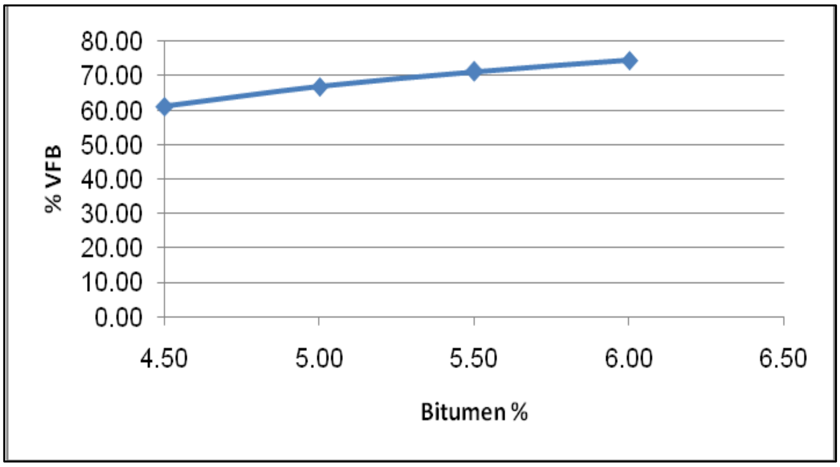

Figure 4.12: VFB% Vs. %Bitumen for 30% RAP and 70% virgin

VMA% Vs. Bitumen %

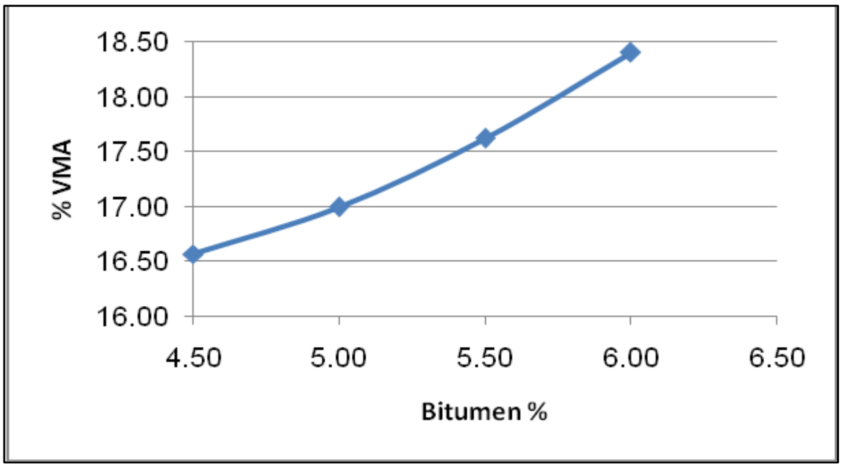

Figure 4.13: VMA% Vs. %Bitumen for 30% RAP and 70% virgin

Calculation of the optimum bitumen percentage

$$Mb\% = \frac{5.5 + 5.4 + 5.4}{3} = 5.43\%.$$

Table 4.5: Calculation of the optimum bitumen percentage for 30% RAP and 70% virgin

Properties	value	MOG Spc, 1998 (Local)	
		Min.	Max.
Stability (kg)	1430	900	-
Flow (mm)	3.03	2	4
Air void Va (%)	5.07	3	7
VMA (%)	17.2	13.5	-
Bulk density (Pa)	2.32	2.3	-

From the results of the table its noted that when 30% virgin aggregate and 70% Rap used its found that the stability will be satisfy and within the specification , and also the flow will be within the range of the specification, with the a specific aggregate gradation the bitumen content will be 5.43% and it is not that adding percent of the rap will increase.

4.7. Trial C: mix of 50% Rap and 50% Virgin aggregate

In this section, the curve, the outputs of job mix with different bitumen contents, The table 4.6 shows when added 50 % RAP aggregate to asphalt mix the curve it will be within the range of Egyptian specification for the coarse aggregate in Asphalt binder course.

The figures (4.14) to (4.19) presents the mechanical properties of asphalt mix with different bitumen contents.

Table 4.6: mechanical properties of asphalt mix with different bitumen content between for mix of 50% RAP and 50% virgin

Bitumen Content 4.5 %										
Sample#	**Volume(cm3)**	**Corr. stability(Kg)**	**Flow (mm)**	**Stiffness (kg/mm)**	**ρA (g/cm3)**	**ρbit (g/cm3)**	**V_a %**	**V_b %**	**VMA %**	**VFB %**
1	525.80	986.00	2.81	350.89	2.22	2.45	9.33	9.84	19.17	51.32
2	531.00	758.00	2.95	256.95	2.26	2.45	7.62	10.02	17.65	56.81
3	491.10	845.00	3.10	272.58	2.36	2.45	3.71	10.45	17.25	60.57
Average	**515.97**	**863.00**	**2.95**	**293.47**	**2.28**	**2.45**	**6.89**	**10.10**	**18.02**	**56.24**
Bitumen Content 5 %										
Sample#	**Volume(cm3)**	**Corr. stability(Kg)**	**Flow (mm)**	**Stiffness (kg/mm)**	**ρA (g/cm3)**	**ρbit (g/cm3)**	**V_a %**	**V_b %**	**VMA %**	**VFB %**
1	516.10	1025.00	3.65	280.82	2.30	2.44	6.12	11.30	17.42	72.40
2	506.20	1064.30	3.78	281.56	2.35	2.44	6.25	11.56	17.81	71.30
3	535.50	1105.90	3.68	300.52	2.28	2.44	6.48	11.07	17.55	63.09
Average	**519.27**	**1065.07**	**3.70**	**287.63**	**2.31**	**2.44**	**6.28**	**11.31**	**17.59**	**68.93**

Bitumen Content 5.5 %										
Sample#	**Volume(cm3)**	**Corr. stability(Kg)**	**Flow (mm)**	**Stiffness (kg/mm)**	**ρ_A (g/cm3)**	**ρ_{bit} (g/cm3)**	**V_a %**	**V_b %**	**VMA %**	**VFB %**
1	518.92	1140.97	3.80	300.25	2.30	2.43	5.19	12.47	17.66	70.60
2	514.50	1218.60	3.50	348.17	2.33	2.43	3.91	12.64	16.55	76.36
3	500.50	1175.37	3.60	326.49	2.33	2.43	3.92	12.64	16.55	76.35
Average	**511.31**	**1178.31**	**3.63**	**324.97**	**2.32**	**2.43**	**4.34**	**12.58**	**16.92**	**74.44**
Bitumen Content 6 %										
Sample#	**Volume(cm3)**	**Corr. stability(Kg)**	**Flow (mm)**	**Stiffness (kg/mm)**	**ρ_A (g/cm3)**	**ρ_{bit} (g/cm3)**	**V_a %**	**V_b %**	**VMA %**	**VFB %**
1	523.95	1071.16	4.20	255.04	2.29	2.43	4.25	13.33	17.58	73.00
2	525.42	1211.25	4.50	269.17	2.29	2.43	4.15	13.32	17.47	76.25
3	533.97	1217.30	3.85	316.18	2.28	2.43	4.18	13.25	17.43	72.00
Average	**527.78**	**1166.57**	**4.18**	**280.13**	**2.28**	**2.43**	**4.19**	**13.30**	**17.49**	**73.75**

Figures (4.14) to (4.19) show mechanical properties of asphalt 50% RAP and 50% virgin

Air Voids Vs. Bitumen%

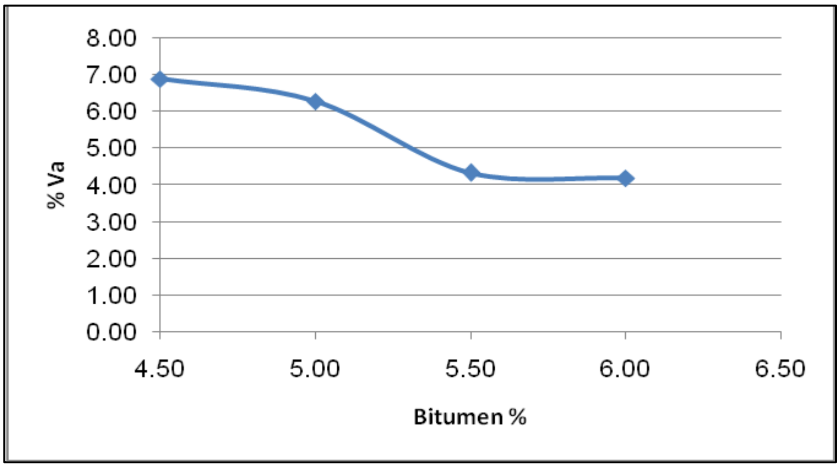

Figure 4.14: Air Voids Vs. % Bitumen for 50% RAP and 50% virgin

Density Vs. Bitumen%

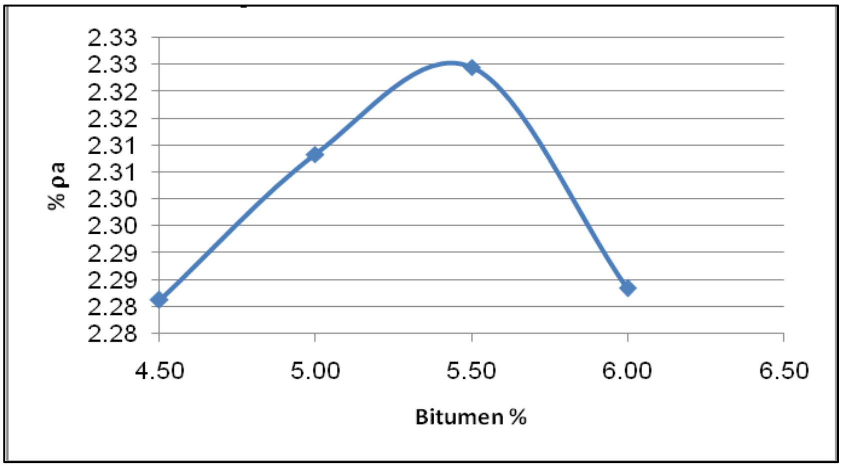

Figure 4.15: Density Vs. % Bitumen for 50% RAP and 50% virgin

Stability Vs. Bitumen%

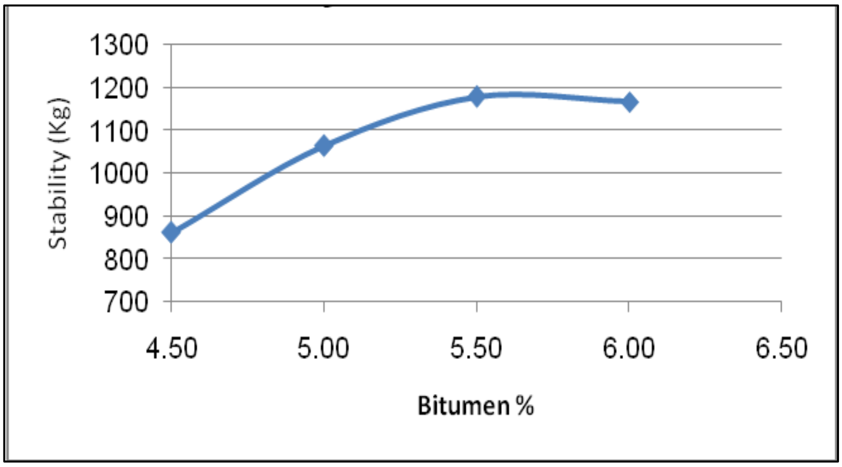

Figure 4.16: Stability Vs. %Bitumen for 50% RAP and 50% virgin

Flow Vs. Bitumen %

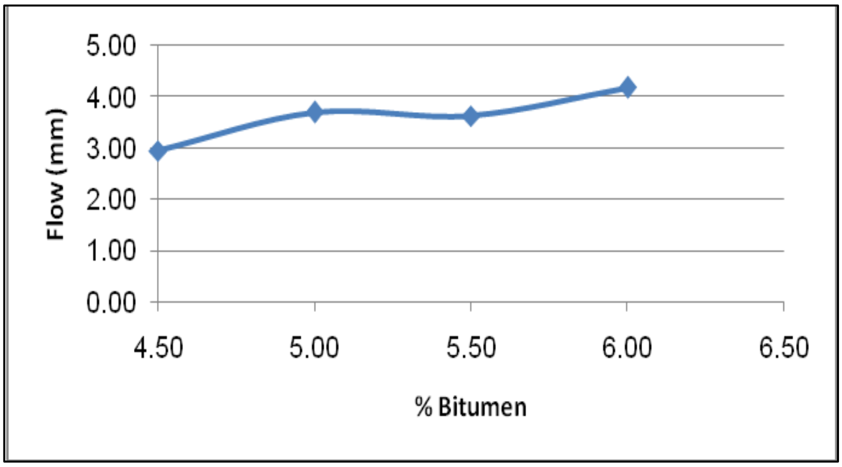

Figure 4.17: Stability Vs. %Bitumen for 50% RAP and 50% virgin

VFB% Vs. Bitumen %

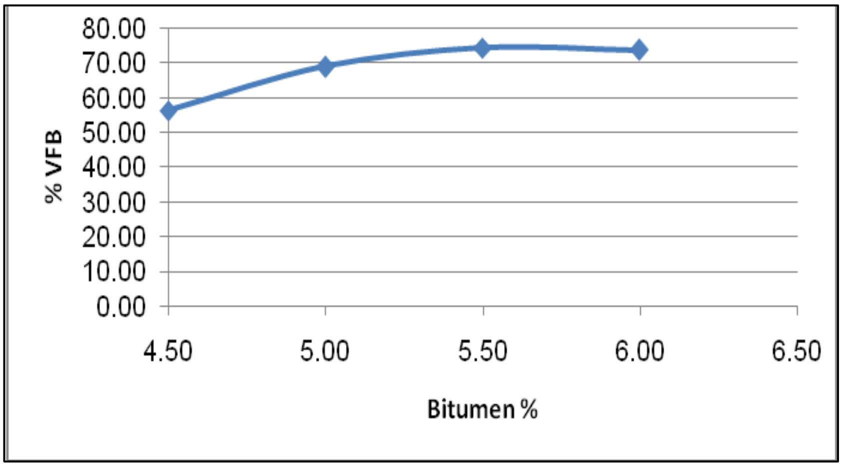

Figure 4.18: VFB% Vs. %Bitumen for 50% RAP and 50% virgin

VMA% Vs. Bitumen %

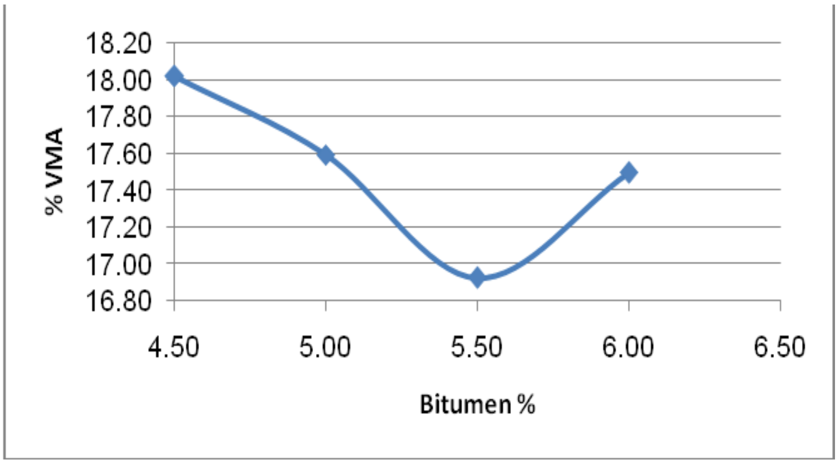

Figure 4.19: VMA% Vs. %Bitumen for 50% RAP and 50% virgin

Calculation of the optimum bitumen percentage

$$Mb\% = \frac{5.28 + 5.65 + 5.45}{3} = 5.46\% .$$

Table 4.7: mechanical properties of asphalt mix with different bitumen content between for mix of 50% RAP and 50% virgin

Properties	value	MOG Spc, 1998 (Local)	
		Min.	Max.
Stability (kg)	1170	900	-
Flow (mm)	3.7	2	4
Air void Va (%)	4.4	3	7
VMA (%)	16.9	13.5	-
Bulk density (Pa)	2.33	2.3	-

From the results of the table its noted that when we 50% virgin aggregate and 50% Rap used its found that the stability will be satisfy and within the specification but the stability decrees when increasing the percent of the of rap added , and also the flow will be within the range of the specification but it is high when comparing the flow in less percent of rap, with the a specific aggregate gradation the bitumen content will be 5.46% and we note that when adding percent of the rap the percent of bitumen will increase.

4.8. Trial D: mix of 70% Rap and 30% Virgin aggregate

In this section, the curve, the outputs of job mix with different bitumen contents,

The table (4.8) shows when added 70 % RAP aggregate to asphalt mix, the curve will not be within the range of Egyptian specification for the coarse aggregate in Asphalt binder course.

The figures (4.20) to (4.25) present the mechanical properties of asphalt mix with different bitumen contents.

Table 4.8: mechanical properties of asphalt mix with different bitumen content for mix of 70% RAP and 30% virgin

Bitumen Content 4.5 %										
Sample#	**Volume(cm3)**	**Corr. stability(Kg)**	**Flow (mm)**	**Stiffness (kg/mm)**	**ρA (g/cm3)**	**ρbit (g/cm3)**	**V_a %**	**V_b %**	**VMA %**	**VFB %**
1	512.90	766.82	4.20	182.58	2.25	2.45	8.30	9.95	18.25	54.52
2	517.00	721.31	4.10	175.93	2.28	2.45	6.98	10.09	17.07	59.14
3	499.90	778.09	3.86	201.58	2.29	2.45	6.36	10.16	16.53	61.48
Average	**509.93**	**698.00**	**4.05**	**186.69**	**2.27**	**2.45**	**7.21**	**10.07**	**17.28**	**58.38**
Bitumen Content 5.0 %										
Sample#	**Volume(cm3)**	**Corr. stability(Kg)**	**Flow (mm)**	**Stiffness (kg/mm)**	**ρA (g/cm3)**	**ρbit (g/cm3)**	**V_a %**	**V_b %**	**VMA %**	**VFB %**
1	515.00	810.69	4.50	180.15	2.29	2.43	5.87	11.26	17.13	65.73
2	528.50	765.44	5.00	153.09	2.28	2.43	6.25	11.21	17.46	64.21
3	534.50	784.05	4.00	196.01	2.28	2.43	6.30	11.21	17.51	64.01
Average	**526.00**	**786.73**	**4.50**	**176.42**	**2.28**	**2.43**	**6.14**	**11.22**	**17.36**	**64.65**

Bitumen Content 5.5 %										
Sample#	**Volume(cm3)**	**Corr. stability(Kg)**	**Flow (mm)**	**Stiffness (kg/mm)**	**ρ_A (g/cm3)**	**ρ_{bit} (g/cm3)**	**V_a %**	**V_b %**	**VMA %**	**VFB %**
1	518.20	807.17	5.30	152.30	2.29	2.43	5.85	12.39	18.23	67.93
2	525.00	751.97	5.70	131.92	2.29	2.43	5.67	12.41	18.08	68.63
3	510.60	840.87	5.70	147.52	2.29	2.43	5.67	12.41	18.08	68.65
Average	**517.93**	**800.00**	**5.57**	**143.91**	**2.29**	**2.43**	**5.73**	**12.40**	**18.13**	**68.40**
Bitumen Content 6.0 %										
Sample#	**Volume(cm3)**	**Corr. stability(Kg)**	**Flow (mm)**	**Stiffness (kg/mm)**	**ρ_A (g/cm3)**	**ρ_{bit} (g/cm3)**	**V_a %**	**V_b %**	**VMA %**	**VFB %**
1	524.50	698.29	6.20	112.63	2.29	2.42	5.38	13.34	18.72	71.26
2	503.70	845.64	6.42	131.72	2.28	2.42	6.00	13.28	19.28	68.87
3	515.10	802.62	6.70	119.79	2.27	2.42	6.18	13.23	19.41	68.15
Average	**514.43**	**782.18**	**6.44**	**121.38**	**2.28**	**2.42**	**5.85**	**13.28**	**19.13**	**69.43**

Figures 4.20 to 4.25 show mechanical properties of asphalt 70% RAP and 30% virgin

Air Voids Vs. Bitumen%

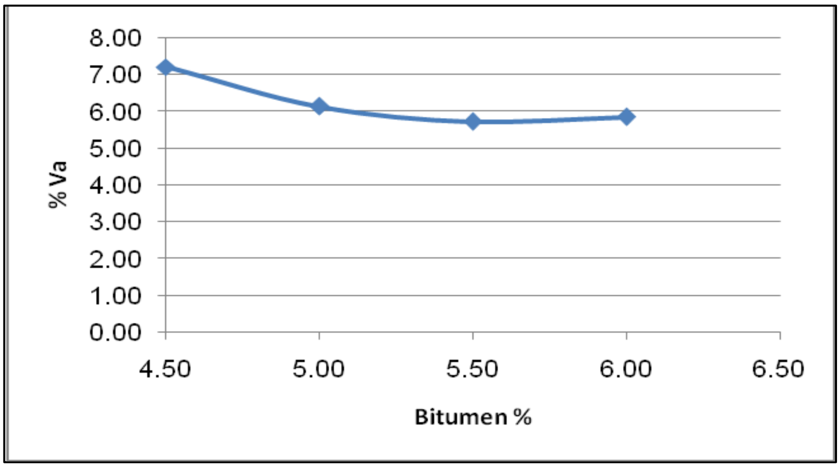

Figure 4.20: Air Voids Vs. % Bitumen for 70% RAP and 30% virgin

Density Vs. Bitumen%

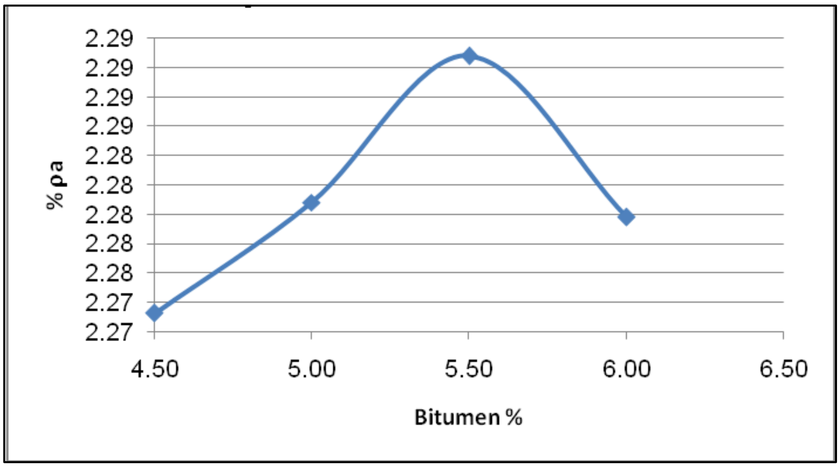

Figure 4.21: Density Vs. % Bitumen for 70% RAP and 30% virgin

Stability Vs. Bitumen%

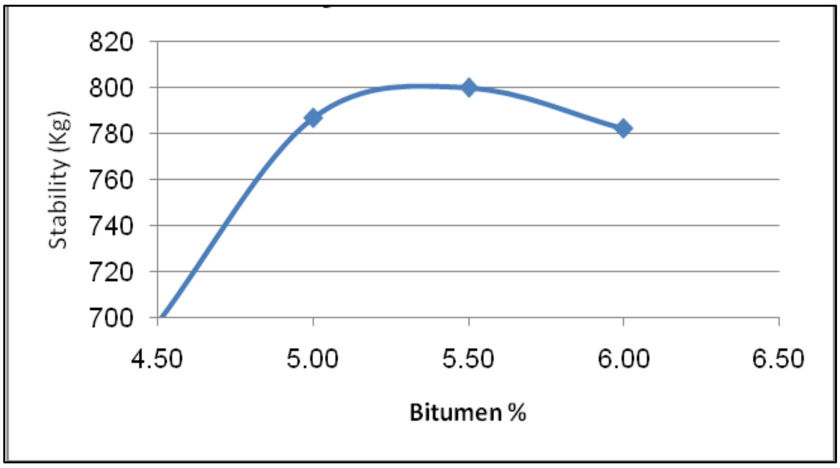

Figure 4.22: Stability Vs. %Bitumen for 70% RAP and 30% virgin

Flow Vs. Bitumen %

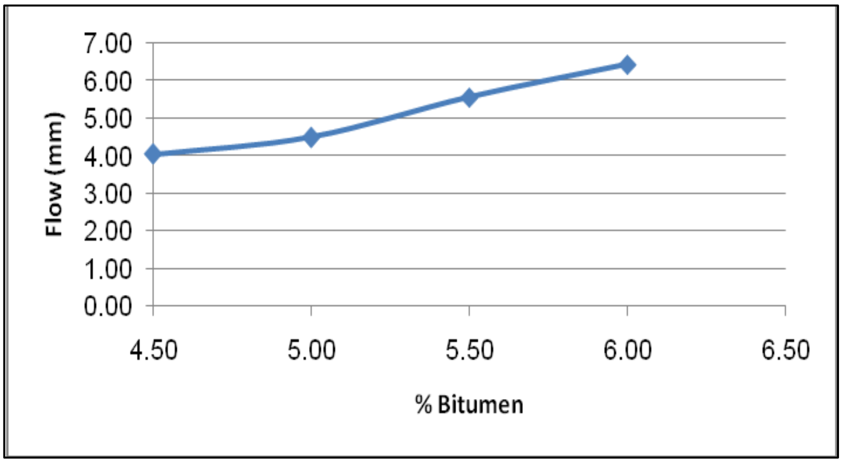

Figure 4.23: Stability Vs. %Bitumen for 70% RAP and 30% virgin

VFB% Vs. Bitumen %

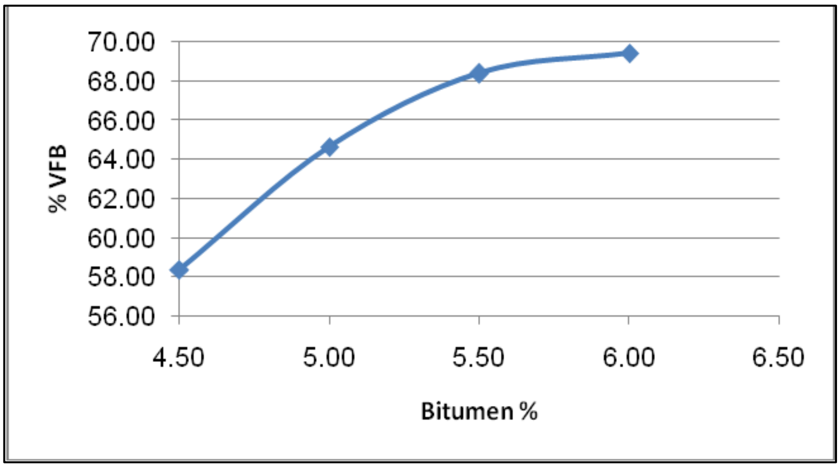

Figure 4.24: VFB% Vs. %Bitumen for 70% RAP and 30% virgin

VMA% Vs. Bitumen %

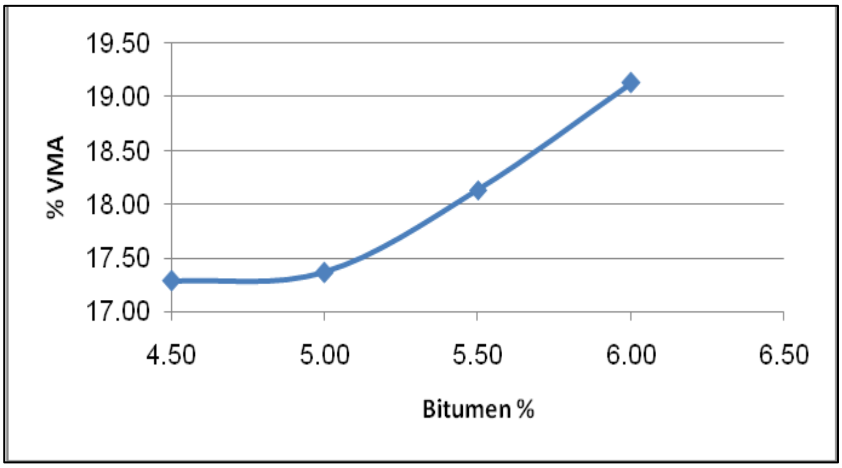

Figure 4.25: VMA% Vs. %Bitumen for 70% RAP and 30% virgin

Calculation of the optimum bitumen percentage

$$Mb\% = \frac{6+5.6+5.6}{3} = 5.7\%.$$

Table 4.9: Calculation of the optimum bitumen percentage for 70% RAP and 30% virgin

Properties	value	MOG Spc, 1998 (Local)	
		Min.	Max.
Stability (kg)	All values are less than 800	900	-
Flow (mm)	All flow values are more than 4	2	4
Air void Va (%)	-	3	7
VMA (%)	-	13.5	-
Bulk density (Pa)	-	2.3	-

From the results of the table its noted that when 30% virgin aggregate and 70% Rap used its found that the stability is not satisfy the specification and the stability decrease when increasing the percent of the of rap added , the flow is high and is not within the range of the specification, and we note that when adding percent of the rap the percent of bitumen will increase, so the previous mix not succeeded

4.9. Trial E: mix of 100% Rap and 0% Virgin aggregate

In this section, the curve, the outputs of job mix with different bitumen contents, The table 4.10 show when added 0 % virgin aggregate to asphalt mix the curve will not locate with of Egyptian specification for the coarse aggregate in Asphalt binder course.

The figures 4.26 to 4.31 show the mechanical properties of asphalt mix with different bitumen contents.

Table 4.10: mechanical properties of asphalt mix with different bitumen content for mix of 100% RAP and 0% virgin

Bitumen Content 4.5 %										
Sample#	**Volume(cm3)**	**Corr. stability(Kg)**	**Flow (mm)**	**Stiffness (kg/mm)**	**ρ_A (g/cm3)**	**ρ_{bit} (g/cm3)**	**V_a %**	**V_b %**	**VMA %**	**VFB %**
1	515.40	532.95	4.30	123.94	2.23	2.42	7.70	9.89	17.60	56.23
2	514.00	475.38	4.20	113.18	2.25	2.42	7.06	9.96	17.03	58.51
3	517.90	562.03	4.10	137.08	2.21	2.42	8.64	9.79	18.43	53.12
Average	**515.77**	**523.45**	**4.20**	**124.74**	**2.23**	**2.42**	**7.80**	**9.88**	**17.69**	**55.95**
Bitumen Content 5.0 %										
Sample#	**Volume(cm3)**	**Corr. stability(Kg)**	**Flow (mm)**	**Stiffness (kg/mm)**	**ρ_A (g/cm3)**	**ρ_{bit} (g/cm3)**	**V_a %**	**V_b %**	**VMA %**	**VFB %**
1	522.00	562.36	5.00	112.47	2.26	2.42	6.63	11.12	17.75	62.66
2	529.80	538.61	4.70	114.60	2.27	2.42	6.33	11.16	17.49	63.82
3	522.50	558.38	4.60	121.39	2.28	2.42	6.01	11.20	17.20	65.09
Average	**524.77**	**553.12**	**4.77**	**116.15**	**2.27**	**2.42**	**6.32**	**11.16**	**17.48**	**63.86**

Bitumen Content 5.5 %										
Sample#	**Volume(cm3)**	**Corr. stability(Kg)**	**Flow (mm)**	**Stiffness (kg/mm)**	**ρ_A (g/cm3)**	**ρ_{bit} (g/cm3)**	**V_a %**	**V_b %**	**VMA %**	**VFB %**
1	523.85	684.35	5.20	131.61	2.24	2.42	7.27	12.15	19.41	62.57
2	521.60	707.37	4.10	172.53	2.26	2.42	6.62	12.23	18.86	64.87
3	519.64	681.27	4.50	151.39	2.29	2.42	5.56	12.37	17.93	68.99
Average	**521.70**	**690.99**	**4.60**	**151.84**	**2.26**	**2.42**	**6.48**	**12.25**	**18.73**	**65.48**
Bitumen Content 6.0 %										
Sample#	**Volume(cm3)**	**Corr. stability(Kg)**	**Flow (mm)**	**Stiffness (kg/mm)**	**ρ_A (g/cm3)**	**ρ_{bit} (g/cm3)**	**V_a %**	**V_b %**	**VMA %**	**VFB %**
1	498.90	693.93	6.30	110.15	2.28	2.43	6.33	13.26	19.59	67.69
2	518.24	645.07	6.40	100.79	2.24	2.43	6.00	13.03	19.03	68.48
3	519.90	618.20	5.70	108.46	2.23	2.43	8.29	12.98	21.27	61.02
Average	**512.35**	**652.40**	**6.13**	**106.47**	**2.25**	**2.43**	**6.87**	**13.09**	**19.97**	**65.73**

Figures 4.26 to 4.31 show mechanical properties of asphalt 100% RAP and 0% virgin

Air Voids Vs. Bitumen%

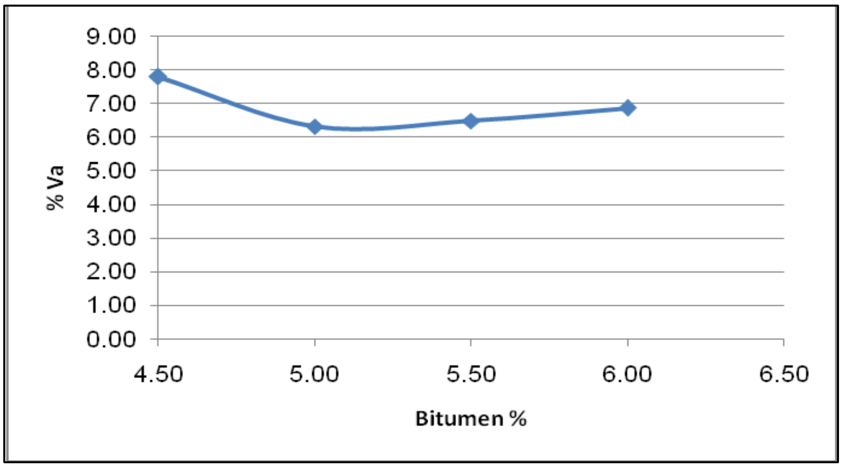

Figure 4.26: Air Voids Vs. % Bitumen for 100% RAP and 0% virgin

Density Vs. Bitumen%

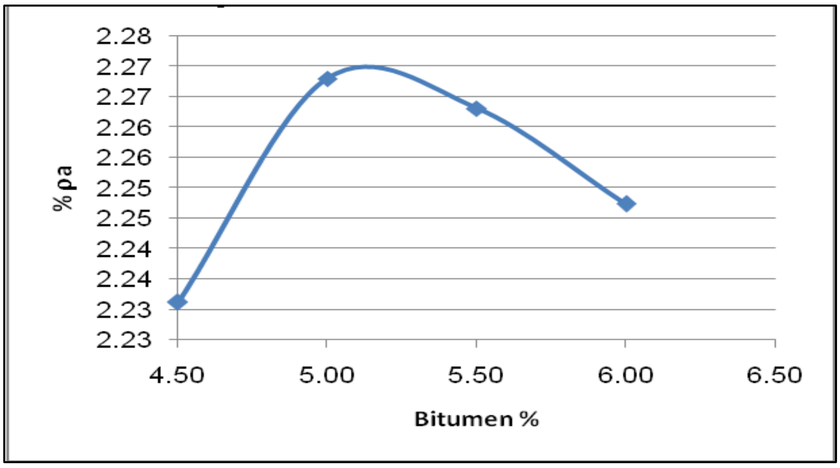

Figure 4.27: Density Vs. % Bitumen for 100% RAP and 0% virgin

Stability Vs. Bitumen%

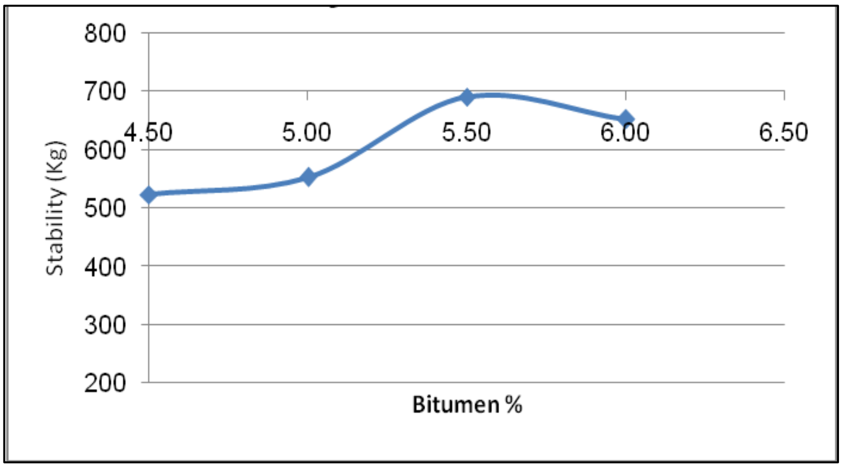

Figure 4.28: Stability Vs. %Bitumen for 100% RAP and 0% virgin

Flow Vs. Bitumen %

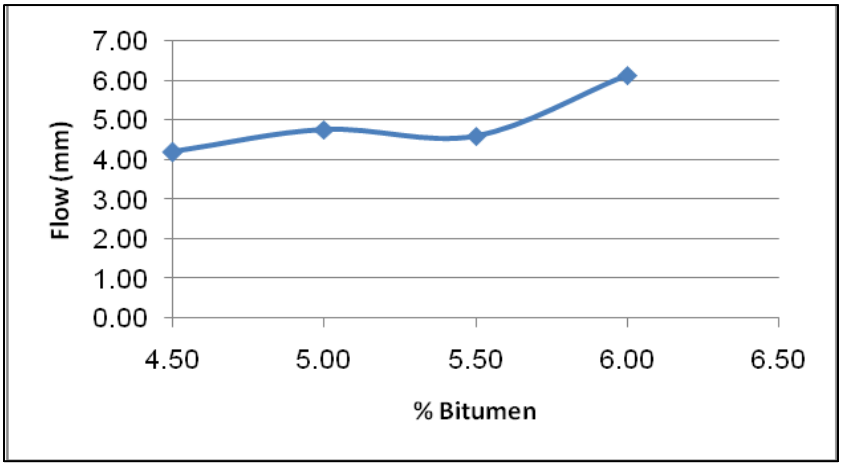

Figure 4.29: Stability Vs. %Bitumen for 100% RAP and 0% virgin

VFB% Vs. Bitumen %

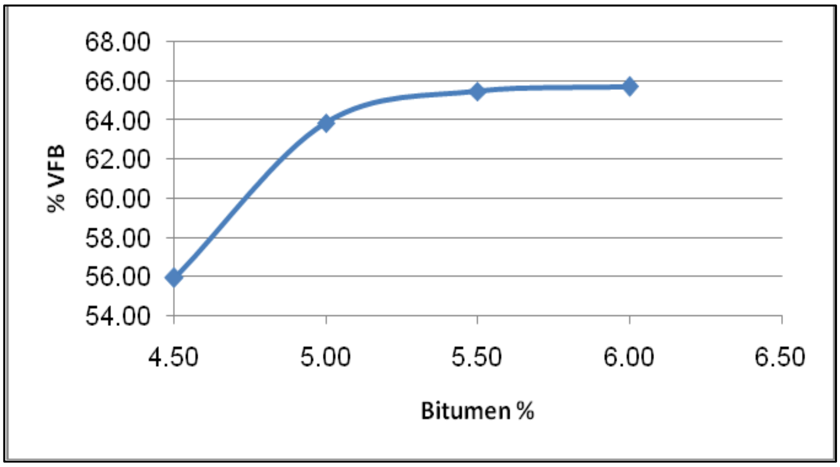

Figure 4.30: VFB% Vs. %Bitumen for 100% RAP and 0% virgin

VMA% Vs. Bitumen %

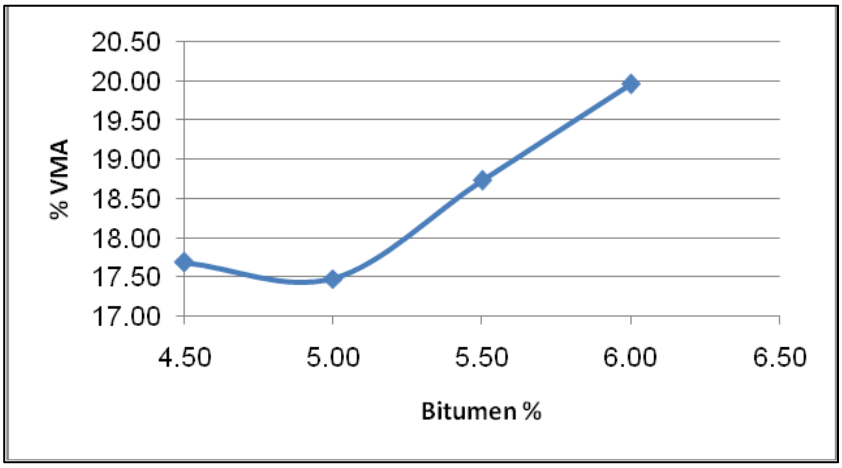

Figure 4.31: VMA% Vs. %Bitumen for 100% RAP and 0% virgin

Calculation of the optimum bitumen percentage

$$Mb\% = \frac{6 + 5.2 + 5.5}{3} = 5.57\% .$$

Table 4.11 : Calculation of the optimum bitumen percentage for 100% RAP and 0% virgin

Properties	value	MOG Spc, 1998 (Local)	
		Min.	Max.
Stability (kg)	All values are less than 700	900	-
Flow (mm)	All flow values are more than 4	2	4
Air void Va (%)	-	3	7
VMA (%)	-	13.5	-
Bulk density (Pa)	-	2.3	-

From the results of the table its noted that when 0% virgin aggregate and 100% Rap used its found that the stability will be low , and the flow is high and is not within the rang of the specification, with the a specific aggregate gradation , and it is noted that when adding percent of the rap the percent of bitumen will increase, so the previous mix not succeeded

4.10. Results

Using the marshal test and the extraction test we found that we can use several percent of rap in the mix of binder for the flowing mixes we found:

A. Mix of 30% Rap and 70% Virgin aggregate

by this mix stability is satisfy and within the specification , and also the flow is within the range of the specification, with the a specific aggregate gradation the best bitumen content will be 5.43%, so we can use the mix with the property.

B. Mix of 50% Rap and 50% Virgin aggregate

when using this mix it is found that the stability will be satisfy and within the specification but the stability decrease when increasing the percent of the of Rap added , and also the flow will be within the range of the specification but it is high when comparing the flow in less percent of Rap, with the a specific aggregate gradation the best percent of bitumen content will be 5.46% and its noted that when adding percent of the rap the percent of bitumen will increase, so this mix can be used.

C. **Mix of 70% Rap and 30% Virgin aggregate**

when using this mix we found that the stability is not satisfy ,the stability decrease when increasing the percent of the of rap added , but the flow is high and is not within the rang of the specification, and it is noted that when adding percent of the rap the percent of bitumen will increase, so the previous mix not succeeded.

D. **Mix of 100% Rap and 0% Virgin aggregate**

when using this mix we found that the stability will be low , and the flow is high and is not within the range of the specification, and we note that when adding percent of the rap the percent of bitumen will increase, so the previous mix not succeeded

so it is noted that:

1- The maximum percent of Rap can be used 50%
2- Preferable percent of Rap is 30%.

Chapter 5

Conclusion and Recommendations

5.1. Conclusion

1- It is possible to use the rap in asphalt binder in Palestine.
2- The maximum percent of Rap can be 50% with the a specific aggregate gradation, the best percent of bitumen content is 5.46% .
3- It is preferable to use a present of rap of 30% with the a specific aggregate gradation, the best bitumen content is 5.43%.
4- The Rap is not considered as a black rock so the bitumen content in the Rap is taken into account when adding the bitumen to the mix.

5.2. Recommendations

1- It is recommended to perform another tests with samples in more places in Gaza strip.
2- It is recommended to perform tests with samples have different ages.
3- It is recommended to conduct economic visibility study for using RAP with different percentages, and its recommended to conduct different test on other percentage of RAP aggregate content such as 40% and 60%.
4- Its recommended to conduct awareness for companies and association on advantages of using RAP aggregate in asphalt binder.

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Appendices

Appendix A

Trial A: mix of 0% RAP and 100% Virgin aggregate

No. of blows on Each Face : 75

Mixing Temp. : 150 C

BITUMEN GRADE B70

TEST DESCRIPTION	SAMPLE NO.			AVREAGE
	1	2	3	
Weight of sample in Air (g)	1132.00	1125.00	1145.00	1134.00
Weight of sample SSD (g)	1155.40	1161.00	1149.40	1155.27
Wight of sample in water(g)	659.00	667.00	651.50	659.17
Bulk volume (cm3)	496.40	494.00	497.90	496.10
Density of compacted mix ρA (g/cm3)	2.28	2.28	2.30	2.29
Max.theoritical density ρbit (g/cm3)	2.44	2.44	2.44	2.44
Average of specimen Height(mm)	60.73	61.55	60.10	60.79
Marshal satbiltiy (Kg)	615.00	678.00	721.00	671.33
Satbiltiy correction factor	1.1080	1.0651	1.0959	1.09
Corrected sabiltiy	1107.00	1078.00	1045.00	1076.67
Flow (mm)	2.80	2.90	3.25	2.98
Sability/flow (Kg/mm)	395.36	371.72	321.54	362.87
Percent bitumen volume Vb (%)	10.10	10.09	10.19	10.12
Air voids contents in total mix Va (%)	6.65	6.78	5.87	6.43
Voids in mineral Agg.(V.M.A) (%)	16.75525	17.87	17.05	17.23
Voids fill with bitumen (V.F.B) (%)	60.28	56.45	59.73	58.82
Percent bitumen content of total mix(%)	4.50	4.50	4.50	4.50

No. of blows on Each Face : 75
Mixing Temp. : 150 C
BITUMEN GRADE B70

TEST DESCRIPTION	SAMPLE NO.			AVREAGE
	4	5	6	
Weight of sample in Air (g)	1180.00	1201.50	1189.00	1190.17
Weight of sample SSD (g)	1182.00	1205.00	1193.00	1193.33
Wight of sample in water(g)	670.00	685.20	675.50	676.90
Bulk volume (cm3)	512.00	519.80	517.50	516.43
Density of compacted mix ρA (g/cm3)	2.30	2.31	2.30	2.30
Max.theoritical density ρbit (g/cm3)	2.45	2.45	2.45	2.45
Average of specimen Height(mm)	69.50	70.00	70.10	69.87
Marshal satbiltiy (Kg)	1635.00	1619.00	1668.00	1640.67
Satbiltiy correction factor	0.8665	0.8570	0.8551	0.86
Corrected sabiltiy	1416.73	1387.48	1426.31	1410.17
Flow (mm)	3.60	3.40	3.60	3.53
Sability/flow (Kg/mm)	393.54	408.08	396.20	399.27
Percent bitumen volume Vb (%)	11.34	11.38	11.31	11.34
Air voids contents in total mix Va (%)	5.74	5.46	6.03	5.74
Voids in mineral Agg.(V.M.A) (%)	17.08	16.84	17.34	17.08
Voids fill with bitumen (V.F.B) (%)	66.40	67.56	65.22	66.40
Percent bitumen content of total mix(%)	5.00	5.00	5.00	5.00

No. of blows on Each Face : 75
Mixing Temp. : 150 C
BITUMEN GRADE B70

TEST DESCRIPTION	SAMPLE NO.			AVREAGE
	7	8	9	
Weight of sample in Air (g)	1175.60	1178.65	1187.60	1180.62
Weight of sample SSD (g)	1178.85	1181.10	1181.54	1180.50
Wight of sample in water(g)	671.00	669.50	671.90	670.80
Bulk volume (cm3)	507.85	511.60	509.64	509.70
Density of compacted mix ρA (g/cm3)	2.31	2.30	2.33	2.32
Max.theoritical density ρbit (g/cm3)	2.44	2.44	2.44	2.44
Average of specimen Height(mm)	57.30	58.20	59.50	58.33
Marshal satbiltiy (Kg)	770.20	752.30	741.00	754.50
Satbiltiy correction factor	1.184	1.156	1.115	1.152
Corrected sabiltiy(kg0	1507.00	1578.00	1568.00	1551.00
Flow (mm)	3.70	3.80	3.78	3.76
Sability/flow (Kg/mm)	407.30	415.26	414.81	412.46
Percent bitumen volume Vb (%)	12.53	12.47	12.61	12.54
Air voids contents in total mix Va (%)	5.05	5.50	4.42	4.99
Voids in mineral Agg.(V.M.A) (%)	14.78	17.97	17.03	16.60
Voids fill with bitumen (V.F.B) (%)	84.78	69.39	74.06	76.08
Percent bitumen content of total mix(%)	5.50	5.50	5.50	5.50

No. of blows on Each Face : 75
Mixing Temp. : 150 C
BITUMEN GRADE B70

TEST DESCRIPTION	SAMPLE NO.			AVREAGE
	10	11	12	
Weight of sample in Air (g)	1175.00	1198.00	1158.60	1177.20
Weight of sample SSD (g)	1139.20	1163.54	1161.20	1154.65
Wight of sample in water(g)	627.30	640.30	656.30	641.30
Bulk volume (cm3)	511.90	523.24	504.90	513.35
Density of compacted mix ρA (g/cm3)	2.30	2.29	2.29	2.29
Max.theoritical density ρbit (g/cm3)	2.44	2.44	2.44	2.44
Average of specimen Height(mm)	60.20	61.60	63.28	61.69
Marshal satbiltiy (Kg)	1423.00	1415.00	1378.00	1405.33
Satbiltiy correction factor	1.093	1.051	1.005	1.05
Corrected sabiltiy	1555.05	1486.60	1385.17	1475.61
Flow (mm)	4.20	4.10	3.90	4.07
Sability/flow (Kg/mm)	370.25	362.59	355.17	362.67
Percent bitumen volume Vb (%)	13.37	13.34	13.37	13.36
Air voids contents in total mix Va (%)	3.85	4.00	3.50	5.90
Voids in mineral Agg.(V.M.A) (%)	17.22	17.34	16.87	17.14
Voids fill with bitumen (V.F.B) (%)	77.64	76.93	65.20	73.26
Percent bitumen content of total mix(%)	6.00	6.00	6.00	6.00

Trial B: mix of 30% Rap and 70% Virgin aggregate

No. of blows on Each Face : 75

Mixing Temp. : 150 C

BITUMEN GRADE B70

TEST DESCRIPTION	SAMPLE NO.			AVREAGE
	1	2	3	
Weight of sample in Air (g)	1158.50	1162.30	1147.58	1156.13
Weight of sample SSD (g)	1161.20	1165.10	1149.30	1158.53
Wight of sample in water(g)	651.50	657.30	648.30	652.37
Bulk volume (cm3)	509.70	507.80	501.00	506.17
Density of compacted mix ρA (g/cm3)	2.27	2.29	2.29	2.28
Max.theoritical density ρbit (g/cm3)	2.44	2.44	2.44	2.44
Average of specimen Height(mm)	61.73	61.55	61.10	61.46
Marshal satbiltiy (Kg)	1220.00	1212.00	1278.00	1236.67
Satbiltiy correction factor	1.0500	1.0488	1.0650	1.05
Corrected sabiltiy	1281.00	1271.15	1361.07	1304.41
Flow (mm)	2.30	2.50	2.70	2.50
Sability/flow (Kg/mm)	556.96	508.46	504.10	523.17
Percent bitumen volume Vb (%)	10.07	10.14	10.15	10.12
Air voids contents in total mix Va (%)	6.66	6.00	5.93	6.20
Voids in mineral Agg.(V.M.A) (%)	17.50000	16.14	16.08	16.57
Voids fill with bitumen (V.F.B) (%)	57.53	62.82	63.11	61.15
Percent bitumen content of total mix(%)	4.50	4.50	4.50	4.50

No. of blows on Each Face : 75
Mixing Temp. : 150 C
BITUMEN GRADE B70

TEST DESCRIPTION	SAMPLE NO.			AVREAGE
	4	5	6	
Weight of sample in Air (g)	1161.11	1206.28	1203.56	1190.32
Weight of sample SSD (g)	1164.90	1210.35	1207.35	1194.20
Wight of sample in water(g)	665.00	688.02	679.00	677.34
Bulk volume (cm3)	499.90	522.33	528.35	516.86
Density of compacted mix ρA (g/cm3)	2.32	2.31	2.28	2.30
Max.theoritical density ρbit (g/cm3)	2.45	2.45	2.45	2.45
Average of specimen Height(mm)	65.32	66.36	64.80	65.49
Marshal satbiltiy (Kg)	1515.00	1520.00	1570.00	1535.00
Satbiltiy correction factor	0.9200	0.9100	0.9400	0.92
Corrected sabiltiy	1393.80	1383.20	1475.80	1417.60
Flow (mm)	2.90	3.05	3.10	3.02
Sability/flow (Kg/mm)	480.62	453.51	476.06	470.06
Percent bitumen volume Vb (%)	11.43	11.37	11.21	11.34
Air voids contents in total mix Va (%)	4.60	5.55	6.83	5.66
Voids in mineral Agg.(V.M.A) (%)	16.03	16.91	18.04	16.99
Voids fill with bitumen (V.F.B) (%)	71.30	67.21	62.13	66.88
Percent bitumen content of total mix(%)	5.00	5.00	5.00	5.00

No. of blows on Each Face : 75
Mixing Temp. : 150 C
BITUMEN GRADE B70

TEST DESCRIPTION	SAMPLE NO.			AVREAGE
	7	8	9	
Weight of sample in Air (g)	1187.80	1181.20	1167.35	1178.78
Weight of sample SSD (g)	1191.61	1185.33	1170.89	1182.61
Wight of sample in water(g)	678.68	675.65	668.62	674.32
Bulk volume (cm3)	512.93	509.68	502.27	508.29
Density of compacted mix ρA (g/cm3)	2.32	2.32	2.32	2.32
Max.theoritical density ρbit (g/cm3)	2.44	2.44	2.44	2.44
Average of specimen Height(mm)	65.00	66.80	69.89	67.23
Marshal satbiltiy (Kg)	1625.00	1587.20	1625.00	1612.40
Satbiltiy correction factor	0.900	0.920	0.843	0.888
Corrected sabiltiy(kg0	1462.50	1460.22	1369.88	1430.87
Flow (mm)	3.00	3.15	2.95	3.03
Sability/flow (Kg/mm)	487.50	463.56	464.36	471.81
Percent bitumen volume Vb (%)	12.54	12.55	12.58	12.55
Air voids contents in total mix Va (%)	5.17	5.20	4.83	5.07
Voids in mineral Agg.(V.M.A) (%)	17.71	17.75	17.41	17.62
Voids fill with bitumen (V.F.B) (%)	70.80	70.70	72.28	71.26
Percent bitumen content of total mix(%)	5.50	5.50	5.50	5.50

No. of blows on Each Face : 75
Mixing Temp. : 150 C
BITUMEN GRADE B70

TEST DESCRIPTION	SAMPLE NO.			AVREAGE
	10	11	12	
Weight of sample in Air (g)	1201.50	1198.50	1202.50	1200.83
Weight of sample SSD (g)	1202.35	1199.50	1204.35	1202.07
Wight of sample in water(g)	674.80	675.80	680.20	676.93
Bulk volume (cm3)	527.55	523.70	524.15	525.13
Density of compacted mix ρA (g/cm3)	2.28	2.29	2.29	2.29
Max.theoritical density ρbit (g/cm3)	2.44	2.44	2.44	2.44
Average of specimen Height(mm)	68.00	67.50	71.02	68.84
Marshal satbiltiy (Kg)	1450.00	1315.52	1327.00	1364.17
Satbiltiy correction factor	0.860	0.905	0.835	0.87
Corrected sabiltiy	1247.00	1190.55	1108.05	1181.86
Flow (mm)	4.00	4.20	3.90	4.03
Sability/flow (Kg/mm)	311.75	283.46	284.11	293.11
Percent bitumen volume Vb (%)	13.27	13.33	13.36	13.32
Air voids contents in total mix Va (%)	4.52	3.95	3.78	4.08
Voids in mineral Agg.(V.M.A) (%)	18.79	18.28	18.14	18.40
Voids fill with bitumen (V.F.B) (%)	77.00	72.92	73.66	74.53
Percent bitumen content of total mix(%)	6.00	6.00	6.00	6.00

Trial C: mix of 50% Rap and 50% Virgin aggregate

No. of blows on Each Face : 75
Mixing Temp. : 150 C
BITUMEN GRADE B70

TEST DESCRIPTION	SAMPLE NO.			AVREAGE
	1	2	3	
Weight of sample in Air (g)	1168.00	1201.80	1158.60	1176.13
Weight of sample SSD (g)	1171.00	1204.00	1162.60	1179.20
Wight of sample in water(g)	645.20	673.00	671.50	663.23
Bulk volume (cm3)	525.80	531.00	491.10	515.97
Density of compacted mix ρA (g/cm3)	2.22	2.26	2.36	2.28
Max.theoritical density ρbit (g/cm3)	2.45	2.45	2.45	2.45
Average of specimen Height(mm)	60.73	61.55	60.10	60.79
Marshal satbiltiy (Kg)	982.00	850.00	1085.00	972.33
Satbiltiy correction factor	1.0500	1.0530	1.0650	1.06
Corrected sabiltiy	986.00	758.00	845.00	863.00
Flow (mm)	2.81	2.95	3.10	2.95
Sability/flow (Kg/mm)	350.89	256.95	272.58	293.47
Percent bitumen volume Vb (%)	9.84	10.02	10.45	10.10
Air voids contents in total mix Va (%)	9.33	7.62	3.71	6.89
Voids in mineral Agg.(V.M.A) (%)	19.17033	17.65	17.25	18.02
Voids fill with bitumen (V.F.B) (%)	51.32	56.81	60.57	56.24
Percent bitumen content of total mix(%)	4.50	4.50	4.50	4.50

No. of blows on Each Face : 70
Mixing Temp. : 150 C
BITUMEN GRADE B70

TEST DESCRIPTION	SAMPLE NO.			AVREAGE
	4	5	6	
Weight of sample in Air (g)	1185.00	1189.00	1205.00	1193.00
Weight of sample SSD (g)	1187.30	1193.00	1208.00	1196.10
Wight of sample in water(g)	671.20	686.80	672.50	676.83
Bulk volume (cm3)	516.10	506.20	535.50	519.27
Density of compacted mix ρA (g/cm3)	2.30	2.35	2.25	2.30
Max.theoritical density ρbit (g/cm3)	2.44	2.44	2.44	2.44
Average of specimen Height(mm)	66.60	67.37	68.30	67.42
Marshal satbiltiy (Kg)	1117.00	1145.00	1201.00	1154.33
Satbiltiy correction factor	0.9250	0.9100	0.8900	0.91
Corrected sabiltiy	1025.00	1064.30	1105.90	1065.07
Flow (mm)	3.65	3.78	3.68	3.70
Sability/flow (Kg/mm)	280.82	281.56	300.52	287.63
Percent bitumen volume Vb (%)	11.30	11.56	11.07	11.31
Air voids contents in total mix Va (%)	6.12	6.25	6.48	6.28
Voids in mineral Agg.(V.M.A) (%)	17.42	17.81	17.55	17.59
Voids fill with bitumen (V.F.B) (%)	72.40	71.30	63.09	68.93
Percent bitumen content of total mix(%)	5.00	5.00	5.00	5.00

No. of blows on Each Face : 70
Mixing Temp. : 150 C
BITUMEN GRADE B70

TEST DESCRIPTION	SAMPLE NO.			AVREAGE
	7	8	9	
Weight of sample in Air (g)	1195.50	1201.30	1168.60	1188.47
Weight of sample SSD (g)	1197.20	1204.00	1171.00	1190.73
Wight of sample in water(g)	678.28	689.50	670.50	679.43
Bulk volume (cm3)	518.92	514.50	500.50	511.31
Density of compacted mix ρA (g/cm3)	2.30	2.33	2.33	2.32
Max.theoritical density ρbit (g/cm3)	2.43	2.43	2.43	2.43
Average of specimen Height(mm)	66.30	67.80	64.89	66.33
Marshal satbiltiy (Kg)	1225.00	1354.00	1218.00	1265.67
Satbiltiy correction factor	0.931	0.900	0.965	0.932
Corrected sabiltiy(kg0	1140.97	1218.60	1175.37	1178.31
Flow (mm)	3.80	3.50	3.60	3.63
Sability/flow (Kg/mm)	300.25	348.17	326.49	324.97
Percent bitumen volume Vb (%)	12.47	12.64	12.64	12.58
Air voids contents in total mix Va (%)	5.19	3.91	3.92	4.34
Voids in mineral Agg.(V.M.A) (%)	17.66	16.55	16.55	16.92
Voids fill with bitumen (V.F.B) (%)	70.60	76.36	76.35	74.44
Percent bitumen content of total mix(%)	5.50	5.50	5.50	5.50

No. of blows on Each Face : 75
Mixing Temp. : 150 C
BITUMEN GRADE B70

TEST DESCRIPTION	SAMPLE NO.			AVREAGE
	10	11	12	
Weight of sample in Air (g)	1198.80	1201.55	1215.00	1205.12
Weight of sample SSD (g)	1201.30	1204.56	1218.15	1208.00
Wight of sample in water(g)	677.35	679.14	684.18	680.22
Bulk volume (cm3)	523.95	525.42	533.97	527.78
Density of compacted mix ρA (g/cm3)	2.29	2.29	2.28	2.28
Max.theoritical density ρbit (g/cm3)	2.43	2.43	2.43	2.43
Average of specimen Height(mm)	68.90	65.50	65.20	66.53
Marshal satbiltiy (Kg)	1220.00	1275.00	1272.00	1255.67
Satbiltiy correction factor	0.878	0.950	0.957	0.93
Corrected sabiltiy	1071.16	1211.25	1217.30	1166.57
Flow (mm)	4.20	4.50	3.85	4.18
Sability/flow (Kg/mm)	255.04	269.17	316.18	280.13
Percent bitumen volume Vb (%)	13.33	13.32	13.25	13.30
Air voids contents in total mix Va (%)	4.25	4.15	4.18	4.19
Voids in mineral Agg.(V.M.A) (%)	17.58	17.47	17.43	17.49
Voids fill with bitumen (V.F.B) (%)	73.00	76.25	72.00	73.75
Percent bitumen content of total mix(%)	6.00	6.00	6.00	6.00

Trial D: mix of 70% Rap and 30% Virgin aggregate

No. of blows on Each Face : 75

Mixing Temp. : 150 C

BITUMEN GRADE B70

TEST DESCRIPTION	SAMPLE NO.			AVREAGE
	1	2	3	
Weight of sample in Air (g)	1152.30	1178.30	1146.80	1159.13
Weight of sample SSD (g)	1155.40	1181.00	1150.40	1162.27
Wight of sample in water(g)	642.50	664.00	650.50	652.33
Bulk volume (cm3)	512.90	517.00	499.90	509.93
Density of compacted mix ρA (g/cm3)	2.25	2.28	2.29	2.27
Max.theoritical density ρbit (g/cm3)	2.45	2.45	2.45	2.45
Average of specimen Height(mm)	60.73	61.55	60.10	60.79
Marshal satbiltiy (Kg)	712.00	685.00	710.00	702.33
Satbiltiy correction factor	1.0770	1.0530	1.0959	1.08
Corrected sabiltiy	766.82	721.31	778.09	755.41
Flow (mm)	4.20	4.10	3.86	4.05
Sability/flow (Kg/mm)	182.58	175.93	201.58	186.69
Percent bitumen volume Vb (%)	9.95	10.09	10.16	10.07
Air voids contents in total mix Va (%)	8.30	6.98	6.36	7.21
Voids in mineral Agg.(V.M.A) (%)	18.25119	17.07	16.53	17.28
Voids fill with bitumen (V.F.B) (%)	54.52	59.14	61.48	58.38
Percent bitumen content of total mix(%)	4.50	4.50	4.50	4.50

No. of blows on Each Face : 75
Mixing Temp. : 150 C
BITUMEN GRADE B70

TEST DESCRIPTION	SAMPLE NO.			AVREAGE
	4	5	6	
Weight of sample in Air (g)	1178.00	1204.00	1217.00	1199.67
Weight of sample SSD (g)	1182.00	1208.00	1220.00	1203.33
Wight of sample in water(g)	667.00	679.50	685.50	677.33
Bulk volume (cm3)	515.00	528.50	534.50	526.00
Density of compacted mix ρA (g/cm3)	2.29	2.28	2.28	2.28
Max.theoritical density ρbit (g/cm3)	2.43	2.43	2.43	2.43
Average of specimen Height(mm)	68.50	71.67	70.30	70.16
Marshal satbiltiy (Kg)	915.00	924.00	921.00	920.00
Satbiltiy correction factor	0.8860	0.8284	0.8513	0.86
Corrected sabiltiy	810.69	765.44	784.05	786.73
Flow (mm)	4.50	5.00	4.00	4.50
Sability/flow (Kg/mm)	180.15	153.09	196.01	176.42
Percent bitumen volume Vb (%)	11.26	11.21	11.21	11.22
Air voids contents in total mix Va (%)	5.87	6.25	6.30	6.14
Voids in mineral Agg.(V.M.A) (%)	17.13	17.46	17.51	17.36
Voids fill with bitumen (V.F.B) (%)	65.73	64.21	64.01	64.65
Percent bitumen content of total mix(%)	5.00	5.00	5.00	5.00

No. of blows on Each Face : 75
Mixing Temp. : 150 C
BITUMEN GRADE B70

TEST DESCRIPTION	SAMPLE NO.			AVREAGE
	7	8	9	
Weight of sample in Air (g)	1185.60	1203.40	1170.45	1186.48
Weight of sample SSD (g)	1190.20	1205.00	1173.50	1189.57
Wight of sample in water(g)	672.00	680.00	662.90	671.63
Bulk volume (cm3)	518.20	525.00	510.60	517.93
Density of compacted mix ρA (g/cm3)	2.29	2.29	2.29	2.29
Max.theoritical density ρbit (g/cm3)	2.43	2.43	2.43	2.43
Average of specimen Height(mm)	67.30	66.58	63.78	65.89
Marshal satbiltiy (Kg)	887.00	817.00	826.00	843.33
Satbiltiy correction factor	0.910	0.920	1.018	0.949
Corrected sabiltiy(kg0	807.17	751.97	840.87	800.00
Flow (mm)	5.30	5.70	5.70	5.57
Sability/flow (Kg/mm)	152.30	131.92	147.52	143.91
Percent bitumen volume Vb (%)	12.39	12.41	12.41	12.40
Air voids contents in total mix Va (%)	5.85	5.67	5.67	5.73
Voids in mineral Agg.(V.M.A) (%)	18.23	18.08	18.08	18.13
Voids fill with bitumen (V.F.B) (%)	67.93	68.63	68.65	68.40
Percent bitumen content of total mix(%)	5.50	5.50	5.50	5.50

No. of blows on Each Face : 75
Mixing Temp. : 150 C
BITUMEN GRADE B70

TEST DESCRIPTION	SAMPLE NO.			AVREAGE
	10	11	12	
Weight of sample in Air (g)	1201.00	1148.00	1169.50	1172.83
Weight of sample SSD (g)	1203.50	1151.70	1173.10	1176.10
Wight of sample in water(g)	679.00	648.00	658.00	661.67
Bulk volume (cm3)	524.50	503.70	515.10	514.43
Density of compacted mix ρA (g/cm3)	2.29	2.28	2.27	2.28
Max.theoritical density ρbit (g/cm3)	2.42	2.42	2.42	2.42
Average of specimen Height(mm)	69.90	64.60	67.28	67.26
Marshal satbiltiy (Kg)	813.00	870.00	882.00	855.00
Satbiltiy correction factor	0.859	0.972	0.910	0.91
Corrected sabiltiy	698.29	845.64	802.62	782.18
Flow (mm)	6.20	6.42	6.70	6.44
Sability/flow (Kg/mm)	112.63	131.72	119.79	121.38
Percent bitumen volume Vb (%)	13.34	13.28	13.23	13.28
Air voids contents in total mix Va (%)	5.38	6.00	6.18	5.79
Voids in mineral Agg.(V.M.A) (%)	18.72	19.28	19.41	19.13
Voids fill with bitumen (V.F.B) (%)	71.26	68.87	68.15	69.43
Percent bitumen content of total mix(%)	6.00	6.00	6.00	6.00

Trial E: mix of 100% Rap and 0% Virgin aggregate

No. of blows on Each Face : 75

Mixing Temp. : 150 C

BITUMEN GRADE B70

TEST DESCRIPTION	SAMPLE NO.			AVREAGE
	1	2	3	
Weight of sample in Air (g)	1151.20	1156.00	1145.00	1150.73
Weight of sample SSD (g)	1155.40	1161.00	1149.40	1155.27
Wight of sample in water(g)	640.00	647.00	631.50	639.50
Bulk volume (cm3)	515.40	514.00	517.90	515.77
Density of compacted mix ρA (g/cm3)	2.23	2.25	2.21	2.23
Max.theoritical density ρbit (g/cm3)	2.42	2.42	2.42	2.42
Average of specimen Height(mm)	60.73	61.55	60.10	60.79
Marshal satbiltiy (Kg)	481.00	446.32	512.85	480.06
Satbiltiy correction factor	1.1080	1.0651	1.0959	1.09
Corrected sabiltiy	532.95	475.38	562.03	523.45
Flow (mm)	4.30	4.20	4.10	4.20
Sability/flow (Kg/mm)	123.94	113.18	137.08	124.74
Percent bitumen volume Vb (%)	9.89	9.96	9.79	9.88
Air voids contents in total mix Va (%)	7.70	7.06	8.64	7.80
Voids in mineral Agg.(V.M.A) (%)	17.59521	17.03	18.43	17.69
Voids fill with bitumen (V.F.B) (%)	56.23	58.51	53.12	55.95
Percent bitumen content of total mix(%)	4.50	4.50	4.50	4.50

No. of blows on Each Face : 75
Mixing Temp. : 150 C
BITUMEN GRADE B70

TEST DESCRIPTION	SAMPLE NO.			AVREAGE
	4	5	6	
Weight of sample in Air (g)	1180.00	1201.50	1189.00	1190.17
Weight of sample SSD (g)	1182.00	1205.00	1193.00	1193.33
Wight of sample in water(g)	660.00	675.20	670.50	668.57
Bulk volume (cm3)	522.00	529.80	522.50	524.77
Density of compacted mix ρA (g/cm3)	2.26	2.27	2.28	2.27
Max.theoritical density ρbit (g/cm3)	2.42	2.42	2.42	2.42
Average of specimen Height(mm)	69.50	70.00	70.10	69.87
Marshal satbiltiy (Kg)	649.00	628.48	653.00	643.49
Satbiltiy correction factor	0.8665	0.8570	0.8551	0.86
Corrected sabiltiy	562.36	538.61	558.38	553.12
Flow (mm)	5.00	4.70	4.60	4.77
Sability/flow (Kg/mm)	112.47	114.60	121.39	116.15
Percent bitumen volume Vb (%)	11.12	11.16	11.20	11.16
Air voids contents in total mix Va (%)	6.63	6.33	6.01	6.32
Voids in mineral Agg.(V.M.A) (%)	17.75	17.49	17.20	17.48
Voids fill with bitumen (V.F.B) (%)	62.66	63.82	65.09	63.86
Percent bitumen content of total mix(%)	5.00	5.00	5.00	5.00

No. of blows on Each Face : 75
Mixing Temp. : 150 C
BITUMEN GRADE B70

TEST DESCRIPTION	SAMPLE NO.			AVREAGE
	7	8	9	
Weight of sample in Air (g)	1175.60	1178.65	1187.60	1180.62
Weight of sample SSD (g)	1178.85	1181.10	1181.54	1180.50
Wight of sample in water(g)	655.00	659.50	661.90	658.80
Bulk volume (cm3)	523.85	521.60	519.64	521.70
Density of compacted mix ρA (g/cm3)	2.24	2.26	2.29	2.26
Max.theoritical density ρbit (g/cm3)	2.42	2.42	2.42	2.42
Average of specimen Height(mm)	57.30	58.20	59.50	58.33
Marshal satbiltiy (Kg)	578.00	612.12	611.00	600.37
Satbiltiy correction factor	1.184	1.156	1.115	1.152
Corrected sabiltiy(kg0	684.35	707.37	681.27	690.99
Flow (mm)	5.20	4.10	4.50	4.60
Sability/flow (Kg/mm)	131.61	172.53	151.39	151.84
Percent bitumen volume Vb (%)	12.15	12.23	12.37	12.25
Air voids contents in total mix Va (%)	7.27	6.62	5.56	6.48
Voids in mineral Agg.(V.M.A) (%)	19.41	18.86	17.93	18.73
Voids fill with bitumen (V.F.B) (%)	62.57	64.87	68.99	65.48
Percent bitumen content of total mix(%)	5.50	5.50	5.50	5.50

No. of blows on Each Face : 75
Mixing Temp. : 150 C
BITUMEN GRADE B70

TEST DESCRIPTION	SAMPLE NO.			AVREAGE
	10	11	12	
Weight of sample in Air (g)	1135.60	1159.50	1158.60	1151.23
Weight of sample SSD (g)	1139.20	1163.54	1161.20	1154.65
Wight of sample in water(g)	640.30	645.30	641.30	642.30
Bulk volume (cm3)	498.90	518.24	519.90	512.35
Density of compacted mix ρA (g/cm3)	2.28	2.24	2.23	2.25
Max.theoritical density ρbit (g/cm3)	2.43	2.43	2.43	2.43
Average of specimen Height(mm)	60.20	61.60	63.28	61.69
Marshal satbiltiy (Kg)	635.00	614.00	615.00	621.33
Satbiltiy correction factor	1.093	1.051	1.005	1.05
Corrected sabiltiy	693.93	645.07	618.20	652.40
Flow (mm)	6.30	6.40	5.70	6.13
Sability/flow (Kg/mm)	110.15	100.79	108.46	106.47
Percent bitumen volume Vb (%)	13.26	13.03	12.98	13.09
Air voids contents in total mix Va (%)	6.33	6.00	8.29	7.52
Voids in mineral Agg.(V.M.A) (%)	19.59	19.03	21.27	19.97
Voids fill with bitumen (V.F.B) (%)	67.69	68.48	61.02	65.73
Percent bitumen content of total mix(%)	6.00	6.00	6.00	6.00

Appendix B

Figure: (B.1) Preparing Marshall samples

Figure (B.2): Blowing the Marshall sample

Figure (B.3): Measuring the samples

Figure (B.4): Measuring the samples

Figure (B.5): Preparing bitumen for Marshall samples

Figure (B.6): Sieve analysis for aggregate

Figure (B.7): RAP in Gaza Strip